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Research Article

ENHANCING RAINFED UPLAND RICE PRODUCTIVITY THROUGH PLANT DENSITY, WEED AND NUTRIENT MANAGEMENT

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Abstract- A field experiment was conducted during autumn seasons of 2012 and 2013 to evaluate compost-fertilizer mixture (*comlizer*) on growth and yield of rainfed direct seeded rice (DSR) in upland situation under reduced plant density and integrated weed management (IW). Rice crop was sown 20 cm apart in band (BS) with recommended fertilizers doses (RFD), and weeds were managed either through application of pretilachlor 750 g/ha a.i. followed by working with grubber at 20 and 40 days after sowing (IW-1), or kept without weed management (weedy). Rice crop was also grown with reduced plant density by drilling the seeds in lines 20 cm apart maintaining 15 cm between seeds (DS). The DS was evaluated either, with RFD and mechanical weed management (MW) by working with grubber at 20 and 40 days after sowing (DAS), or *comlizer* in single split (*Comlizer*-S) or double splits (*Comlizer*-D) with pretilachlor 750 g/ha a.i. followed by grubber at 30 DAS (IW-2). IW-1 and IW-2 significantly reduced weed density and dry weight compared to MW or weedy. Application of *comlizer* in two splits increased effective tillers per unit area, average number of filled grains per panicle, and grain yield of rice compared to recommended fertilizer dose. The positive effect of *comlizer* application on growth and yield parameters of rice was explained by improvement in root growth and available nutrient status in soil *vis-à-vis* nutrient uptake by the crop. The root growth in terms of dry weight and volume was enhanced due to split application of *comlizer* that utilized a consistent pool of available nutrients from soil.

Keywords- *Comlizer*, Rainfed rice, Integrated weed management, Reduced plant density.

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Introduction

The approach to crop establishment and weed management for rice has gained attention during last few years in Asia. The farmers are changing the ways to establish crop and manage weeds because of hurdles due to unavailability and rising cost of major resources such as labour, water and the energy [1]. Besides, the average productivity of rainfed transplanted rice in Asia is declining due to climate variability [2-7]. Seeding of rice seeds after dry-tillage is a common practice in rainfed upland, lowland, and flood prone areas of Asia [8], and had recently received attention from farmers in irrigated areas with water scarcity [9].However, this favours growth of highly competitive weeds causing significant losses in grain yield as high as 91 to 99% [10], arising out of poor nutrient and water use efficiency by the crop. Optimum plant density enhanced growth and yield of DSR [11,12], but reduction in plant density must be complemented with effective weed management for sustainable yield [13, 14].

Compared to broadcasting, band application of P-fertilizers enhances P-uptake in plants in soils with high P-fixing capacity [15], and this method performed better in wheat and sorghum [16]. Split application of phosphorous (P) to azolla enhanced rice grain yield and P-uptake [17], while that of organomineral fertilizer was reported to improve growth and yield of rice [18]. Contrary to this, split application of phosphorous and potassium (K) did not produce any significant effect on grain yield of rice [19]. Foliar application of phosphorous in wheat was reported to be very effective [20, 21], while positive correlation was reported for P and K uptake at the maximum tillering and harvesting stage of *indica* and *japonica* rice [22].

Compost blending was reported to increase the immobilization of fertilizer-N which may influence crop availability and loss of fertilizer-N [23]. In soils with low inorganic-N content, combined application of chemical fertilizer increased compost efficiency through faster mineralization but resulted in increased NO_3 leaching [24]. Enrichment of compost as compost-fertilizer product with use of chemical fertilizer [8, 25, 26, 28] or through microbial inoculation [29] had already been reported. Split application of *comlizer* with reduced doses of fertilizers was found to enhance yield of transplanted rice [30], tuberose [31] and African marigold [32]. Accordingly, the present investigation was formulated to evaluate the performance of direct seeded rice under integrated weed management, reduced plant density and *comlizer* nutrition. It was hypothesized that optimum plant density with minimum competition from weed during early and late vegetative stages of the crop would increase the nutrient use efficiency and ultimately crop yield.

Materials and Methods

The experiment was conducted in 2013 at Instructional *cum* Research Farm, Jorhat (26°44´N, 94°l0´E and 91 m above MSL), and in 2014 at Regional Agricultural Research station, North Lakhimpur (27°14´N, 94°07´E and 102 m above MSL) of Assam Agricultural University, Jorhat, India during March to July. The two sites, Jorhat and Lakhimpur, share similar climate during March to July averaged over long-time records (unpublished data). The daily temperature of Jorhat and Lakhimpur increases from March to June with an average maximum temperature of 31°C in March to 38°C in May/June, and with an average minimum temperature of 12°C in March to 22°C in June. Similar to daily temperature, the monthly rainfall and number of rainy days in a month also increase from an average of 99 mm precipitation with 13 rainy days in March to 472 mm (487 mm in Jorhat) with 22 rainy days in July. The relative humidity fluctuates between 71% in March to 84% in June, while the mean total duration of bright sunshine hours remains at 10 hours/day during March to June. The soils of the two sites are classified as Entisols (Jorhat) and Inceptisols (Lakhimpur).

Rice (variety – *Inglongkiri*) seeds were sown on 25-03-2013 and on 22-03-2014 under dry soil condition in field during autumn seasons of 2013 and 2014, respectively. The soils of the experimental sites were sandy loam in texture and had pH 5.6, organic carbon 6.5 g/kg, available N 247.6, P 8.2, K 70.6 kg/ha in 2013, and had pH 5.1, organic carbon 8.6 g/kg, available N 314.6, P 11.5, K 104.7 kg/ha in 2014 season. Seeds were sown in lines at 20 cm apart either as band (BS) or drilled maintaining 15 cm between the seeds (DS), and nutrient and/or weed was managed as per the treatments. The treatments were arranged in randomized block design and replicated thrice with individual plot size of 5m x 4m. The RFD (N: P: K 20: 4.4: 8.3 kg/ha) was applied as urea, single super phosphate and muriate of potash, respectively, where the P-fertilizer was applied at the time of sowing and rest of the fertilizers were applied in two equal splits at 20 and 40 DAS. The *comlizer* was prepared by mixing biofertilizer-enriched vermicompost (1000 kg/ha) with half of RFD(½RFD) just before application. Vermicompost was enriched with biofertilizer by incubating the compost for 15 days after inoculation of biofertilizers *viz., Azotobacter* and phosphate solubilizing bacteria (PSB) maintaining 25±1 % (w/w) moisture content [29]. The biofertilizer was applied @ 2 g/kg vermicompost (w/w), where each gram of biofertilizer culture contained about 10^7 to 10^8 effective colony-forming units (cfu) of respective bacteria. The crop was harvested on 14-07-2013 and 09-07-2014 in 2013 and 2014 seasons, respectively.

