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Intercropping of dry direct seeded boro rice with leafy vegetable for better weed suppression and higher profitability

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ABSTRACT

Dry direct seeded boro rice, grown in unpuddled and unsaturated/aerobic soil condition, requires only 50-60% water as compared to traditional flooded transplanted rice, and therefore it could be adopted as a water saving rice cultivation system in boro season of Bangladesh. However, high weed infestation is one of the major constraints in dry direct seeded boro rice. Therefore, an experiment was conducted to study the feasibility of growing different leafy vegetables as intercrop in dry direct seeded boro rice for higher profitability and better weed suppression following a randomized complete block design with three replications. Four leafy vegetables *viz.*, jute, gima kalmi, Indian spinach and red amaranth were intercropped with dry direct seeded boro rice (cv. BRRI dhan28) following three different rice planting patterns such as 50 cm spaced 2 row rice strip, 75 cm spaced 4 row rice strip, and 100 cm spaced 5 row rice strip. Sole rice was also maintained as control. The highest weed density and dry matter were found in Indian spinach intercropping with 50 cm spaced 2 row rice strip which was statistically identical with sole rice and some other intercropping systems. Performance of red amaranth as intercrop was the best in terms of weed suppression followed by jute. Rice yield was the highest (3.8 t ha^{-1}) in sole cropping, and intercropping resulted in significant yield reduction. Although intercropping diminished rice yield, but increased net return and benefit cost ratio (BCR) as compared to rice sole cropping (net return 49,910 Tk ha^{-1} and BCR 1.58). Among the vegetables, gima kalmi performed the best followed by red amaranth in terms of yield. Red amaranth intercropping following 50 cm spaced 2 row rice strip resulted in highest weed suppression (32% less weed biomass compared to sole rice) while gima kalmi intercropping following 50 cm spaced 2 row rice strip showed the highest net return (2,20,340 Tk ha^{-1}) and BCR (3.30).

Keywords: Direct seeded rice, intercropping, leafy vegetables, weed management, land equivalent ratio

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1 Introduction

Compared to other field crops, rice is mostly grown under irrigated condition which accounts for about 50% of the total amount of water diverted for irrigation and 80% of the amount of fresh water diverted (Farooq et al., 2009). This is due to the high unproductive water losses by evaporation, surface run-off, and percolation. Producing one kilogram of unprocessed rice grain under irrigation is estimated to use between 1500 and 5000 L of water, depending on the local climate, soil type and cultivation system (Tao et al., 2006; Rahman et al., 2017). This amount is about twice or even more than the amount consumed by wheat or maize (Baumann, 2000; Arefin et al., 2018). Under this situation, there is a need for developing water saving rice production technology to sustain boro rice production and ensure food security in the country. Taking the advantages of saving water and labor and increasing system productivity, dry direct seeded rice (DDSR) has been emerged as an optimal option for rice production (Kumar and Ladha, 2011). Dry direct seeded rice refers to the process of establishing the crop from seeds sown in the non-puddled and unsaturated soil in contrast; the seedlings from nursery are transplanted in the puddled soil in transplanted flooded rice. Dry direct seeding is adopted in upland rice and aerobic rice (Bouman and Tuong, 2001). Direct seeded boro rice requires only 50–60% water as compared to flooded transplanting rice. Rahman et al. (2012) stated that dry direct seeding could be practiced as the highly productive and cost-effective irrigation water saving rice cultivation system in boro season. Direct seeding has also the potential to decrease CH_4 emissions (Wassmann et al., 2004).

Although DDSR has several advantages, poor germination, uneven crop stand and high weed infestation are the major constrains to the adoption of dry direct seeded boro rice. Dry direct seeding technology is highly constrained by non-optimal seedling establishment due to cold establishment and weed infestation (Rahman et al., 2012). The concurrent emergence of competitive weeds, absence of water to suppress the weeds at the time of seedling emergence and prevalence of difficult to control weeds are the major reasons for the severe infestation of weeds in the DDSR. Weeds will adversely affect the yield, quality and cost of production due to competition for various growth factors (Singh et al., 2008). Because of wide adaptability and faster growth, weeds dominate the crops habitat and reduce the yield potential (Rao et al., 2007). Therefore, sustainable weed management is a huge challenge for the adoption of this technology.

Intercropping is an agricultural practice of cultivating two or more crops in the same land area at the same time. The most remarkable advantage of intercropping is producing a greater yield or income through more efficient use of agricultural resources e.g., nutrient, water, heat and radiation (Lithourgidis et al., 2011; Wang et al., 2015, 2017). Furthermore, intercropping can improve soil fertility, prevent soil erosion, and reduce the occurrence of diseases, insects and weeds (Hauggaard-Nielsen et al., 2013; Brooker et al., 2014; Jensen et al., 2015). Greater productivity in intercropping system is commonly achieved by minimizing inter-specific competition and maximizing complementary use of growth resources. Ghaffarzadeh et al. (1994) recorded that strip intercropping had 20–24% greater maize yields and 10–15% smaller soybean yields in the maize/soybean intercropping in Iowa. Sharma and Shyam (1992) reported that intercropping gave higher equivalent yield than rice alone. Intercropping is one option for reducing weed problems through non-chemical methods (Vandermeer, 1989). Baumann (2000) suggested that leek could be intercropped with celery (*Apium graveolens* L.) to improve weed suppression relative to a leek monoculture.

Intercropping is one of the strategies to reduce the weed infestation in rice field, which is cost effective and eco-friendly. Higher productivity can be obtained by the maximum utilization of resources through intercropping. Moreover, due to very low market price rice production is no more a profitable venture and farmers are losing their interest in growing rice. Fortunately, field condition of dry direct seeded boro rice seems favorable for growing several leafy vegetables as intercrop. Conventional method of planting rice, however does not allow intercropping because of narrow row spacing. Keeping in this view, a new method of planting rice in widely spaced multi-row strips has been developed. Strip plantation gives better paddy yield over conventional planting and also facilitates harvesting and handling of intercrops. Therefore intercropping may be considered as a viable option to maximize productivity and minimize weed pressure through weed suppression. Moreover, growing leafy vegetables in rice field will certainly meet the nutritional requirement of the farmers. The present study was therefore undertaken to evaluate the potentiality of growing different leafy vegetables as intercrop and their effect on reducing weed pressure in dry direct seeded boro rice.

