Cultivar mixture ratio and weed management significantly influenced the tillering ability of BRRI dhan56. The highest tillering ability (15.30 hill^{-1}) of BRRI dhan56 was observed in 2:3 row ratio and lowest one (13.58 hill^{-1}) was found in 4:2 row ratio of Binadhan-13 and BRRI dhan56 (Table 1). With the increase in number of weeding, tillering ability was gradually increased. The highest number of tillers hill^{-1} were recorded with three weeding treatment (Table 1).

3.2 Yield contributing characters and yield of rice

All yield contributing characters except 1000-grain weight and yield of Binadhan-13 and BRRI dhan56 were significantly affected by cultivar mixture ratio and weed management (Table 2). However, their interaction did not produce any significant effect on the yield contributing characters and yield of Binadhan-13 and BRRI dhan56.

Table 2: Effect of rice cultivar mixture ratio and weed management on yield contributing characters and yield of Binadhan-13 and BRRI dhan56

Treatment	No. of effective tillers hill^{-1}		Grains panicle^{-1}		1000-grain weight (g)		Grain yield hill^{-1} (g)	
	Binadhan-13	BRRI dhan56	Binadhan-13	BRRI dhan56	Binadhan-13	BRRI dhan56	Binadhan-13	BRRI dhan56
Cultivar mixture ratio (Binadhan-13: BRRI dhan56)								
Sole Binadhan-13	9.717c	9.617c	76.78b	106.1b	13.56	22.09	10.36b	22.85c
2:3	10.79ab	10.69ab	78.69a	108.0a	13.94	22.48	12.11a	26.31a
3:2	10.87a	10.77a	76.76ab	106.1ab	14.03	22.57	11.88a	25.98ab
2:4	10.48b	10.38b	76.27b	105.6b	14.01	22.54	11.45a	25.02b
4:2	10.97a	10.87a	75.63b	105.0b	13.63	22.16	11.53a	25.57ab
Sx̄	0.111	0.111	0.656	0.656	0.166	0.166	0.218	0.386
Level of sig.	**	**	*	*	NS	NS	**	**
Weed management								
No weeding	9.56d	9.47d	71.51d	100.80d	11.04d	19.57d	7.57d	18.70d
One weeding	10.33c	10.23c	75.03c	104.40c	12.95c	21.49c	10.04c	22.93c
Two weeding	10.88b	10.78b	77.83b	107.20b	15.23 b	23.76b	12.89b	27.44b
Three weeding	11.48a	11.38a	82.93a	112.30a	16.11a	24.65a	15.36a	31.52a
Sx̄	0.099	0.099	0.587	0.587	0.148	0.148	0.195	0.345
Level of sig.	**	**	**	**	**	**	**	**
CV (%)	3.63	3.67	2.96	2.14	4.16	2.57	6.60	5.33

In a column, figures with same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). ** =Significant at 1% level of probability, * =Significant at 5% level of probability, NS= Non-significant.

The highest number of effective tillers hill^{-1} (10.97) of Binadhan-13 was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 4:2 row ratio which was statistically similar to those of 3:2 and 2:3 row ratios. Sole Binadhan-13, on the other hand, resulted in the lowest effective tillers hill^{-1} (9.72) (Table 2). The result shows that number of effective tillers hill^{-1} was increased with the increase in weeding frequency. No weeding resulted in the lowest number of effective tillers hill^{-1} (9.56). While three weeding resulted in the maximum numbers of effective tillers hill^{-1} (11.48). One weeding and two weeding resulted in 10.33 and 10.88 effective tillers hill^{-1}, respectively (Table 2).

In case of BRRI dhan56, the highest number of effective tillers hill^{-1} (10.87) was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 4:2 row ratio which was statistically similar to those of 3:2 and 2:3 row ratios. Sole BRRI dhan56, on the other hand, resulted in the lowest effective tillers hill^{-1} (9.62) (Table 2). Result showed that numbers of effective tillers hill^{-1} were increased with the increase in weeding frequency. No weeding resulted in the lowest numbers of effective tillers hill^{-1} (9.47). While three weeding resulted in the maximum numbers of effective tillers hill^{-1} (11.38). One weeding and two weeding resulted in 10.23 and 10.78 numbers of effective tillers hill^{-1}, respectively (Table 2).