Seven treatments were evaluated and comprised of T_1 – band sown (BS) with recommended fertilizer dose (RFD) and weedy (BS-RFD-Weedy); T_2 – band sown with recommended fertilizer dose, and pretilachlor (50% EC) 750 g/ha a.i. followed by grubber 20 and 40 DAS (BS-RFD-IW-1); T_3 – reduced plant density by drilled seed sowing (DS), unfertilized with IW-1 (DS-UF-IW-1); T_4–DS with RFD and IW-1 (DS-RFD-IW-1); T_5–DS with RFD, and mechanical weed management (MW) by grubber at 20 and 40 DAS (DS-RFD-MW); T_6–DS with ½RFD-*comlizer* at the time of sowing (*Comlizer*-S) with pretilachlor 750 g/ha a.i. followed by grubber at 30 DAS (IW-2) (DS-*Comlizer*-S-IW-2); T_7 - DSwith ½RFD-*comlizer*in two equal splits at the time of sowing and at 30 DAS (*Comlizer*-D) with IW-2 (DS-*Comlizer*-D-IW-2).Pre-emergence herbicide pretilachlor was applied on 28-03-2013 and 25-03-2014, respectively in 2013 and 2014 seasons, with a spray volume of 500 l/ha using a manual operated knapsack sprayer fitted with flood-jet nozzle in the respective treatments.

The vermicompost in each year was analyzed for total nutrient content following standard protocol. The bacterial count was done in the compost before and after inoculation with biofertilizer cultures, and in the *comlizer* after mixing with fertilizer. One gram of the compost or *comlizer* sample was serially diluted and hundred microlitres of it was plated separately for *Azotobacter* (Burk's medium) and PSB (Pikovskaya's medium). The plates were incubated at 28±2 ^{0}C for 48–72 hours and the colony-forming units (cfu) were counted.

Growth characters of the crop at specific stage were recorded in five randomly selected plants in each plot, and the mean value was used for statistical analysis. At the time of harvest, five hills were collected through random selection. The lengths of the panicles were measured and the number of panicles and the number of grains were counted in each hill. The mean value for each parameter was calculated from the observations recorded for five hills. The grain yield and straw yield were obtained by harvesting the crop in a plot excluding the border rows, and expressing the result as kg/ha.

In each plot five plants were arbitrarily selected and dug out carefully with least disturbance to the roots. The plants were washed with tape water, followed by repeated washings in a jet of distilled water with wash bottle to get rid of adsorbed soils, and soaked with filter paper for drying the excess water. The plants were dried in a hot air oven at 55±1^0 C till constant weight and the weight was recorded. The shoot and root portions were separated and the weight of shoot portions was measured for each set of plants. The mean weight of whole plant (shoot + root) and of shoot portion was worked out, and the average root weight was calculated by subtraction method. To estimate root volume, three sets of five plants each were collected from each plot and cleaned as described earlier. The total volume of separated roots for each set was determined by water displacement technique, and the average of the three sets was taken as root volume per plant by dividing with five.

Weed population and dry matter accumulation at specific growth stages of rice crop were estimated. The species-wise count was made and the value was converted into number per square metre. The weight of weeds for each species, after oven during at 55±1^{0}C till constant weight, was recorded and expressed as gram per square metre. The plant samples of both crop and weed, collected at various growth stages, were analysed for total nutrient concentration following wet digestion. Representative surface (0 – 15 cm) soil samples were collected from respective field before the experiment, at specific time during the experiment, and after harvest of crop. Soil samples were air dried and processed, and the relevant parameters were estimated following standard methods. Data were statistically analyzed using analysis of variance technique and treatment means were compared by Fisher's least significant difference test at 5% probability level.

Results and Discussion

Vermicompost and comlizer analysis

The various parameters of vermicompost before and after incubation with biofertilizer culture, and of *comlizer* (immediately after mixing with mineral fertilizer) are presented in [Table-1]. The C: N ratio of vermicompost declined in both the seasons after incubation with biofertilizer culture. Inoculation with biofertilizer culture increased the population of bacteria in the compost. However, mixing with chemical fertilizers, to form *comlizer*, reduced the population of *Azotobacter* and phosphate solubilizing bacteria. The total content of N, P and K in the compost decreased during the incubation period in both the seasons.

The vermicompost used in the two seasons showed some degree of variation in the properties like pH, nutrient content and population of bacteria, which was due to difference in raw materials used for preparation of the composts. Variation in nutrient content of vermicompost produced from different raw materials had been reported [33]. Incubation with biofertilizer culture reduced the pH and content of nutrients but increased the population of bacteria in the compost. Incubation of the composts with biofertilizer cultures reduced the C:N ratio from 13.6 to 8.2 in 2013 season and from 14.2 to 7.2 in 2014 season. The reduction in pH, organic carbon and C:N ratio during incubation of farmyard manure and compost was earlier reported [34]. The increase in the population of *Azotobacter* and PSB in the compost following their inoculation may be due to synergistic effect of the organisms [35, 36], while the relatively higher population of PSB may be due to its ability to use the substrates efficiently thereby enhancing its growth [37]. Reduction in C:N ratio of compost due to incubation is desirable as C:N ratio less than 20 signifies mature compost [38], although a ratio of 15 or less is preferable [39, 40] for faster mineralization following its application in soil.