2 Materials and Methods

2.1 Experimental site

The experimental field was located at 24°43′9.9″N, 90°25′44.2″E at an elevation of 18 m above the sea level. The experimental field belongs to non-calcareous dark grey floodplain soil under the Sonatala series, which falls under Old Brahmaputra Floodplain Agro-ecological Zone (AEZ-9) of Bangladesh (FAO-UNDP, 1988; Islam et al., 2011). The experimental field was a medium high land with moderate drained condition. The soil was silty loam in texture, almost neutral in reaction and low in organic matter content (Islam et al., 2017). The climate of the locality is sub-tropical in nature and is characterized by high temperature and heavy rainfall during Kharif season (April to September) and scanty of rainfall associated with moderately low temperature during Rabi season (October to March). The average air temperature, rainfall (monthly total), relative humidity (monthly average) and sunshine hours (monthly total) during the experimental period ranged from 22.1-28.8 °C, 0.20–496.1 mm, 74.7–84.9% and 97.8–191.6 hr, respectively.

2.2 Experimental treatments and design

Thirteen different planting patterns of rice-leafy vegetable intercropping were included as treatments in this study. The treatments were, (i) Rice sole (RS); (ii) Jute intercropped with rice following 50 cm spaced 2 row rice strip (2RR + J); (iii) Gima kalmi intercropped with rice following 50 cm spaced 2 row rice strip (2RR + G); (iv) Indian spinach intercropped with rice following 50 cm spaced 2 row rice strip (2RR + IS); (v) Red amaranth intercropped with rice following 50 cm spaced 2 row rice strip (2RR + RA); (vi) Jute intercropped with rice following 75 cm spaced 4 row rice strip (4RR + J); (vii) Gima kalmi intercropped with rice following 75 cm spaced 4 row rice strip (4RR + G); (viii) Indian spinach intercropped with rice following 75 cm spaced 4 row rice strip (4RR + IS); (ix) Red amaranth intercropped with rice following 75 cm spaced 4 row rice strip (4RR + RA); (x) Jute intercropped with rice following 100 cm spaced 5 row rice strip (5RR + J); (xi) Gima kalmi intercropped with rice following 100 cm spaced 5 row rice strip (5RR + G); (xii) Indian spinach intercropped with rice following 100 cm spaced 5 row rice strip (5RR + IS) and (xiii) red amaranth intercropped with rice following 100 cm spaced 5 row rice strip (5RR + RA). The treatments are illustrated in Fig. 1. The experiment was laid out in a randomized complete block design with three replications. Besides, three plots were also maintained as weed monoculture (without any crop) to study natural weed vegetation in absence of crop. Each plot size was 16 m^2.

2.3 Plant materials

A brief description of the crop varieties used in this experiment is given in Table 1.

2.4 Crop husbandry

The experimental land was dry ploughed with a power tiller on 7th February, 2017 followed by harrowing and leveling without puddling to obtain a smooth seedbed. Weeds and stubbles were removed from the field. Fertilizers were applied to the plots at the rate of 300, 125, 80, 80 kg ha^{-1} of urea, triple super phosphate, muriate of potash and gypsum, respectively. The whole amount of triple super phosphate, muriate of potash and gypsum were applied as basal dose at the time of final land preparation. Urea was top dressed in three equal splits at 15, 30 and 45 days after sowing (DAS). Sprouted seeds of rice were directly sown in the dry cultivated land following the planting patterns such as 50 cm spaced 2 row strip, 75 cm spaced 4 row strip or 100 cm spaced 5 row rice strip as per treatment. In sole rice, spacing was maintained as 25 cm $\times$ 15 cm. For all the planting patterns hill to hill distance for rice was maintained 15 cm. In each hill, 4–5 rice seeds were sown. In case of sole rice, seed rate was maintained 40 kg ha^{-1}. In case of intercropping, rice seed rate was adjusted accordingly as per planting pattern. Jute, gima kalmi, Indian spinach and red amaranth were direct seeded as intercrop in space between the rice strips on the same day. Seed rate used for Jute, gima kalmi, Indian spinach, red amaranth were 8, 9, 12, 3.5 kg ha^{-1}, respectively which were adjusted as per planting pattern. Jute and red amaranth were broadcast while gima kalmi and Indian spinach were sown in line maintaining 15 cm spacing between seeds. red amaranth was sown twice at the same day of rice sowing and at 35 days after rice sowing (DAS). Jute also was sown twice at the same day of rice sowing and at 35 DAS of rice while, gima kalmi and Indian spinach were sown once at the same day of rice sowing.

A light irrigation was given just after sowing for proper seed germination and better seedling establishment. Another two irrigation were given at 30 and 60 DAS. After every irrigation and rainfall excess water was drained out immediately to avoid damage to vegetables. No disease infestation was noticed either in rice or in vegetables. Only Cup 50EC were sprayed @20 mL 10 L^{-1} water at 40 DAS to prevent cutworm infestation in vegetables.