Maximum number of grains panicle^{-1} (78.69) of Binadhan-13 was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 2:3 row ratio which was statistically similar with 3:2 row ratios. The 4:2 row ratio, on the other hand resulted in the lowest grains panicle^{-1} (75.63) which was statistically similar with the row ratio of 2:4 and monoculture of Binadhan-13 (Table 2). The table shows that number of grains per panicle was increased with the increase in weeding frequency. No weeding resulted in the lowest number of grains per panicle (71.51). Maximum number of grains panicle^{-1} (82.93) was found when three weeding was done (Table 2). As shown in table 2, 1000-grain weight of Binadhan-13 was increase with the increased in weeding frequency. Three weeding resulted in the highest 1000-grain weight (16.11 g) and lowest (11.04 g) was found when no weeding treatment was done (Table 2).

In BRRI dhan56, the highest number of grains panicle^{-1} (108.0) was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 2:3 row ratio which was statistically similar with 3:2 row ratios. The 4:2 row ratio, on the other hand, resulted in the lowest grains panicle^{-1} (105.0) which is statistically similar with the row ratios of 2:4 and monoculture of BRRI dhan56 (Table 2). As shown in Table 2, number of grains panicle^{-1} was increased with the increase in weeding frequency. No weeding resulted in the lowest number of grains panicle^{-1} (100.80). Maximum number of grains panicle^{-1} (112.30) was found when three weeding was done (Table 2). Result shows that 1000 grain weight was increase with the increase in weeding frequency. Three weeding resulted in the highest 1000-grain weight (24.65 g). Lowest 1000-grain weight (19.57 g) was found when no weeding treatment was given (Table 2).

Highest grain yield hill^{-1} (12.11 g) of Binadhan-13 was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 2:3 row ratio which was statistically similar with 3:2, 2:4, 4:2 row ratios. Sole Binadhan-13, on the other hand, resulted in the lowest grain yield hill^{-1} (10.36 g) (Table 2). Grain yield hill^{-1} was increased with the increase in weeding frequency. No weeding resulted in the lowest grain yield hill^{-1} (7.57 g). Maximum grain yield hill^{-1} (15.36 g) was found while three weeding treatment was done (Table 2).

On the other hand, the highest grain yield hill^{-1} (26.31 g) of BRRI dhan56 was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 2:3 row ratio which was statistically similar with 3:2 and 4:2 row ratios. Sole Binadhan-13, on the other hand, resulted in the lowest grain yield hill^{-1} (22.85 g) (Table 2). Table 2 shows that grain yield hill^{-1} was increased with the increase in weeding frequency. No weeding resulted in the lowest grain yield hill^{-1} (18.70 g). Maximum grain yield hill^{-1} (31.52 g) was found when three weeding treatment was done (Table 2).

3.3 Total yield of rice

Cultivar mixture ratio exerted significant influence on total grain yield of rice (Figure 2). It is evident from the study that cultivar mixture ratio produced a significant advantage in grain yield over sole culture. Figure 2 shows that the highest total grain yield of 4.89 t ha^{-1} was obtained when

Binadhan-13 and BRRI dhan56 were transplanted in 4:2 row ratio. On the other hand, the lowest total grain yield (2.07 t ha^{-1}) of rice was recorded with sole culture of Binadhan-13. Sole culture of BRRI dhan56 produced the second highest grain yield which was statistically similar with that produced by transplanting Binadhan-13 and BRRI dhan56 in 3:2 row ratio. Transplanting Binadhan-13 and BRRI dhan56 in 2:3 or 2:4 row ratio resulted in significantly higher totalgrain yield than sole culture of Binadhan-13 but significantly lower than sole culture of BRRI dhan56 (Figure 2).

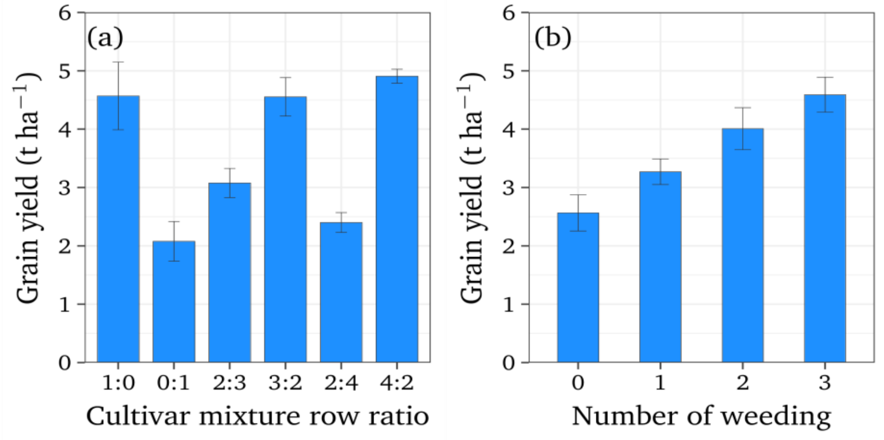

Figure 2: Effect of rice cultivar ratio (a) and weed management (b) on combined grain yield of rice