Growth parameters

The plant height and number of leaves per plant are presented in [Table-2]. Irrespective of seasons or growth stages, i.e. 30 and 60 DAS, the plant height was not affected by the treatments. The number of leaves per plant was significantly reduced under weedy or unfertilized conditions [Table-2]. The maximum number of leaves in a plant at 30 DAS was observed with DS-Comlizer-S-IW-2 in 2013 and with DS-Comlizer-D-IW-2 in 2014, while at 60 DAS it was with the latter in both the seasons. This might be due to relatively better fertility status of the soil in 2014 season, which may also be accounted for statistically at par values between DS-UF-IW-1 and DS-RFD-MW in 2014 season. Fertilizer application significantly affected DMA in rice plant at 30 DAS, as the lowest value was recorded in DS-UF-IW-1 [Table-3], however at 60 DAS, weed management played a significant role in enhancing dry matter production of rice. Among the fertilizer treatments, DS-*Comlizer*-S-IW-2 recorded maximum DMA at 30 DAS, while at 60 DAS DS-*Comlizer*-D-IW-2 produced highest DMA in plants. The difference in DMA between DS-RFD-MW and DS-RFD-IW-1 was not significant in 2013, but differed significantly in 2014 season which might be due to relatively higher weed infestation in the latter season.

Table-1 *Properties of vermicompost and comlizer during 2013 and 2014 season*

Material	pH	Bacterial population (-log x 10^{-5} cfu/g)		Total nutrient content (%)			
		Azotobacter	PSB*	C	N	P	K
Season 2013							
Vermicompost before inoculation with biofertilizer	6.26	4.8	7.6	23.6	1.59	1.18	2.04
Vermicompost after incubation with biofertilizer	6.04	17.3	20.6	13.6	1.46	1.05	1.85
Comlizer-S	6.11	12.6	17.2	ND	ND	ND	ND
Comlizer-D	6.18	13.3	16.4	ND	ND	ND	ND
Season 2014							
Vermicompost before inoculation with biofertilizer	6.46	5.6	7.1	26.5	1.86	1.02	1.82
Vermicompost after incubation with biofertilizer	6.11	18.6	22.3	12.8	1.78	0.93	1.74
Comlizer-S	6.16	14.3	18.7	ND	ND	ND	ND
Comlizer-D	6.37	14.8	19.6	ND	ND	ND	ND

*PSB – phosphate solubilizing bacteria, ND = Not determined

Table-2 *Plant height, number of leaves per plant and dry matter accumulation of rice plants at different growth stages*

Treatment	Plant height (cm)				Number of leaves /plant				Dry matter accumulation (g/plant)			
	30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
BS-RFD-Weedy	27.3	28.6	61.7	60.4	7.1	7.7	5.9	6.3	0.47	0.44	1.24	1.18
BS-RFD-IW-1	28.8	29.5	66.4	67.1	8.8	9.0	7.9	8.1	0.62	0.65	2.35	2.24
DS-UF-IW-1	26.2	25.6	60.4	61.3	7.2	7.5	6.2	6.7	0.44	0.44	1.48	1.34
DS-RFD-IW-1	26.7	26.5	64.6	63.8	8.5	8.9	7.3	7.7	0.63	0.65	2.14	2.00
DS-RFD-MW	29.0	28.7	63.1	60.8	9.0	8.8	7.5	7.2	0.56	0.61	2.18	2.02
DS-*Comlizer*-S-IW-2	31.5	32.9	66.9	68.3	9.2	9.7	7.4	7.6	0.64	0.68	2.17	2.02
DS-*Comlizer*-D-IW-2	28.4	27.8	63.8	62.1	9.4	8.9	7.8	8.2	0.64	0.67	2.46	2.37
CD (P=0.05)	NS	NS	NS	NS	1.2	1.1	1.1	1.0	0.08	0.04	0.16	0.12
CV (%)	7.0	9.5	4.1	6.5	8.2	6.8	9.2	7.5	7.49	4.23	4.60	5.61

Table-3 *Root weight, root: shoot ratio and root volume of rice plants at different growth stages*

Treatment	Root weight (g/plant)				Root: shoot ratio				Root volume (cubic cm/plant)			
	30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
BS-RFD-Weedy	0.22	0.19	0.48	0.45	0.89	0.76	0.64	0.63	0.32	0.31	0.78	0.74
BS-RFD-IW-1	0.28	0.26	0.66	0.64	0.83	0.65	0.39	0.40	0.38	0.38	1.06	1.14
DS-UF-IW-1	0.21	0.19	0.46	0.42	0.95	0.74	0.45	0.45	0.32	0.31	0.73	0.72
DS-RFD-IW-1	0.27	0.27	0.63	0.62	0.73	0.72	0.42	0.45	0.36	0.38	1.01	1.02
DS-RFD-MW	0.26	0.27	0.64	0.62	0.84	0.78	0.42	0.44	0.36	0.35	1.00	1.04
DS-*Comlizer*-S-IW-2	0.26	0.26	0.64	0.62	0.68	0.62	0.42	0.44	0.37	0.38	1.01	1.05
DS-*Comlizer*-D-IW-2	0.26	0.26	0.69	0.67	0.70	0.63	0.39	0.39	0.38	0.39	1.11	1.16
CD (P=0.05)	0.04	0.02	0.05	0.05	0.13	0.09	0.03	0.05	0.03	0.04	0.10	0.11
CV (%)	8.57	4.38	4.37	4.87	9.06	7.18	4.03	5.91	4.41	6.19	5.67	6.12