2.5 Data collection procedure

The rice was harvested at maturity and was determined when 90% of the grains became golden yellow in color. Five hills (excluding border hills) were randomly selected from each unit plot and uprooted before harvesting for recording the data on yield parameters. After sampling, whole plot was harvested. The harvested crop of individual plot was bundled, properly tagged and then brought to the threshing floor. The crops were then threshed and the fresh weights of grain and straw were recorded plot-wise. The grains and straw were sun dried separately and finally, grain yield was adjusted to 14% moisture content and converted to t ha^{-1}. All the intercrops such as, red amaranth, jute, Indian spinach and gima kalmi were harvested at their optimum stages (vegetative

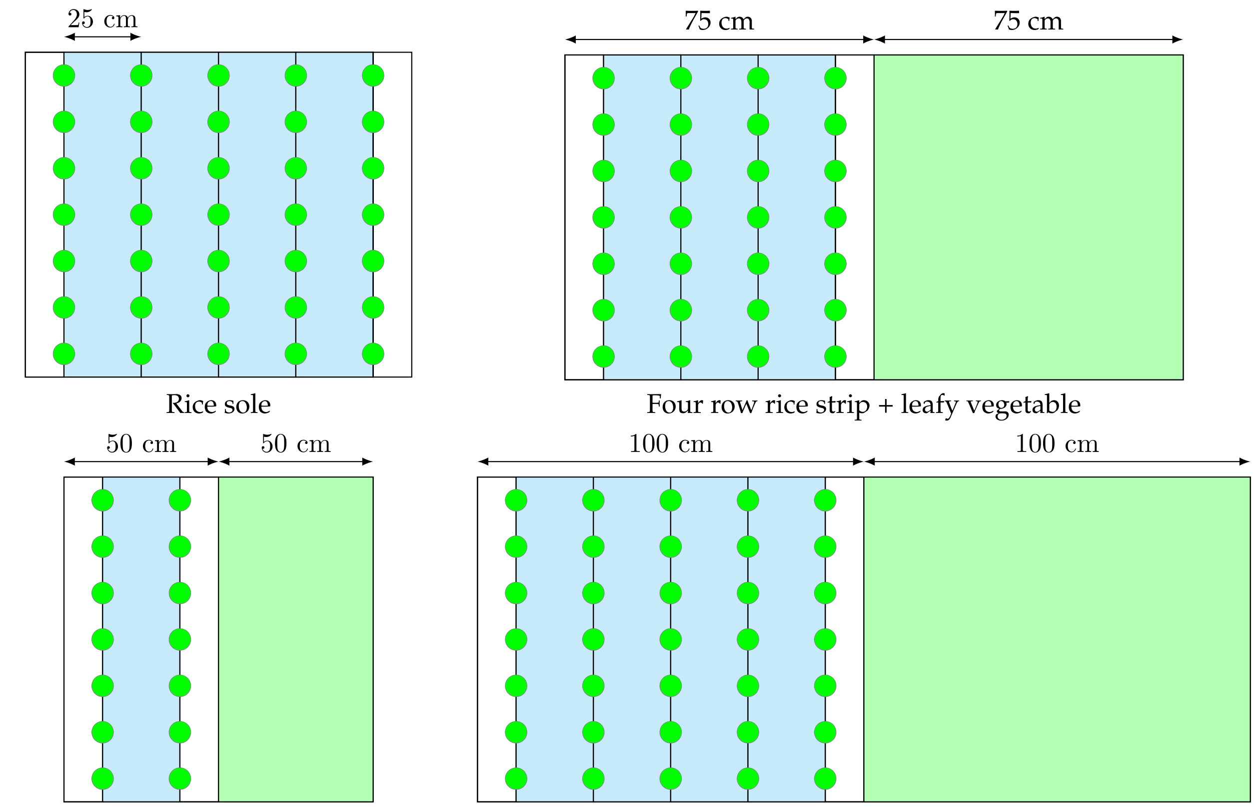

Figure 1. Schematic diagram showing planting patterns included as treatments. Green circles on lines designate rice hills and green rectangles designate leafy vegetable patches.

Table 1. A brief description of the crop varieties used in this experiment

Crop	Cultivar/ variety	Days to harvest	Yield (t ha^{-1})	Developed/ marketed by†
Rice *(Oryza sativa)*	BRRI dhan28	130–135	5–6	BRRI
Red amaranth *(Amaranthus cruentus)*	Altapeti-20	30–35	9–10	Lal Teer Seed Ltd.
Gima kalmi *(Ipomoea reptans)*	Evergreen 25	20–30	40–45	Metal Seed Ltd.
Indian spinach *(Basella alba)*	Read Leaf	35–40	20–25	Metal Seed Ltd.
Jute *(Corchorus capsularis)*	CVL-1	30–35	7–8	BJRI

† BRRI = Bangladesh Rice Research Institute, BJRI = Bangladesh Jute Research Institute

stage). Red amaranth and jute were harvested two times whereas Indian spinach and gima kalmi were harvested one and four times, respectively during the growth of the rice crop.

The relative yield of crop was calculated by the equation developed by De Wit and Van den Bergh (1965).

$$Y_R = \frac{\sum Y_{c_i}}{Y_c} \quad (1)$$

Here, Y_R = relative yield of crop, Y_{c_i} = yield of component crop, and Y_c = yield of sole crop.

Rice equivalent yield was calculated as per Anjaneyulu et al. (1982):

$$Y_{REq(v)} = Y_r + \frac{Y_{int} + P_{int}}{P_r} \quad (2)$$

Here, $Y_{REq(v)}$ = rice equivalent yield, Y_R = yield of rice, P_r = sale price of rice, Y_{int} = yield of intercrop (jute or gima kalmi or Indian spinach or red amaranth), and P_{int} = sale price of intercrop.

Land equivalent ratio was calculated as per Mead and Willey (1980):

$$LER = \frac{Y_{int(r)}}{Y_r} + \frac{Y_{int(v)}}{Y_v} \quad (3)$$

Here, LER = land equivalent ratio, $Y_{int(r)}$ =intercrop yield of rice, Y_r = sole yield of rice, $Y_{int(v)}$ = intercrop yield of vegetable , and Y_v = sole yield of vegetable.

Benefit cost ratio (BCR) was calculated as per:

$$BCR = \frac{I_G}{C_T} \quad (4)$$

Here, BCR = benefit cost ratio, I_G = gross income, and C_T = total cost.