Total grain yield of rice was significantly affected by weed management practices. Total grain yield was increased gradually with the increasing number of weeding. It is evident from the study that one weeding, two weeding, three weeding resulted in respectively 27%, 55% and 78% increase in total grain yield compared to no weeding (Figure 2).

Interaction between cultivar mixture ratio and weed management significantly affected the total grain yield of rice (Table 3). Transplanting of Binadhan-13 and BRRI dhan56 interacted favorably with three weeding treatment to produce the highest total grain yield of 6.21 t ha^{-1}. On the other hand, the lowest grain yield of 1.28 t ha^{-1} was recorded when sole Binadhan-13 interacted with no weeding treatment. Result shows that three weeding coupled with sole or any rice cultivar mixture ratio always resulted in higher grain yield compared to two weeding or one weeding treatments. And, no weeding irrespective of cultivar mixture ratio produced very low total grain yield (Table 3).

Table 3: Interaction effects of rice cultivars and weed management on weed density, weed dry matter and combined grain yield of rice

Interaction (cultivars mixture ratio × weed management)		Weed density (no. m^{-2})	Weed dry matter (g m^{-2})	Combined grain yield (t ha^{-1})
Sole Binadhan-13	No weeding	119.52	150.67	3.26g
	One weeding	42.55	52.00	4.13f
	Two weeding	37.58	46.00	5.22d
	Three weeding	19.27	24.67	5.66b
Sole BRRI dhan56	No weeding	113.94	139.33	1.28l
	One weeding	61.88	78.33	1.80jk
	Two weeding	39.45	50.33	2.46hi
	Three weeding	24.93	32.00	2.74h
(Binadhan-13: BRRI dhan56) 2:3	No weeding	110.22	132.67	2.23i
	One weeding	36.39	46.00	2.66h
	Two weeding	31.00	38.00	3.37g
	Three weeding	19.37	24.33	4.03f
(Binadhan-13: BRRI dhan56) 3:2	No weeding	113.56	139.00	3.36g
	One weeding	31.55	40.33	4.26ef
	Two weeding	24.55	30.00	4.96d
	Three weeding	20.59	25.00	5.59bc
(Binadhan-13: BRRI dhan56) 2:4	No weeding	108.09	134.00	1.70k
	One weeding	42.48	52.33	2.11ij
	Two weeding	33.95	43.33	2.62h
	Three weeding	19.42	23.33	3.18g
(Binadhan-13: BRRI dhan56) 4:2	No weeding	99.05	125.33	3.54g
	One weeding	35.09	43.00	4.54e
	Two weeding	26.65	32.33	5.28cd
	Three weeding	21.42	27.33	6.21a
Sx̄		7.20	7.88	0.123
Level of sig.		NS	NS	**
CV (%)		19.57	26.59	5.89

In a column, figures with same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). ** =Significant at 1% level of probability. NS = Non-significant.

3.4 Weed community and their growth

3.4.1 Floristic composition of weeds

Seven weed species belonging to six families infested the experimental field (Table 4). Based on their morphology, the following groups were distinguished: grass, broadleaved and sedges. Among the seven weed species, two were grasses, three were broadleaved and two were sedge. Scientific name, family name, morphological type and summed dominance ratio (SDR) of the weeds found in plots are presented in Table 4. The experimental field was mostly infested with broadleaved. Based on the SDR values, broadleaved weed species *Monochoria vaginalis* (SDR of 58.5%) was the predominant species and grass weed *Echinochloa crus-galli* emerged as second most dominant weed species (SDR 14.40%) in the experimental plots and the least dominant weed species was broadleaved weed *Nymphaea nouchali* (SDR 2.3%) (Table 4).