The root: shoot ratio varied significantly among the treatments and growth stages [Table-3]. At 30 DAS, the maximum root: shoot ratio was recorded in DS-UF-IW-1 during 2013 season and in DS-RFD-MW during 2014 season. The highest ratio at 60 DAS was observed in BS-RFD-Weedy plot for both the seasons. The root: shoot ratio in BS-RFD-IW-1 differed significantly in 2013 season to DS-*Comlizer*-S-IW-2or DS-*Comlizer*-D-IW-2. Statistical significance was not observed between the root: shoot ratios of DS-*Comlizer*-S-IW-2 or DS-*Comlizer*-D-IW-2 at 30 DAS, but differed significantly at 60 DAS. In both the seasons, there was no statistical difference between BS-RFD-Weedy and DS-UF-IW-1 in root weight and root volume [Table-3], but the lowest root weight was observed in the latter, irrespective of seasons and growth stages. At 30 DAS, the root weight did not differ statistically among the fertilizer or weed management treatments. However, at 60 DAS the root weight in DS-*Comlizer*-D-IW-2 was significantly higher, except for BS-RFD-IW-1. The trend in root volume was similar to that observed for root weight [Table-3]. Application of DS-*Comlizer*-D-IW-2 produced highest root volume in rice plant irrespective of growth stages and seasons, and was at par with BS- RFD-IW-1. The lowest root volume was observed in unfertilized plot (DS-UF-IW-1), irrespective of seasons and growth stages. At 30 DAS, there was no statistical difference among the fertilizer and weed management treatments under reduced plant density (DS). However, at 60 DAS, DS-*Comlizer*-D-IW-2 was statistically superior to others under reduced plant density (DS).

Response of rice in terms of increased plant height to fertilizer dose [41] and source [42] has been reported. In the present study we did not observe any significant change in plant height up to 60 DAS. However, the number of leaves per plant significantly increased due to weed management and *comlizer* application. Thus the benefit of weed management and fertilizer application in terms of higher nutrient efficiency resulted in partitioning of dry matter accumulation in leaves [43]. Significant increase in root dry mass and volume in DS-*Comlizer*-D-IW-2 could facilitate nutrient uptake compared to others.

Nutrient (P and K) uptake by rice shoot and root

The P uptake by shoot at 30 DAS significantly increased in DS-*Comlizer*-S-IW-2 and DS-*Comlizer*-D-IW-2over others [Table-4]. In case of root, P uptake significantly decreased in unfertilized (DS-UF-IW-1) or weedy plot (BS-RFD-Weedy). The K uptake by root or shoot significantly decreased in weedy and unfertilized plots, but showed no significant difference among plant density, weed and fertilizer treatments at 30 DAS. At 60 DAS, P and K uptake by shoot or root was highest in DS-*Comlizer*-D-IW-2, and showed statistical significance to rests of the treatments except BS- RFD-IW-1 for root uptake of P and K in both the seasons.

Rapid increase in root dry weight during 50-75 DAS had earlier been reported [44]. Higher root-shoot ratio is often implicated for P stressed plants as compared with P sufficient plants [45]. This is due to severely reduced leaf growth under P stress, which leads to diminished leaf demand for assimilates consequently causing translocation of photosynthates to the root [46] for better root growth. This was further substantiated by the root: shoot ratio [Table-3], where DS-*Comlizer*-D-IW-2 recorded significantly lower values up to 60 DAS. The root weight of rice increased due to DS-*Comlizer*-D-IW-2 over DS-RFD-IW-1, but the corresponding root volume was statistically not significant. The corresponding higher P uptake by rice shoot and root further reiterates efficient nutrient uptake in plants supplied with *comlizer*.

Table-4 *Nutrient (P and K) uptake by rice shoot and root at 30 and 60 DAS in 2013 and 2014 seasons*

Treatment	P uptake (mg/plant) by rice root and shoot								K uptake (mg/plant) by rice root and shoot							
	Shoot				Root				Shoot				Root			
	30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
BS-RFD-Weedy	0.51	0.46	1.92	2.04	0.42	0.37	0.84	0.92	2.95	2.75	8.24	8.63	1.91	1.62	4.94	5.23
BS-RFD-IW-1	0.75	0.86	5.08	5.15	0.51	0.54	1.49	1.65	4.08	4.99	20.05	21.31	2.71	2.89	7.60	8.18
DS-UF-IW-1	0.37	0.46	2.23	2.34	0.31	0.34	0.85	0.81	2.47	2.99	10.93	9.75	1.99	1.66	4.79	5.11
DS-RFD-IW-1	0.75	0.76	4.58	4.76	0.50	0.51	1.33	1.55	3.87	4.15	17.08	16.52	2.44	2.44	6.86	7.43
DS-RFD-MW	0.54	0.69	4.31	4.17	0.43	0.43	1.40	1.48	3.40	4.45	17.77	17.47	2.30	2.31	6.57	7.28
DS-*Comlizer*-S-IW-2	0.88	0.92	4.68	4.92	0.50	0.57	1.37	1.50	4.40	5.07	17.54	18.76	2.64	2.76	6.59	6.94
DS-*Comlizer*-D-IW-2	0.89	1.03	5.87	6.05	0.49	0.54	1.57	1.61	4.38	5.20	21.53	22.23	2.62	2.91	7.85	8.71
CD (P=0.05)	0.12	0.16	0.72	0.89	0.08	0.11	0.25	0.20	0.49	0.61	2.61	2.28	0.42	0.63	0.95	0.81
CV (%)	9.8	11.4	9.9	12.1	10.2	8.6	11.0	12.6	7.5	10.3	12.3	9.1	9.9	11.1	10.3	8.25

Weed flora, density, dry weight and nutrient uptake

Integrated weed management with herbicide and grubber (IW-1 or IW-2) significantly reduced population and dry matter accumulation of weed per unit area [Table-5], compared to mechanical weeding (MW) or weedy plot. The weed density and dry weight per unit area did not vary statistically among the plant density or fertilizer treatments in integrated weed management (IW-1 or IW-2). The weed intensity was relatively severe in 2014 season and recorded as high as 237.1 g/m^2 of dry matter accumulation at 60 DAS in the weedy plot.