2.6 Weed data

A quardrate of size 0.5 m × 0.5 m were placed randomly in two places of each plots for collecting weed samples. Weed were clipped at ground level, identified and counted by species, and separately oven dried at 70 °C to constant weight. Weed density (WD) and weed dry weight (WDW) were expressed as no. m^{-2} and g m^{-2}, respectively. Dominant weed species were identified using the summed dominance ratio (SDR) computed as follows (Janiya and Moody, 1989):

$$SDR = \frac{D_i/D_T}{DW_i/DW_T} \quad (5)$$

Here, SDR = summed dominance ratio, D_i = density of ith weed species, D_T = total weed density, DW_i = dry weight of ith weed species, and DW_T = total weed dry weight.

Relative contribution of different weed groups (Grass, Broadleaf, Sedge) to the weed vegetation in terms of RD (D_i/D_T) and RDW (DW_i/DW_T) were also calculated.

2.7 Statistical analysis

Data were analyzed using the analysis of variance (ANOVA) technique with the help of computer package programme MSTAT-C and mean differences were adjudged by Duncan's Multiple Range Test (Gomez and Gomez, 1984).

3 Results

3.1 Yield contributing characters of rice

Rice-leafy vegetable intercropping pattern significantly influenced the number of effective tillers hill^{-1} and number of grains panicle^{-1} (Table 2). The highest number of effective tillers hill^{-1} (10.3) and number of grains panicle^{-1} of rice (90.37) were obtained from rice sole cropping planted following 25 cm × 15 cm row spacing, which was statistically similar to that observed in jute or Indian spinach intercropping following 100 cm spaced 5 row rice strip. The lowest number of effective tillers hill^{-1} (7.6) was recorded when gima kalmi was intercropped following 50 cm spaced 2 row rice strip while the lowest number of grains panicle^{-1} (79.47) was recorded when red amaranth was intercropped following 75 cm spaced 4 row rice strip. But intercropping exerted no significant influence on 1000-grain weight of rice (Table 2).

3.2 Rice yield

Grain and straw yields of rice were significantly influenced by rice-leafy vegetable intercropping pattern (Table 2). The highest grain yield (3.8 t ha^{-1}) and straw yield (4.16 t ha^{-1}) were observed in rice sole cropping planted following 25 cm × 15 cm row spacing. While the lowest grain yield (1.7 t ha^{-1}) and straw yield (2.1 t ha^{-1}) were recorded when red amaranth was intercropped with rice following 50 cm spaced 2 row rice strip which was statistically similar to that observed in gima kalmi or red amaranth intercropping following 100 cm spaced 5 row rice strip and any of the vegetables intercropped following 75 cm spaced 4 row rice strip or jute intercropping following 50 cm spaced 2 row rice strip (Table 2).

3.3 Harvest index

Rice-leafy vegetable intercropping pattern exerted significant influence on the harvest Index of rice (Table 2). The highest harvest index (47.71%) was calculated in rice sole cropping planted following 25 cm × 15 cm row spacing which was statistically similar to that observed in jute or Indian spinach or red amaranth intercropping following 100 cm spaced 5 row rice strip and red amaranth following 75 cm spaced 4 row rice strip and jute or Indian spinach intercropping following 50 cm spaced 2 row rice strip. The lowest

Table 2. Effect of rice-leafy vegetable intercropping pattern on yield attributes and yield of rice

Treatments†	No. of effective tillers hill^{-1}	No. of grains panicle^{-1}	1000–grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
Rice sole	10.27a	90.37a	19.43	3.80a	2.600 bc	45.93abc
2RR + J	7.86cd	85.73abc	18.27	1.93cd	2.533 bc	44.00 c
2RR + G	7.63d	81.40cd	18.57	2.20bc	2.833 b	47.00 ab
2RR + IS	8.26bcd	83.27bcd	18.5	2.16bc	2.567 bc	45.48 abc
2RR + RA	8.66bcd	81.47cd	18.67	1.73d	2.600 bc	43.27 c
4RR + J	8.10bcd	84.07bcd	18.53	1.96cd	2.300 bc	44.12 c
4RR + G	8.53bcd	82.50bcd	18.7	1.83cd	2.567 bc	44.64 bc
4RR + IS	8.30bcd	85.00bc	18.53	2.06cd	2.367 bc	44.60 bc
4RR + RA	8.46bcd	79.47d	18.43	1.90cd	2.400 bc	44.50 bc
5RR + J	9.06abc	86.07abc	18.33	2.20bc	2.833 b	43.77 c
5RR + G	8.76bcd	83.97bcd	18.4	2.00cd	2.767 b	43.93 c
5RR + IS	9.26ab	87.33ab	18.53	2.50b	2.100 c	45.18 abc
5RR + RA	8.03bcd	81.70cd	18.53	2.13bcd	4.167 a	47.71 a
Level of sig.	**	**	NS	**	**	*
CV (%)	8.08	3.19	3.52	10.1	10.5	3.29

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); ** and * designate significance at 1% and 5% levels of probability, NS = Not significant;
† 2RR = 50 cm spaced 2 row rice strip, 4RR = 75 cm spaced 4 row rice strip, 5RR = 100 cm spaced 5 row rice strip, J = Jute, G = Gima kalmi, IS = Indian spinach, RA = Red amaranth

Table 3. Dominant weed species with family name, relative density (RD), relative dry weight (RDW) and summed dominance ratio (SDR) (averaged over all weed monoculture plots)