Table 4: List of weed species found in the experimental field with their summed dominance ratio (SDR)

Sl. no.	Scientific name	Family	Type	SDR (%)
1	*Monochoria vaginalis*	Pontederiaceae	Broad leaved	58.5
2	*Echinochloa crus-galli*	Gramineae	Grass	14.4
3	*Digitaria sanguinalis*	Gramineae	Grass	10.6
4	*Marsilea quadrifolia*	Marsileaceae	Broad leaved	6.3
5	*Scirpus juncoides*	Cyperaceae	Sedge	4.7
6	*Fimbristylis miliacea*	Cyperaceae	Sedge	3.2
7	*Nymphaea nouchali*	Nymphaeaceae	Broadleaved	2.3

3.4.2 Weed density and dry matter

Weed density was significant only for weed management (Table 5). As expected, weed density was decreased with the increase in number of weeding performed. The highest weed density of 110.7 weeds m^{-2} was recorded from no weeding treatment. One weeding, two weeding and three weeding resulted in around 63, 71 and 82% reduction in weed density (Table 5).

Weed dry matter was significantly affected by cultivar mixture ratio and weed management but their interaction was not significant (Table 3 and 5). Maximum weed dry matter 75 g m^{-2} was recorded from sole BRRI dhan56 plots which was statistically similar to sole Binadhan-13 plots. On the other hand, all the mixture ratios resulted in similar (ranged from 57 to 63.25 g m^{-2}) weed dry matter, which was significantly lower than those recorded from either monoculture of Binadhan-13 or BRRI dhan56 (Table 5).

Table 5: Effect of rice cultivar mixture ratio on weed density and weed dry matter

Treatment	Weed density (no. m^{-2})	Weed dry matter (g m^{-2})
Cultivar mixture ratio (Binadhan-13: BRRI dhan56)		
Sole Binadhan-13	54.73	68.33 ab
Sole BRRI dhan56	60.05	75.00 a
2:3	49.25	60.25 b
3:2	47.56	58.58 b
2:4	50.98	63.25 b
4:2	45.55	57.00 b
$S\bar{x}$	3.94	3.50
Level of significance	NS	**
Weed management		
No weeding	110.70a	136.80 a
One weeding	41.66 b	52.00 b
Two weeding	32.20 c	40.00 c
Three weeding	20.83 d	26.11 d
$S\bar{x}$	3.22	2.94
Level of significance	**	**
CV (%)	26.59	19.57

In a column, figures with same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). ** =Significant at 1% level of probability. NS = Non-significant.
A significant effect of weed management on weed dry matter was observed in this study. Like weed density, weed dry matter was also found the highest (136.8 g m^{-2}) in weedy treatment. Weed dry matter was gradually decreased with the increase of in frequency of weeding. One weeding, two weeding and three weeding resulted in around 62, 71 and 81 % reduction in weed dry matter, respectively (Table 3).

4. DISCUSSION

Growing different rice cultivars in mixture enhances functional diversity and improves yield by providing positive interactions between cultivars and thus makes the system more efficient and sustainable as well. As mentioned by a researcher, advantages of cultivar mixture include yield stabilization, compensation effect and disease control. Disease control also helps to achieve other two goals. Furthermore, inter-planting cultivars offers a unique opportunity for on-farm conservation of genetic resources by allowing farmers to grow widely adopted traditional rice cultivars.

In this study Binadhan-13 and BRRI dhan56 were inter-planted in different row ratios under varying weed management practices to evaluate their combined yield performance and weed suppression ability. The selection criteria of the cultivars were mostly plant stature, growth duration, grain yield and quality/market price. Binadhan-13 was a tall (150-160 cm), lodging susceptible and late-maturing variety (140 days) with moderate yield and fine (14 g/1000 grains) aromatic grains with high market price; while BRRI dhan56 was a semi-dwarf (110 cm) and mid-maturing (110 days) variety with high yield potential and coarse (22 g/1000 grains) grains. Because of wide variation in agronomic traits between cultivars, it was expected that the peak demand for resources would occur in different times to satisfy the selection criteria of component cultivars in mixtures as mentioned by a researcher, and at the same time one variety will provide physical support to other to prevent lodging. Advantages of inter-planting rice cultivars over monoculture in terms of rice growth and yield are evident from our study. Based on the combined rice grain yield, the best row mixture ratios were in the order 4:2, 3:2, 2:3 and 2:4 Binadhan-13 to BRRI dhan56. Cultivar mixture also suppressed weed growth better than pure-line culture. These findings are in conformity with those of many researchers who confirmed that growing rice cultivars in mixture improves functional diversity by ensuring enhanced positive interactions between cultivars and in turn improves rice yield, and therefore cultivar mixture is considered to be a very practical strategy for yield improvement in rice with less investment.