Table-5 *Weed density and dry weight at various crop growth stages*

Treatment	Weed density (number/m^2) at days after sowing						Weed dry weight (g/m^2) at days after sowing					
	2013 season			2014 season			2013 season			2014 season		
	20	40	60	20	40	60	20	40	60	20	40	60
BS-RFD-Weedy	49.3	62.0	77.0	63.7	116.3	132.7	22.1	42.6	110.8	42.3	134.3	237.1
BS-RFD-IW-1	24.3	15.0	31.0	30.7	19.7	33.3	13.7	21.3	35.4	18.1	29.2	46.6
DS-UF-IW-1	25.0	13.3	28.3	28.3	17.3	35.0	12.6	20.5	39.6	17.0	24.9	44.3
DS-RFD-IW-1	24.7	13.0	30.7	34.3	22.3	33.7	13.9	22.6	29.9	20.3	25.5	47.6
DS-RFD-MW	44.7	24.0	41.0	59.0	30.7	48.3	20.2	37.4	60.9	40.6	42.1	57.6
DS-*Comlizer*-S-IW-2	23.7	12.3	28.0	34.7	20.0	39.7	12.5	19.4	27.4	19.7	26.0	46.0
DS-*Comlizer*-D-IW-2	25.3	11.7	26.0	32.7	17.3	34.3	11.6	19.8	28.2	20.0	25.7	44.5
CD (P=0.05)	5.9	4.3	8.0	6.3	5.2	6.8	2.7	5.1	8.0	4.5	7.9	13.1
CV (%)	10.6	11.3	12.0	8.7	8.4	7.5	10.1	10.9	9.5	9.9	10.1	9.8

The species-wise distribution of weed dry weight at 40 DAS of rice is depicted in [Fig-1a and 1b] and that at 60 DAS is shown in [Fig-2a and 2b] for broadleaved and grassy weeds, respectively. Weedy plot showed maximum diversity and intensity of species throughout the period and thereafter. The broadleaved weeds like *Mimosa diplotricha*C. Wright ex Sauvalle and *Spilanthes paniculata*Wall., which are known for high N-content, either disappeared or considerably reduced in *comlizer* applied plots at later stages of the crop growth (60 DAS).

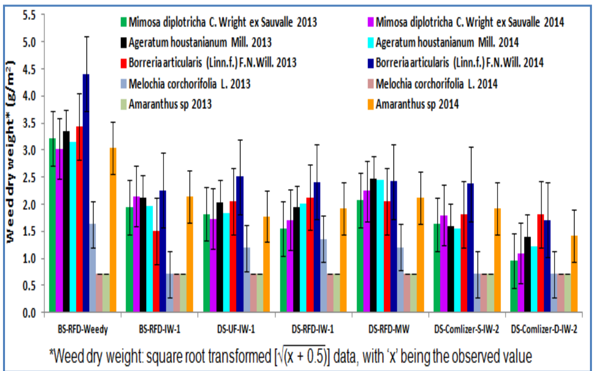


Fig-1a Species-wise distribution of weed dry weight of broadleaved weeds at 40 DAS in 2013 and 2014 seasons

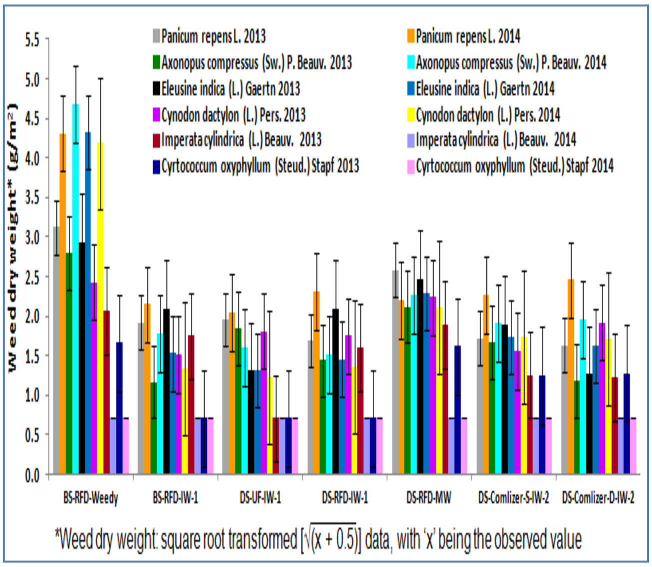
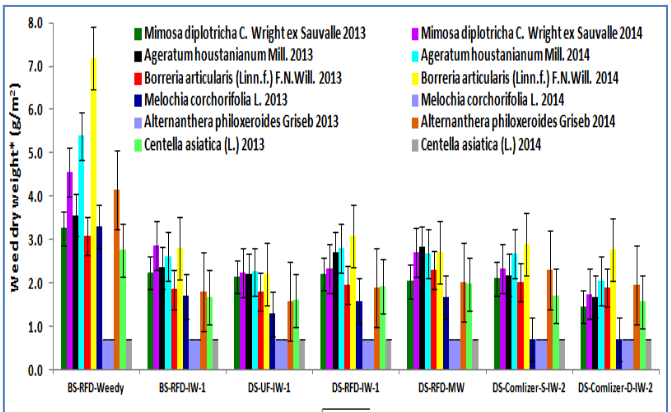


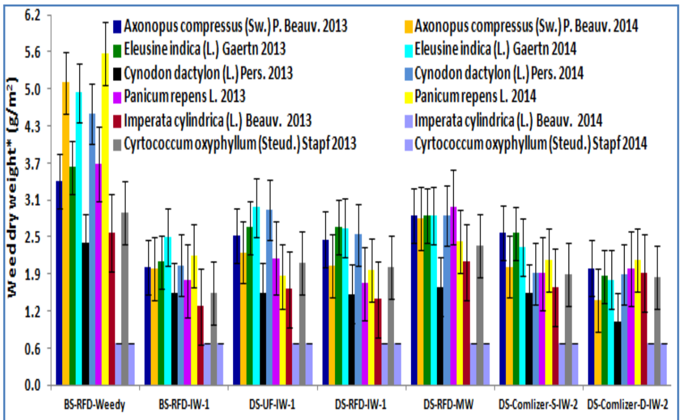
Fig-1b Species-wise distribution of weed dry weight of grassy weeds at 40 DAS in 2013 and 2014 seasons



*Weed dry weight: square root transformed [√(x + 0.5)] data, with 'x' being the observed value

Fig-2a Species-wise distribution of weed dry weight of broadleaved weeds at 60 DAS in 2013 and 2014 seasons