Common name	Scientific name	Family	Group	RD (%)	RDW (%)	SDR (%)
Angta	*Panicum distichum*	Gramineae	Grass	41.12	32.74	36.93
Shama	*Echinochloa crusgalli*	Gramineae	Grass	11.96	26.25	19.11
Fulka	*Leptochloa chinensis*	Gramineae	Grass	10.56	18.22	14.39
Gaicha	*Paspalum commersonii*	Gramineae	Grass	8.83	7.51	8.17
Anguli	*Digitaria sangunalis*	Gramineae	Grass	10.43	1.82	6.13
Bara chucha	*Cyperus iria*	Cyperaceae	Sedge	4.9	3.74	4.32
Titbegun	*Solanum torvum*	Solanaceae	Broadleaf	3.66	2.87	3.27
Hazardana	*Phyllanthus niruri*	Euphorbiaceae	Broadleaf	3.66	2.65	3.16
Keshuti	*Eclipta alba*	Compositae	Broadleaf	1.63	1.63	1.63
Khudesshama	*Echinochloa colonum*	Gramineae	Grass	1.63	1.63	1.63
Kanaibashi	*Commelina benghalensis*	Commelinaceae	Broadleaf	1.62	0.94	1.28

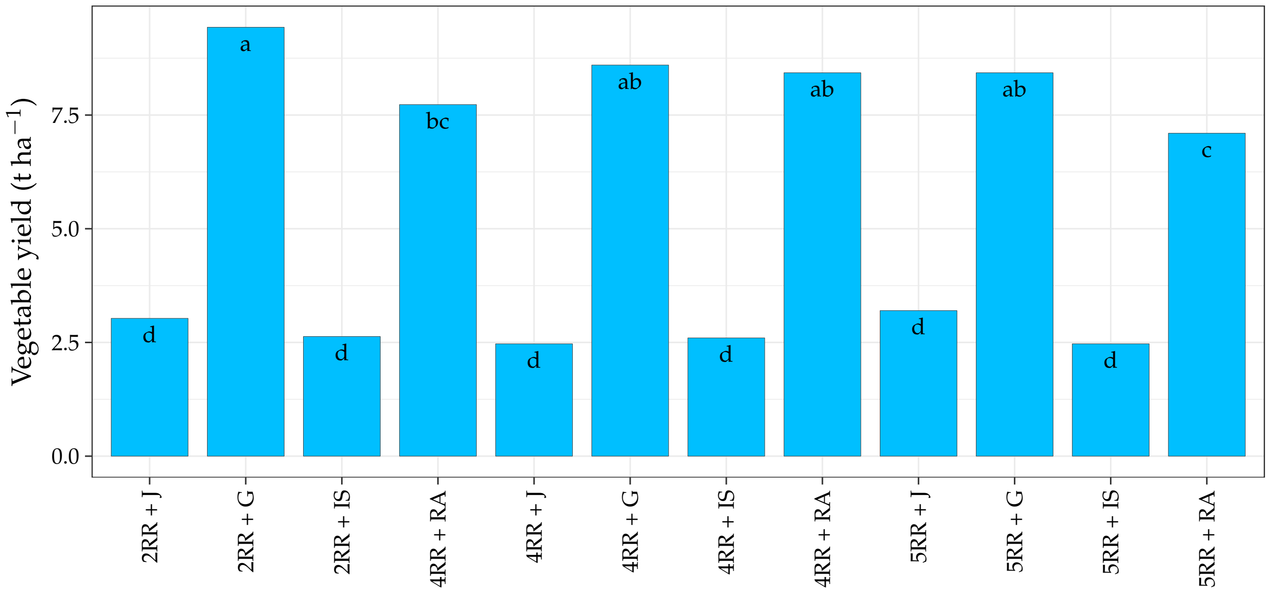

Figure 2. Yield of leafy vegetables as influenced by rice-leafy vegetable intercropping pattern. Here, 2RR = 50 cm spaced 2 row rice strip, 4RR = 75 cm spaced 4 row rice strip, 5RR = 100 cm spaced 5 row rice strip, J = Jute, G = Gima kalmi, IS = Indian spinach, RA = Red amaranth

harvest index, on the other hand was recorded when gima kalmi was intercropped with rice following 100 cm spaced 5 or 75 cm spaced 4 row rice strip or 50 cm spaced 2 row rice strip (Table 2).

3.4 Yield of leafy vegetables

Leafy vegetable yield was significantly influenced by rice-leafy vegetable intercropping pattern (Fig. 2). Among the different intercropping patterns, the highest vegetable yield (9.43 t ha^{-1}) was recorded from gima kalmi intercropped with rice following 50 cm spaced 2 row rice strip which was statistically similar to the yield of same vegetable when intercropped with rice following 75 cm spaced 4 row rice strip or 100 cm spaced 5 row rice strip and yield of red amaranth intercropped following 75 cm spaced 4 row rice strip. Indian spinach and jute intercropped with rice following 100 cm spaced 5 row rice strip and 75 cm spaced 4 row rice strip, respectively resulted in the lowest vegetable yield (2.47 t ha^{-1}). Indian spinach intercropped with rice following 50 cm spaced 2 row rice strip or 75 cm spaced 4 row rice strip and jute following 100 cm spaced 5 row rice strip also resulted in similar yield (Fig. 2).

3.5 Weed species composition

Eleven weed species belonging to six families infested the experimental field (Table 3). Among the eleven weed species, six were grasses, four were broadleaf and one was sedge. Common name, scientific name, family name, morphological type, relative density (RD%), relative dry weight (RDW%) and summed dominance ratio (SDR%) of the weeds found in experimental plots are presented in Table 3. Results show that experimental field was mostly infested with grasses. Among the weeds, grassy weeds constituted about 84.53% RD and 88.17% RDW, followed by broadleaved species (10.57% RD and 8.09% RDW, respectively) and sedges (4.90% RD and 3.74% RDW, respectively) (Fig. 3). Based on the summed dominance ratio (SDR%) values, grass weed species *Panicum distichum* (SDR of 36.93%) was the predominant species in the experimental field and grassy weed *Echinochloa crusgalli* emerged as second most dominant weed species (SDR of 19.11%) (Table 3). On the other hand, the least dominant weed species was broadleaf weed *Commelina benghalensis* (SDR of 1.28%) followed by broadleaf weed species *Eclipta alba* and *Echinochloa colonum* (SDR of 1.63%) (Table 3).