Like species diversity, genetic diversity within single-species contributes to greater ecosystem productivity and stability as well and hence cultivar mixtures offer a number of potential benefits especially under low-input and organic farming. Several mechanisms are believed to account for the yield advantages in cultivar mixture like complementary use of above- and below-ground resources, compensatory effects between cultivars with different competitive abilities and facilitation effect of one cultivar on the growth of other [29-31]. In case of compensation, yield of one component cultivar increases while the other decreases without affecting combined yield when grown in mixtures [32].

In the present study, yield of both Binadhan-13 and BRRI dhan56 were increased when grown in mixture compared to their respective sole culture. So, compensation mechanism is not responsible for yield advantage in this case. While facilitation occurs when one component cultivar benefits another component by providing physical support (such as by preventing lodging), improving microclimate, ameliorating abiotic stresses and providing protection against different biotic stresses like weed, insects and diseases [33]. Although degree lodging of the rice cultivars and any changes in microclimate due to cultivar mixture were not monitored in this study but weed growth in terms of density and biomass production was studied. As weed biomass was recorded lower in different ratios of cultivar mixture than in sole culture of either cultivar, therefore, facilitation effect applies here. Moreover, higher resistance to lodging of tall cultivar Binadhan-13 in mixture due to physical support provided by short cultivar BRRI dhan56 might also contribute to increased combined yield of mixture. Higher yield in mixture might also be due to better disease control in cultivar mixture as reported by many researchers although that observation was beyond the scope of the present study. However, monitoring of any changes in microclimate, lodging resistance and disease incidence would better explain the mechanism behind yield advantages in cultivar mixture occurred in this study.

The mechanism which is mostly applicable here is complementary use of resources by the cultivars. In cultivar mixture, overall use of above- and below-ground resources are better than pure-line sole culture. This occurs only when component cultivars differ in their resource use in terms of space and time. Complementarity occurs when component cultivars vary in their architectures and growth duration. In this study, Binadhan-13 took 140 days to mature while BRRI dhan56 matured only in 110 days. They had also differences in their plant stature; Binadhan-13 was a tall variety (>150 cm) while BRRI dhan56 was a semi-dwarf one (< 110 cm). This huge difference in both plant stature and maturity period ensured the maximum utilization of the resources by the cultivars in space and time dimensions which ultimately resulted in increased combined yield.

In this study, performances of different mixture ratios in terms of yield were variable. This happened due to the differences in their spatial pattern resulted from inter-planting ratios of cultivars. As stated by many researchers [34,35] mixture ratio influences competitiveness of component cultivars and consequently the yield. A researcher on the contrary, opined that varying spatial arrangements determined plant population of each component cultivar that ultimately influenced the combined yield of the mixture [36]. As described by another researcher, when cultivars are planted in mixture heterogeneity is increased and both the cultivars enjoy greater capacity to adjust under different limited resources and various stresses resulting higher yield than pure-line mono culture.

Findings of the present study confirm that cultivar mixtures suppress weed growth better than sole culture of respective cultivar. Similar findings have been reported by many researchers who concluded from their studies that cultivars grown in mixture can reduce weed dry matter production by enhancing competitive ability of crop. Based on a study, cultivar mixture resulted in taller plants compared with pure-line sole crop due to intra-specific competition for resources especially for solar radiation and space [37]. Taller plants better suppress weeds than dwarf plants as reported by many researchers [38-42]. In our study, plant height of Binadhan-13 was recorded higher in different mixtures than in sole culture, which might help reduce weed growth (data not shown). However, mixture ratio had no effect on plant height of BRRI dhan56. Since plant height of Binadhan-13 varied with its relative proportion in the mixture, therefore there is scope for manipulating mixture proportions of component cultivars for better weed management. Another researcher also opined in the same tune.

Higher number of tillers in cultivar mixture compared with respective monocrop might also contribute to better weed suppression. Apart from taller plants, high tillering ability also is a good measure of plant vigor which enhances plant competitiveness against weeds. As reported by a scholar, tillering affects competitive ability of rice against weeds through changes in leaf area index and canopy coverage [43]. Although, contrasting findings have also been reported. High tillering resulted in faster canopy coverage which prevents sunlight from reaching the underlying weeds and thereby smothering the weeds. Another potential reason behind better weed control may be the allelopathic differences between the rice cultivars which was not taken into account in this analysis. However, the competitive effect of cultivar mixtures against weeds depends on several factors including plant architecture, growth behavior and weed species composition, botanical characteristics of weeds, agronomic management and agro-ecological conditions among others.