The total nutrient uptake by weeds at various growth stages of rice was estimated in 2013 season for macronutrients (N, P, K) and the data are shown in [Table-6]. The weedy plot recorded significantly higher nutrient uptake (N, P, K) irrespective of growth stages. Between integrated weed management (IW-1 or IW-2) and MW, the total removal differed significantly for all the nutrients and higher values were recorded for the latter. Among the fertilizer treatments or sowing methods receiving integrated weed management (IW-1 or IW-2), DS-*Comlizer*-D-IW-2 resulted lowest removal of nutrients by weeds and significant variations were observed with other treatments, at specific growth stages and for specific nutrient. Effective weed management in dry seeded rice with pre-emergence herbicide had been reported [47, 48], which contributed to the integrated weed management with mechanical weeding following pre-emergence herbicide application up to 60 DAS. The weed density and dry weight was not affected by planting method or fertilizer application in herbicide applied plots. The effect of fertilizer placement on weed biomass was earlier also not observed in herbicide treated plot [49]. However, we observed significant difference in total nutrient uptake by weeds among the fertilizer treatments [Table-7]. The variation in nutrient uptake may be attributed to the species diversity among the treatments [Fig-1a, 1b and 1c]. *Eleusine indica* (L.) Gaertnhas high P and K uptake ability than *Axonopus compresus*(Sw.) P. Beauv.[50]. *Cynodon dactylon* (L) Pers. had been reported to have edaphic ecotypes that differ markedly in response to fertilizer application [51].



*Weed dry weight: square root transformed [√(x + 0.5)] data, with 'x' being the observed value

Fig-2b Species-wise distribution of weed dry weight of grassy weeds at 60 DAS in 2013 and 2014 seasons

Table-6 *Nutrient uptake by weeds (g/ha) at different growth stages of rice in 2013*

Treatment	20 DAS						40 DAS						60 DAS					
	N		P		K		N		P		K		N		P		K	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
BS-RFD-Weedy	1954	2234	462	421	2456	1943	3135	7943	743	1829	4875	8903	8284	11018	1843	3393	12730	14706
BS-RFD-IW-1	1211	1267	279	225	1583	1052	1691	2131	437	447	2503	1746	2697	2375	716	730	4090	3106
DS-UF-IW-1	1046	1121	260	215	1481	947	1532	1727	414	444	2277	1497	3220	2206	725	788	4654	3315
DS-RFD-IW-1	1218	1206	278	215	1509	991	1654	1841	452	415	2730	1574	2670	2413	614	759	3570	3263
DS-RFD-MW	1957	2163	445	388	2346	1886	2891	2956	683	645	4456	2763	4338	2932	1110	961	6825	4017
DS-*Comlizer*-S-IW-2	1033	949	271	195	1386	867	1430	1879	393	477	2222	1858	1885	2288	527	717	3203	2830
DS-*Comlizer*-D-IW-2	928	799	214	169	1246	722	1202	1088	361	333	2039	1315	1497	1540	492	526	3170	1843
CD (P=0.05)	279	324	61	45	215	208	324	604	92	130	732	510	417	441	107	128	429	705
CV (%)	12	13	13	10	8	10	9	12	12	11	16	10	7	7	8	6	5	8

Yield, yield attributing characters and nutrient uptake in rice crop

Except for weedy plot (BS-RFD-Weedy), the number of hills per unit area was not affected by the treatments in both the seasons [Table-7]. Application of DS-*Comlizer*-D-IW-2 produced maximum number of effective panicles per hill and differed significantly to the rests of the treatments, except BS-RFD-IW-1 in 2013 season. The least number of panicles per hill was recorded in BS-RFD-Weedy followed by DS-UF-IW-1, and both differed significantly to other treatments. Under reduced plant density, mechanical weeding (MW) or IW-1 with RFD or IW-2 with ½RFD-*comlizer* (S) showed no statistical variations, but were statistically inferior to band sowing (BS) with RFD and IW-1 (BS-RFD-IW-1).

In both the seasons, the longest panicle was recorded with DS-*comlizer*-D-IW-2 and was at par with line sowing with BS-RFD-IW-1 [Table-7]. Weedy plot (BS-RFD-Weedy) produced the shortest panicle of rice both in 2013 and 2014 season, and was at par with unfertilized plot (BS-unfertilized-IW-1), and both differed significantly to rests of the treatments. Similar to that of panicle number, mechanical weeding (MW) or integrated weed management (IW-1) with RFD or IW-2 with ½RFD-*comlizer* (S) under reduced plant density showed no statistical variation among themselves, but differed significantly to DS-*comlizer*-D-IW-2.

Keeping the rice field weedy resulted in lowest number of filled grains and highest number of false grains in a panicle, which was statistically at par with unfertilized crop, and both differed significantly to the rests of the treatments [Table-7]. Addition of ½RFD-*comlizer* (D) under reduced plant density (DS-*comlizer*-D-IW-2) recorded maximum number of filled grains in a panicle, and was at par with BS-RFD-IW-1. However, the number of false grains per panicle in DS-*Comlizer*-D-IW-2 was significantly lower than mechanical weeding or IW with RFD or IW with ½RFD-*comlizer* (S) under reduced plant density. The difference in the average weight of thousand grains of rice was not significant among the treatments [Table-7]. The grain and straw yields of rice and total nutrient uptake by rice grain and straw are presented in [Table-8]. The highest grain and straw yields were observed for DS-*Comlizer*-D-IW-2 in both the seasons and differed significantly to rest of the treatments. Among the other treatments, reduced plant density (DS) with RFD-IW-1 or RFD-MW or ½RFD-*comlizer*-S produced lower grain and straw yields in both the seasons compared to band sowing (BS) with RFD-IW-1. Weedy plot recorded the lowest grain and straw yields in both the seasons and differed significantly to the unfertilized plot. Band sowing of rice with RFD and IWM-1 (BS-RFD-IWM-1) gave highest return in terms of monetary benefit per unit of production cost, closely followed by DS-*Comlizer*-D-IW-2. The lowest B:C ration was recorded for in weedy plot (BS-RFD-Weedy) followed by unfertilized (BS-UF-IWM-1) rice production [Table-8].