3.6 Weed growth

Rice-leafy vegetable intercropping pattern was found to be significant for weed density at both 15 and 45 days after sowing (DAS) (Table 4). The results revealed that highest weed density was observed in Indian spinach intercropped with rice following 50 cm spaced 2 row rice strip at both 15 and 45 DAS (175.7 and 164.7 weeds m^{-2}, respectively). At 15 DAS, the highest weed density (175.7 weeds m^{-2}) was found in Indian spinach intercropped with rice following 50 cm spaced 2 row rice strip which was statistically identical with those recorded in some other intercropping. The lowest weed density (122 weeds m^{-2}), on

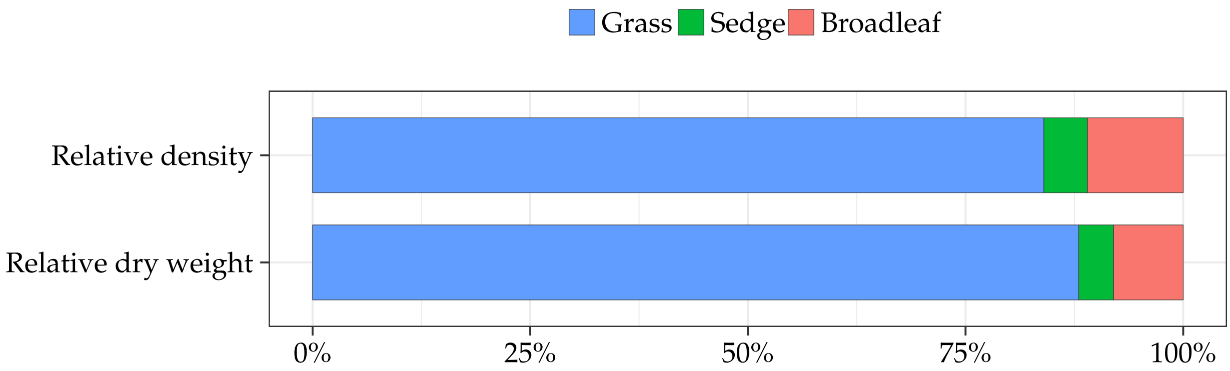

Figure 3. Relative density and relative dry weight of different weed groups

the other hand was recorded with red amaranth intercropped with rice following 50 cm spaced 2 row rice strip which was statistically similar with those observed in red amaranth intercropped with rice following 75 cm spaced 4 row rice strip or 100 cm spaced 5 row rice strip. At 45 DAS, the highest weed density (164.7 weeds m^{-2}) was found in Indian spinach intercropped with rice following 50 cm spaced 2 row rice strip; while red amaranth intercropped with rice following 50 cm spaced 2 row rice strip resulted in the lowest weed density of 110 weeds m^{-2} (Table 4).

Weed dry weight at different sampling dates was significantly influenced by rice-leafy vegetable intercropping pattern (Table 4). The results revealed that highest weed dry weight was observed in Indian spinach intercropped with rice following 50 cm spaced 2 row rice strip at both 15 and 45 DAS (71.75 and 65.93 g m^{-2}, respectively). The lowest weed dry weight (65.93 g m^{-2}), on the other hand was recorded in red amaranth intercropped with rice following 50 cm spaced 2 row rice strip which was statistically similar with those observed in red amaranth intercropped with rice following 75 cm spaced 4 row rice strip and 100 cm spaced 5 row rice strip. At 45 DAS, the highest weed dry weight (164.7 g m^{-2}) was found in Indian spinach intercropped with rice following 50 cm spaced 2 row rice strip which was statistically similar to those observed in many others intercropping patterns. The lowest weed dry weight (44.90 g m^{-2}) was found in red amaranth intercropped with rice following 50 cm spaced 2 row rice strip which was statistically similar to those observed in red amaranth intercropped with rice following 75 cm spaced 4 row rice strip and 100 cm spaced 5 row rice strip (Table 4).

3.7 Relative yield of rice

Relative yield determines competitive ability of component crops in intercropping system. In this study, the relative yield of rice ranged from 0.45 to 0.66, which indicates that rice yield loss was reduced by around 50% due to intercropping with different leafy vegetable (Table 5). The highest yield reduction (55%) with of rice was occurred when red amaranth was intercropped with rice following 50 cm spaced 2 row rice strip. On the other hand, when Indian spinach was intercropped with rice following 100 cm spaced 5 row rice strip, the lowest yield reduction (34%) was recorded (Table 5).

3.8 Rice equivalent yield

All the intercropping patterns resulted in higher rice equivalent yield than sole rice cropping. Table 5 shows that the rice equivalent yield ranged from 4.43 to 10.05 t ha^{-1} among the different treatments, while in case of sole rice cropping, the value was 3.8 t ha^{-1}. The highest rice equivalent yield (10.05 t ha^{-1}) was obtained when gima kalmi intercropped with rice following 50 cm spaced 2 row rice strip. While the lowest one was observed in jute intercropped with rice following 75 cm spaced 4 row rice strip. Although relative yield of rice was lower than sole crop in every cases, but intercropping with leafy vegetable resulted in higher yield advantage over the sole rice cropping. As a result of intercropping, yield advantage over sole rice cropping is evident and it ranges from 16.57 to 164.47% (Table 5).

3.9 Land equivalent ratio

Land equivalent ratio (LER) was recorded more than 1 for all the intercropping systems, and LER values ranged from 1.27 to 1.55 (Table 5). The LER >1 confirms the advantages of intercropping as compared to sole cropping, while LER < 1 indicates a disadvantage of intercropping. The highest LER of 1.55 (jute intercropped with rice following 5 row rice strip) means an intercrop benefit of 0.55. Jute intercropped with rice following 4 row rice strip, on the contrary resulted in the lowest LER of 1.22 with an intercrop benefit of only 0.22 (Table 5).