Findings of the present study confirms the advantages of inter-planting Binadhan-13 and BRRI dhan56 in terms of weed suppression and yield ability over their sole culture, and thus cultivar mixture could be considered as an effective tool for increasing yield and weed management in rice. Binadhan-13 and BRRI dhan56 inter-planted in 4:2 row ratios appeared as the best mixture ratio which resulted in 136% and 7% yield advantages and 17% and 24% weed dry matter reduction over sole culture of Binadhan-13 and BRRI dhan56, respectively. However, further site specific and in depth studies are required by including different functionally diverse (with respect to agronomic traits and pest resistance) potential rice varieties from the huge genetic pool, and by considering other agronomic management factors to harvest the maximum benefit of cultivar mixture approach.

In addition, to choose right combination and design proper mixture ratio, cultivars should be carefully selected considering their plant architecture, growth behavior and maturity period to reduce intra-specific competition. In general, farmers mostly prefer highly adopted traditional local varieties, varieties with high market price and varieties producing grains with special quality such as fine grains with aroma. Therefore, it can be recommended that farmers may prefer to that combination containing one cultivar having quality grain with high market price (for example Binadhan-13) and another one for high yield potential (such as BRRI dhan56). However, when weed management is of huge concern, one of the component cultivars should preferably be strongly weed-competitive or allelopathic which can support another one (weak-competitor) through facilitation mechanism. In conclusion, cultivar mixture strategy can be adopted as an effective tool for better weed management and increased yield of rice. Further in-depth studies are required to devise a formula for determining best cultivar combination and correct mixture ratios to achieve the maximum benefit.

5. CONCLUSION

Based on the combined rice grain yield, different mixture ratios performed in the order 4:2, 3:2, 2:3 and 2:4 Binadhan-13 to BRRI dhan56. Binadhan-13 and BRRI dhan56 inter-planted in 4:2 row ratio appeared as the best mixture ratio which resulted in 136% and 7% yield advantages and 17% and 24% weed dry matter reduction over sole culture of Binadhan-13 and BRRI dhan56, respectively. In conclusion, cultivar mixture strategy can be adopted as an effective tool for better weed management and increased yield of rice. Additional site-specific research on this aspect is required to devise a formula for determining best cultivar combination and correct mixture ratios to achieve the maximum benefit.

REFERENCES

[1] Mitra, B.K., Karim, A.J.M.S., Haque, M.M., Ahmed, G.J.U., Bari, M.N. 2005. Effect of weed management practices on transplanted aman rice. Journal of Agronomy, 4, 238-241. doi: 10.3923/ja.2005.238.241

[2] Order, W., Phengchanh, S., Keobulapha, B. 1997. Weeds in slash-and-burn rice fields in northern Laos. Weed Research, 37, 111–119. doi: 10.1046/j.1365-3180.1996.d01-6.x

[3] Marwat, K.B., Saeed, M., Gul, B., Hussain, Z. 2006. Performance of different herbicides in wheat (*Triticum aestivum* L.) under rainfed conditions of Kohat, Pakistan. Pakistan Journal of Weed Science Research, 12, 163–168.

[4] Hussain, S., Ramzan, M., Akhter, M., Aslam, M. 2008. Weed management in direct seeded rice. The Journal of Animal and Plant Sciences, 18, 86–88.

[5] Blackshaw, R.E., Moyer, J.R., Harker, K.N., Clayton, G.W. 2005. Integration of agronomic practices and herbicides for sustainable weed management in a zero-till barley field pea rotation. Weed Technology, 19, 190–196. doi: 10.1614/WT-04-128R

[6] Bastiaans, L., Kropff, M.J., Goudriaan, J., Van Laar, H.H. 2000. Design of weed management systems with a reduced reliance on herbicides poses new challenges and prerequisites for modelling crop-weed interactions. Field Crop Research, 67, 161–179. doi: https://doi.org/10.1016/S0378-4290(00)00091-5

[7] Marshall, E.J.P., Brown, V.K., Boatman, N.D., Lutman, P.J.W., Squire, G.R., War, L.K. 2003. The role of weeds in supporting biological diversity

within crop fields. Weed Research, 43, 77–89. doi: 10.1046/j.1365-3180.2003.00326.x

[8] O' Donovan, J.T., Harker, K.N., Clayton, G.W., Newman, J.C., Robinson, D., Hall, L.M. 2001. Barley seeding rate influence the effects of variable herbicide rates on wild oat. Weed Science, 49, 746–754. doi: 10.1614/0043-1745(2001)049[0746:BSRITE]2.0.CO;2

[9] Grichar, W.J., Besler, B.A., Brewer, K.D. 2004. Effect of row spacing and herbicide dose on weed control and grain sorghum yield. Crop Protection, 23, 263–267. doi: 10.1016/j.cropro.2003.08.004

[10] Rodriguez, E.E. 2006. Effect of cultivar mixture on the competitive ability of barley against weed, MS Thesis, Swedish University of Agricultural Sciences.