Table-7 *Growth and yield parameters of rice during 2013 and 2014 seasons*

Treatment	Number of hills/m²		Number of panicle/m²		Panicle length (cm)		Filled grains/panicle		False grains/panicle		Thousand grain weight (g)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
BS-RFD-Weedy	10.0	7.3	53.5	48.9	25.0	24.2	102.5	103.1	21.9	24.2	17.8	18.2
BS-RFD-IW-1	30.7	31.3	97.7	99.6	29.8	29.3	125.1	126.5	9.1	8.5	19.9	19.1
DS-UF-IW-1	28.7	27.7	62.9	67.5	25.4	25.3	112.9	112.8	16.1	17.1	18.7	17.9
DS-RFD-IW-1	27.3	28.0	87.2	86.8	27.4	27.8	123.4	122.8	13.3	12.2	19.2	18.9
DS-RFD-MW	27.0	27.7	88.1	90.7	27.5	27.6	122.3	123.3	11.3	11.7	19.1	18.7
DS-*Comlizer*-S-IW-2	29.7	28.3	86.5	87.9	27.4	28.0	123.1	121.4	11.5	12.1	18.5	19.3
DS-*Comlizer*-D-IW-2	29.3	28.7	104.3	105.6	30.0	30.2	127.1	129.3	8.3	7.9	20.0	19.0
CD (P=0.05)	4.4	3.9	6.3	6.9	2.0	2.2	9.9	8.0	2.1	1.9	NS	NS
CV (%)	9.5	8.7	4.4	4.6	4.1	4.5	4.7	3.8	8.9	7.9	9.2	9.5

Table-8 *Grain and straw yield of rice and total* nutrient uptake by the crop (kg/ha)*

Treatment	Grain yield			B:C# ratio	Straw yield			N-uptake		P-uptake		K-uptake	
	2013	2014	Mean		2013	2014	Mean	2013	2014	2013	2014	2013	2014
BS-RFD-Weedy	935	792	864	-0.16	1600	1371	1486	9.1	7.9	4.3	3.6	15.1	13.2
BS-RFD-IW-1	2180	2328	2255	0.64	3556	3878	3717	20.9	22.3	9.5	10.2	34.4	37.6
DS-UF-IW-1	1321	1371	1346	0.01	2167	2394	2280	11.5	12.2	5.1	6.0	20.2	22.1
DS-RFD-IW-1	2184	1935	2060	0.43	3689	3319	3504	18.6	18.1	9.3	8.9	34.3	32.5
DS-RFD-MW	2126	2013	2069	0.28	3333	3559	3446	18.5	19.3	9.2	8.5	32.0	34.4
DS-*Comlizer*-S-IW-2	1803	1997	1900	0.16	2889	3321	3105	16.6	19.1	7.9	8.8	27.7	31.9
DS-*Comlizer*-D-IW-2	2579	2694	2636	0.60	4000	4044	4022	24.5	25.7	11.5	11.7	39.3	40.7
CD (P=0.05)	189	265			209	668		2.5	2.1	1.5	0.9	4.5	3.8
CV (%)	6	8			4	12		8.2	6.6	10.4	6.0	8.7	7.1

*Total uptake = grain + straw #Benefit: cost ratio calculated on the basis of net profit

Nutrient uptake by grain and straw of rice crop

The highest uptake of N, P and K by rice grain and straw in 2013 and 2014 seasons was observed in ½RFD-*comlizer* (D) and the difference to rests of the treatments was statistically significant [Table-8]. Presence of weeds significantly reduced nutrient uptake by crop in both the seasons, and differed significantly to unfertilized condition except for N and P uptake in 2013 season. Except for N and P uptake in 2013 season, mechanical weeding (MW) or IW-1 with RFD or IW-2 with ½RFD-*comlizer* (S) under reduced plant density significantly decreased nutrient uptake by crop compared to band sowing with RFD and IW.

The improvement in yield attributing characters and grain yield due to application of ½RFD-*comlizer* (D) may be attributed to significant increase in vegetative growth *vis-à-vis* root growth and a continuous pool of available nutrients in soil throughout the growth period. The periodic contents of ammonical and nitrate nitrogen, available P were significantly higher in split application of ½RFD-*comlizer* [Table-9 and 10]. Thus, the initial benefit obtained during vegetative growth through effective weed management and nutrient supply was transformed into higher yield of rice.

Soil fertility status

[Table-9] depicts the ammonical nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) in soil at 40 and 60 days after sowing in 2013 and 2014 seasons. At both the growth stages, NH_4-N and NO_3-N contents in soil were highest due to application of DS-*comlizer*-D-IW-2 and showed statistical significance to rests of the treatments. The lowest content for all the parameters were observed under unfertilized plot.

The available potassium content in soil did not vary significantly due to the treatments at 40 and 60 DAs. However, application of DS-*comlizer*-D-IW-2 recorded highest values of available P and K in soil. The lowest value for all the parameters was recorded in the unfertilized plot. The available P content of soil in fertilizer applied plots did not vary significantly, but increased significantly over unfertilized plot. The soil fertility status after harvest of crop in each season is presented in [Table-10]. None of the parameters, *viz.,* pH, soil organic carbon and available nutrient content was affected by the treatments. Compared to reports for upland rice soils by many authors, we observed higher NH_4-N than NO_3-N, irrespective of the stages of sampling. Similar results in upland rice soils of Manipur, India were also reported [52]. Lower nitrate than ammonical nitrogen concentration was ascribed to sampling just after rainfall [53], which may be partly responsible for observations in the present investigation. In both the seasons, the rice crop received about 32 to 102 mm rainfall [Fig-3] in the week (19^{th} week) following application of second dose of fertilizer, irrespective of the treatments.