Table 4. Effect of rice-leafy vegetable intercropping pattern on weed density and weed dry weight at different sampling dates

Treatments†	Weed density (no. m^{-2})		Weed dry weight (g m^{-2})	
	15 DAS	45 DAS	15 DAS	45 DAS
Rice sole	173.3ab	163.0ab	71.47a	65.90a
2RR + J	152.7bc	137.3cd	62.23bc	56.83bc
2RR + G	160.7abc	141.3bcd	65.33abc	60.67abc
2RR + IS	175.7a	164.7a	71.75a	65.93a
2RR + RA	122.0 e	110.0e	49.70e	44.90e
4RR + J	154.0bc	142.3bcd	62.53bc	57.93bc
4RR + G	155.7abc	144.7abc	63.48bc	58.27abc
4RR + IS	170.3abc	150.0abc	68.95ab	64.37ab
4RR + RA	130.7e	120.7de	53.07de	48.10de
5RR + J	150.7cd	135.7cd	60.40cd	54.50cd
5RR + G	153.0bc	133.0cd	62.16bc	54.97cd
5RR + IS	167.7abc	151.0abc	68.03abc	61.23abc
5RR + RA	132.3de	121.7de	53.83de	48.77de
Level of sig.	**	**	**	**
CV (%)	7.21	8.39	6.78	7.14

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); ** designates significance at 1% level of probability; † 2RR = 50 cm spaced 2 row rice strip, 4RR = 75 cm spaced 4 row rice strip, 5RR = 100 cm spaced 5 row rice strip, J = Jute, G = Gima kalmi, IS = Indian spinach, RA = Red amaranth

Table 5. Relative yield of rice, rice equivalent yield, land equivalent ratio, cost and return analysis of different rice-vegetable intercropping

Treatment†	Relative yield (rice)	Rice equiv. yield (t ha^{-1})	Land equiv. ratio (LER)	Total variable cost (Tk ha^{-1})	Gross return (Tk ha^{-1})	Net return (Tk ha^{-1})	Benefit cost ratio
Rice sole	–	3.8	1	84,925	1,34,835	49,910	1.58
2RR + J	0.51	4.96	1.42	91,050	1,60,890	69,840	1.76
2RR + G	0.58	10.05	1.52	95,575	3,15,915	2,20,340	3.3
2RR + IS	0.57	4.79	1.51	86,325	1,57,745	71,420	1.82
4RR + RA	0.45	8.17	1.35	1,06,025	2,94,390	1,88,365	2.77
4RR + J	0.52	4.43	1.27	91,050	1,46,110	55,060	1.6
4RR + G	0.48	8.99	1.34	95,575	2,81,490	1,85,915	2.94
4RR + IS	0.54	4.66	1.47	86,325	1,52,845	66,520	1.77
4RR + RA	0.5	8.92	1.49	1,06,025	2,79,585	73,560	2.63
5RR + J	0.58	5.4	1.55	91,050	1,75,000	83,950	1.92
5RR + G	0.53	9.02	1.37	95,575	2,87,665	1,92,090	3
5RR + IS	0.66	4.97	1.54	86,325	1,63,265	76,940	1.89
5RR + RA	0.56	8.04	1.48	1,06,025	2,54,325	1,48,300	2.39

† 2RR = 50 cm spaced 2 row rice strip, 4RR = 75 cm spaced 4 row rice strip, 5RR = 100 cm spaced 5 row rice strip, J = Jute, G = Gima kalmi, IS = Indian spinach, RA = Red amaranth

3.10 Cost benefit analysis

Total variable cost, gross return, net return and benefit cost ratio of rice vegetable intercropping system are presented in Table 5. Total variable cost was less in sole rice cropping than that of other intercrop combinations. The highest total variable cost was calculated (1,06,025 Tk ha^{-1}) for red amaranth because of higher seed price and seed requirement for 2 times sowing. The total variable cost for gima kalmi and jute were 95575 and 91,050 Tk ha^{-1}, respectively. Indian spinach, on the other hand resulted in the lowest total variable cost of 86,325 Tk ha^{-1} due to less seed rate and only one time sowing. Table 5 shows that the lower gross return was calculated in case of sole rice. Among the intercrop species, gima kalmi resulted in the highest gross return irrespective of planting pattern (2,81,490 Tk ha^{-1} to 3,15,915 Tk ha^{-1}) because of highest vegetable yield. On the contrary, Intercropping with jute or Indian spinach resulted in lower gross return due to very low vegetable yield. Lower net return was calculated in case of sole rice than in intercropping. Among the intercrop species, gima kalmi resulted in the highest net return irrespective of planting pattern (1,85,915 Tk ha^{-1} to 2,20,340 Tk ha^{-1}) followed by red amaranth. The lowest net return was found in rice sole cropping. The highest (3.3) benefit-cost ratio (BCR) was obtained from gima kalmi intercropped with rice following 50 cm spaced 2 row rice strip. Second highest BCR (3.00) was obtained from gima kalmi intercropped with rice following 100 cm spaced 5 row rice strip. Intercropping with red amaranth also resulted in BCR >2, while for other vegetables the BCR values were <1. The lowest BCR (1.58) was calculated in rice sole cropping (Table 5).

4 Discussion

In the world of shrinkage resources like cultivable land, irrigation water and energy, resource poor farmers are unable to meet their ever increasing diversified domestic needs for food, feed and others following the prevailing sole cropping system (Jabbar et al., 2010). A shift from sole/mono cropping to multiple/intercropping offers an excellent opportunity for intensifying land use, yield advantages through yield stability and improved yield and profitability per unit area and time (Saleem et al., 2000; Nazir et al., 2002; Bhatti et al., 2006; Oroka and Omoregie, 2007). Also, it helps maintaining soil fertility by making efficient use of soil nutrients (Maingi et al., 2001) and ensuring maximum utilization of resources (Jeyabal and Kuppuswamy, 2001) and controlling weeds, insects and diseases (Wiley, 1979; Saeed et al., 1999). Intercropping/mixed cropping is most practiced by subsistence farmers to increase diversity of their products and to minimize risk (Okonji and Emmanuel, 2012).