[11] Binang, W.B., Ekeleme, F., Ntia, J.D. 2011. Management of weeds of rainfed lowland rice using cultivar mixture strategies. Asian Journal of Agricultural Research, 5, 306–311. doi: 10.3923/ajar.2011.306.311

[12] Mundt, C.C. 2002. Use of multiline cultivars and cultivar mixtures for disease management. Annual Review of Phytopathology, 40, 381–410.

[13] Helland, S.J., Holland, J.B. 2002. Genome-wide genetic diversity among components does not cause cultivar mixture responses. Crop Science Society of America, 43, 1618-1627. doi: 10.2135/cropsci2003.1618

[14] Finckh, M.R., Gacek, E.S., Goyeau, H., Lannou, C., Merz, U., Mundt, C.C., Munk, L., Nadziak, J., Newton, A.C., de Vallavieille-Pope, C., Wolfe, M.S. 2000. Cereal variety and species mixtures in practice, with emphasis on disease resistance. Agronomie, 20, 813–837. doi: 10.1051/agro:2000177

[15] Binang, W.B., Okapara, D.O., Nita, J.D., Shiyam, J.O. 2010a. Spatial and temporal deployment of cultivar effects on rice cuitivar mixtures. Research Journal of Agriculture and Biological Science, 6, 1099–1102.

[16] Bowden, R.L., Shroyer, J.P., Roozeboom, K.L., Claassen, M.M. 1980. Performance of wheat variety blends in Kansas. Kansas Agricultural Experiment Station Research Reports, doi: https://doi.org/10.4148/2378-5977.7327

[17] Esteven, E. 2006. Effect of cultivar mixture on the competitive ability of barley against weeds. MS Thesis, Department of Crop Production Ecology, Sveriges Lantbruks University, Uppsala, Sweden.

[18] Wolfe, M.S. 2000. Crop Strength through Diversity. Nature, 406, 681–682.

[19] Newton, A.C., Guy, D.C. 2009. The Effects of Uneven, Patchy Cultivar Mixtures on Disease Control and Yield in Winter Barley. Field Crops Research, 110, 225–228. doi: 10.1016/j.fcr.2008.09.002

[20] Haghshenas, A., Emam, Y., Ghadiri, H., Kazemeini, S.A., Kamgar-Haghighi, A.A. 2013. Effect of mixed cropping of an early and a middle-ripening wheat cultivar on mitigation of competition during post-anthesis moisture stress. Journal of Agricultural Science and Technology, 15, 491–503

[21] Bahani, F.A., Pirdashti, H., Niknejhad, Y. 2014. Effect of rice (*Oryza sativa* L.) cultivar mixture on paddy yield and yield components under different nitrogen levels. International Journal of Farming and Allied Sciences, 3, 317–319.

[22] Sharma, A., Ghosh A. 2000. Performance of early and long-duration rice (*Oryza sativa*) varieties in pure and mixed cropping systems under intermediate lowland condition. Indian Journal of Agricultural Science, 70, 282–286.

[23] Castilla, N.P., Vera Cruz C.M., Mew, T.W., Zhu, Y. 2003. Using rice cultivar mixtures: a sustainable approach for managing diseases and increasing yield. International Rice Research Notes, 28, 5–11.

[24] Cox, C.M., Garrett, K.A., Bowden, R.L., Fritz, A.K., Dendy, S.P., Heer, W.F. 2004. Cultivar mixtures for the simultaneous management of multiple diseases: Tan spot and leaf rust of wheat. Phytopathology, 94, 961–969.

[25] UNDP and FAO. 1988. Land resources appraisal of Bangladesh for agricultural development report no. 2. Agro-ecological Regions of Bangladesh. United Nations Development Programme and Food and Agricultural Organization, Rome, Italy. 212–221.