Table-9 *Ammonical and nitrate nitrogen in soil at different growth stages of the crop*

Treatment	Ammonical nitrogen (mg/kg)				Nitrate nitrogen (mg/kg)			
	40 DAS		60 DAS		40 DAS		60 DAS	
	2013	2014	2013	2014	2013	2014	2013	2014
BS-RFD-Weedy	52.6	58.6	76.5	84.5	37.5	42.6	44.6	47.7
BS-RFD-IW-1	55.5	61.8	77.1	96.2	40.2	46.2	48.8	54.9
DS-UF-IW-1	51.9	50.0	58.7	68.9	35.8	36.6	38.4	42.6
DS-RFD-IW-1	53.7	59.8	75.8	97.3	39.2	38.4	42.1	52.5
DS-RFD-MW	57.7	61.6	76.9	83.8	38.3	38.6	45.7	50.6
DS-*Comlizer*-S-IW-2	55.5	65.7	89.6	108.4	37.6	45.0	47.5	48.2
DS-*Comlizer*-D-IW-2	78.6	83.2	91.2	109.3	46.7	52.4	56.4	65.5
CD (P=0.05)	10.5	9.8	12.3	10.8	6.1	5.9	7.3	9.7
CV (%)	9.7	8.9	8.9	6.5	9.2	7.1	8.8	9.9

The soil of the experimental site being sandy loam in texture, part of the mineralized NO_3-N might have leached to deeper layers. However, the crop received optimum weekly rainfall thereafter with increasing temperature [Fig-3], and thus the treatment DS-*comlizer*-D-IW-2 with better growth could utilize the resources more efficiently resulting in highest grain yield of rice in both the seasons. Reducing the C:N ratio of rice straw and rice husks by the addition of mineral nitrogen increased the dehydrogenase activity drastically in the first day of incubation, suggesting immediate use of mineral nitrogen by microbial activity [54]. Higher mineralization of mineral nitrogen in soils takes place with high organic carbon content [55]. On the other hand, higher leaching losses of nutrients from organic and inorganic fertilizer mixture than organomineral fertilizers had been reported [56]. The C: N ratio of the organic fertilizer (37: 1) was higher than that of.

Table-10 *Available nutrient (P and K) in soil at different growth stages of the crop in 2013*

Treatment	Available phosphorous (mg/kg)				Available potassium (mg/kg)			
	40 DAS		60 DAS		40 DAS		60 DAS	
	2013	2014	2013	2014	2013	2014	2013	2014
BS-RFD-Weedy	4.3	4.6	5.0	4.7	32.9	33.9	33.4	34.3
BS-RFD-IW-1	4.1	4.8	4.3	5.1	33.9	33.7	34.3	33.6
DS-UF-IW-1	3.7	3.8	4.1	3.8	31.9	30.4	30.9	30.2
DS-RFD-IW-1	4.5	4.7	4.4	4.2	34.4	32.8	33.2	31.8
DS-RFD-MW	4.3	4.4	4.2	4.6	31.6	33.2	33.6	33.4
DS-*Comlizer*-S-IW-2	4.4	4.8	5.0	4.4	35.1	33.7	35.2	34.0
DS-*Comlizer*-D-IW-2	4.6	5.0	5.1	5.4	34.4	33.3	36.3	35.5
CD (P=0.05)	0.8	1.1	1.0	1.3	NS	NS	NS	NS
CV (%)	9.3	10.8	8.3	11.2	5.8	7.9	8.2	6.7

Table-11 *Soil fertility parameters at harvest of the crop in 2013 and 2014 seasons*

Treatment	pH		Organic carbon(g/kg)		Available nutrients (kg/ha)					
					N		P		K	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
BS – RFD - weedy	5.5	5.2	6.4	8.2	250.9	314.5	20.3	22.5	96.0	132.3
BS - RFD – IW-1	5.6	5.0	6.5	8.1	226.8	299.6	19.6	25.2	91.4	104.8
DS – unfertilized - IW-1	5.4	5.3	6.6	7.9	248.8	309.2	17.8	24.1	88.4	122.3
DS – RFD – IW-1	5.6	5.1	6.6	8.1	223.7	307.5	16.8	23.8	84.5	114.8
DS – RFD - MW	5.5	5.2	6.4	8.2	235.2	315.4	18.9	24.6	92.5	120.5
DS –*Comlizer*-SS – IW-2	5.5	5.2	6.8	8.0	225.8	314.1	18.1	26.5	94.9	116.4
DS –*Comlizer*-DS – IW-2	5.4	5.4	6.8	8.2	230	285.0	16.4	26.4	83.1	108.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	4.8	5.8	12.6	7.3	8.1	7.2	10.4	8.0	11.3	11.4

the *comlizer* (14: 1) used in the present study and thus there was least chance that nutrients were lost

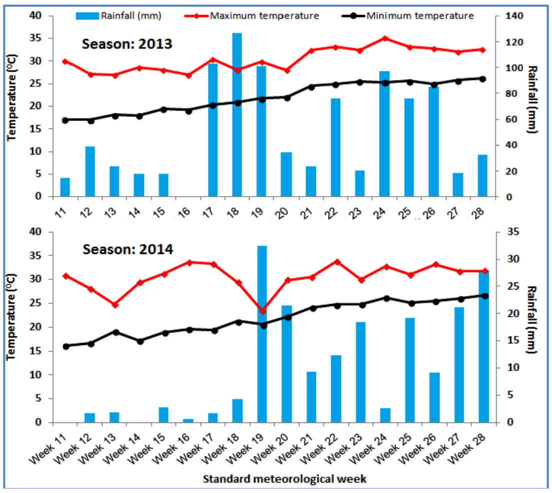


Fig-3 Weekly rainfall and average maximum and minimum temperature during the crop growth period in 2013 and 2014 seasons

Conclusion

Application of *comlizer* (compost-fertilizer mixture) improved growth and yield in rice compared to chemical fertilizers. Reduced plant density and effective weed management complemented the effect of *comlizer*. Split application of fertilizers as *comlizer* was beneficial, which needs further investigation, especially for phosphorous. This study left us with many questions than answers, which need to be clarified through further study. Nevertheless, *comlizer* offers scope to reduce fertilizer dose without sacrificing crop yield, the appropriate ratio and time of application need to be worked out.

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Abbreviations

DSR: Direct Seeded Rice
RFD: Recommended Fertilizers Doses
PSB: Phosphate Solubilizing Bacteria

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of Interest: None declared

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