Unsaturated/aerobic soil condition in dry direct seeded rice offers a unique opportunity to grow different winter season leafy vegetables as intercrop in between widely spaced multi-row rice strips. Strip plantation not only increases rice yield but also facilitates harvesting of intercrops conveniently without causing much damage to main crop (Saeed et al., 1999). In this study an attempt was made to grow leafy vegetables with dry direct seceded rice for better weed suppression and higher bio-economic efficiency.

Rice growth in terms of plant stature and tillering ability were influenced by different intercropping systems in this study. Although in most of the cases, rice growth was reduced in presence of intercrop vegetables, but in some cases rice growth was enhanced due to intercropping. This was due to the variation in the competitive behavior among intercrop vegetable species (Saleem et al., 2000; Ogola et al., 2012). Over shading of rice plants by intercrop species at early growth stages and also completion for resources between rice and leafy vegetable species might adversely affect rice growth. Aggressivity of the intercrop species might also contributed to the reduced growth of rice plant of the intercropping system (Oroka and Omoregie, 2007).

Rice yield in our study was lower in all the intercropping systems compared to sole rice cropping. Similar reduction in rice yield due to intercropping has also been documented by many researchers (Singh et al., 1996; Saeed et al., 1999). The reduction in rice grain yield was mostly attributed to reduced number of effective tillers hill^{-1} and grains panicle^{-1}. As mentioned by Saleem et al. (2000), suppressive effect of intercrop species on rice growth parameters and yield attributes was due to inter-specific competition for different resources during early stages of rice growth and also inability of rice plants to recover that loss at later stages. Khan (1984) and Ahmad (1990) also opined in the same tune. Saeed et al. (1999) on the contrary revealed that over shading of rice plants by intercrop species at early growth stages and also completion for resources between rice and leafy vegetable species adversely affected rice yield parameters and ultimately grain yield. The maximum reduction in rice grain yield was recorded due to intercropping with red amaranth/jute which was mostly due to luxuriant growth and shading effect at early growth stage of those leafy vegetables.

Although it transpires from the present findings that different intercropping systems caused substantial rice yield reduction, but total productivity of the system was increased in all the cases. The productivity advantage of rice-leafy vegetable intercropping might be attributed to more efficient uses of resources due to differences in plant architecture and growth duration of the component crops (Webster and Wilson, 1980). Moreover, the space allocated for different component crops is directly related to the resources available to each component crops (Oroka and Omoregie, 2007), which resulted in differences in overall productivity among different intercropping systems. A rice yield difference among row arrangements in intercropping system has also been confirmed by Ogola et al. (2012). As stated by many researchers (Sullivan, 2001; Abayomi et al., 2001), relative crowding coefficient and aggressivity index mostly regulate the interspecific completion in intercropping system and finally determine the system productivity. But, those two parameters were not measured in this study. It is noteworthy that some intercropping pattern (especially rice-legume) resulted in increased rice yield, which could be attributed to the biological nitrogen fixation by legume intercrop and extensive root system of the cereal (Chen et al., 2004). In fact, competitive behavior and suppressive effect of intercrop component mostly determine the yield reduction of main crop (Muoneke et al., 2007). The selection of intercrop species and space allocated for every component crop is very crucial since they minimize intercrop competition and enhance the system productivity through maximizing complementary effects.

In terms of rice yield equivalent, all the intercropping systems yielded higher than rice monocropping. In this study, rice equivalent yield was increased due to intercropping and it ranged from 22 to 164%. Increase in rice equivalent yield due to intercropping has also been documented earlier (Sharma and Shyam, 1992; Saud, 1999; Saeed et al., 1999; Joshi, 2002; Jabbar et al., 2010). Land equivalent ratio (LER), on the other hand, were found >1 within the narrow range of 1.27–1.55 for all the intercropping systems which confirms the advantages in intercropping as compared to sole cropping. The LER value of this study indicates that a larger area of land will be planted to obtain same yield of sole crops of each component as compared to intercrop mixtures. Huge differences in the yield potential among vegetable species might contribute to the variation in LER among different intercropping systems. Higher bio-efficiency in terms of LER as a consequence of intercropping as also been documented by many researchers (Saeed et al., 1999; Oroka and Omoregie, 2007; Ogola et al., 2012). Harvest index of rice was markedly reduced due to intercropping in this study which indicates that the efficiency of rice plants to convert dry matter into economic yield is negatively affected due to competition from component crop of the intercropping system. Reduction in harvest index in intercropping has been documented by many researchers (Ghauhan et al., 1994; Saeed et al., 1999; Ogola et al., 2012).

In monetary terms, all the intercropping systems performed better than rice sole culture in terms of net return and benefit cost ratio. These results are in consonance with the findings of Jha et al. (1991), Chandra et al. (1992) and Saleem et al. (2000) who also calculated higher net return and benefit cost ratio from intercropping over rice sole cropping. The high net return and benefit cost ratio observed in intercropping systems was the consequence of higher yield potential and market price of leafy vegetables compared to those of rice. In fact, high bio-efficiency of intercropping resulted in higher economic return from over rice sole cropping (Ogola et al., 2012).

5 Conclusions

Present study confirms the feasibility of growing leafy winter vegetables as intercrop in dry direct seeded boro rice. Moreover, it is also evident from this study that rice-vegetable intercropping results in higher yield and monetary return compared to rice sole cropping. Based on the present findings, gima kalmi and red amaranth can be suggested and promoted as promising intercrop component of dry direct seeded boro rice. However, further site specific in depth research considering all the agronomic management issues are recommended to develop a complete production package for direct seeded boro rice-leafy vegetable intercropping system before large scale adoption of this technology.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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