[26] Cruz, E.D., Moody, K., Mamos, M.B. 1986. Reducing variability in sampling weeds in upland rice (*Oryza sativa*). Philippine Journal of Weed Science, 13, 56–67.

[27] Janiya, J.D., Moody, K. 1989. Weed populations in transplanted and wet seeded rice as affected by weed control method. Tropical Pest Management, 35, 8-11. doi:10.1080/09670878909371311.

[28] Gomez, M.A, Gomez, A.A. 1984. Statistical Procedures for Agricultural Research. John Willey and Sons. New York, Chichester, Brisbane, Toronto.

[29] Willey, R.W. 1979. Intercropping - its importance and research needs. Part 2. Agronomy and research approaches. Commonwealth Agricultural Bureaux.

[30] Fukai, S., Trenbath, B.R. 1993. Processes determining intercrop productivity and yields of component crops. Field Crops Research, 34, 247–271. doi: 10.1016/0378-4290(93)90117-6

[31] García-Barrios, L. 2003. Plant-plant interactions in tropical agriculture. Chapter 2. In: Vandermeer J H (Edt.). Tropical Agroecosystems. Boca Raton, Florida: CRC Press. pp. 11–58.

[32] Khalifa, M.A., Qualset, C.O. 1974. Intergenotypic competition between tall and dwarf wheats. I. In mechanical mixtures. Crop Science, 14, 795-799. doi:10.2135/cropsci1974.0011183X001400060005x

[33] Callaway, R.M. 1995. Positive interactions among plants. *Bot Rev,* 61: 306–349.

[34] Fernández, O.N., Vignolio, O.R., Requesens, E.C. 2002. Competition between corn (*Zea mays*) and bermuda grass (*Cynodon dactylon*) in relation to crop plant arrangement. Agronomie, 22, 293–305. doi: 10.1051/agro:2002015

[35] Binang, W.B., Okpara, D.A., Shiyam, J.O., Ntia, J.D. 2010b. Evaluation of cultivar inter-planting ratio on the productivity of rice-rice system. Research Journal of Agriculture and Biological Science, 6, 1055–1059.

[36] Kalu, B.A., Obasi, N.O., Adezwa, D.K., Avav, T. 1998. Evaluation of yam/maize and yam/sorghum Intercrops. In: Nationally coordinated Research projects (NARP). Cassava/yam.1998 ann. Rep. for 1997. National Root Crops Research Institution, Umudike. pp. 55–56.

[37] Jedel, K.W., Mackill, D.J., Colowit, P.M., Payne, R.W. 1988. Competitive ability in mixtures of small grain cereals. Journal of Animal and Plant Science, 59, 1010–1116.

[38] Anwar, M.P., Juraimi, A.S., Man, A., Puteh, A., Selamat, A., Begum, M. 2010. Weed suppressive ability of rice (*Oryza sativa* L.) germplasm under aerobic soil conditions. Australian Journal of Crop Science, 4, 706–717.

[39] Arefin, M.A., Rahman, M.R., Rahman, A.N.M.A., Islam, A.K.M.M., Anwar, M.P. 2018. Weed competitiveness of winter rice (*Oryza sativa*) under modified aerobic system. Archievs of Agriculture and Environmental Science, 3, 1–14. doi: 10.26832/24566632.2018.030101

[40] Juraimi, A.S., Uddin, M.K., Anwar, M.P., Mohamed, M.T.M., Ismail, M.R., Man, A. 2013. Sustainable weed management in direct seeded rice culture: A review. Australian Journal of Crop Science, 7, 989–1002.

[41] Rahman, A.N.M.A., Islam, A.K.M.M., Arefin, M.A., Rahman, M.R., Anwar, M.P. 2017. Competitiveness of winter rice varieties against weed under dry direct seeded conditions. Agricultural Sciences, 8, 1415–1438. doi: 10.4236/as.2017.812101

[42] Shabi, T.H., Islam, A.K.M.M., Hasan, A.K., Juraimi, A.S., Anwar, M.P. 2018. Differential weed suppression ability in selected wheat varieties in Bangladesh. Acta Scientifica Malaysia, 2, 1–7. doi: 10.26480/asm.02.2018.01.07

[43] Fischer, A., Chatel, M., Ramirez, H., Lozano, J., Guimaraes, E.1995. Components of early competition between upland rice (*Oryza sativa*) and *Brachiara brizan tha* (Hochst. Ex A. Rich) Stapf. International Journal of Pest Management, 41, 100–103. doi: 10.1080/09670879509371931