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Brown Manuring - An Effective Technique for Increasing Productivity and Profitability of Aerobic Rice

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Abstract

The field experiment was conducted at Agronomy field unit, ZARS, UAS-B, GKVK, Bengaluru during summer 2022 and 2023 to study brown manuring - an effective technique for increasing productivity and profitability of aerobic rice. The experiment was composed of three factors *viz.,* factor I: Brown manuring (C_1-Rice and C_2-Rice + Sunhemp), factor II: RDF levels (N_1- 75% RDF, N_2- 100% RDF and N_3- 125% RDF) and factor III: Herbicides [H_1- No herbicide, H_2- Pendimethalin (1000 g *a.i.* ha^{-1}) PE *fb* Pyrazosulfuron (25 g *a.i.* ha^{-1}) (POE at 25 DAS) and H_3- Bensulfuron methyl + Pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) PE *fb* Bispyribac sodium (25 g *a.i.* ha^{-1}) 25-30 DAS] with total of 18 treatment combinations replicated thrice and laid out in RCBD design with Factorial concept. The results indicated that, rice + sunhemp recorded higher plant height (77.75 cm), dry matter production (96.20 g plant^{-1}), grain yield (4579 kg ha^{-1}), straw yield (6283 kg ha^{-1}) and B-C ratio (1.92) over sole rice. Among different RDF levels, 125 per cent RDF has recorded higher plant height (75.58 cm), dry matter production (93.98 g plant^{-1}) and grain yield (4455 kg ha^{-1}). Application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) noticed higher plant height (75.09 cm), dry matter production (93.45 g plant^{-1}), grain yield (4437 kg ha^{-1}) and B-C ratio (1.91). Combination of rice + sunhemp with 125 per cent RDF along with application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) recorded higher plant height (80.92 cm), dry matter production (99.62 g plant^{-1}), grain yield (4774 kg ha^{-1}) and straw yield (6747 kg ha^{-1}).

Keywords : Brown manuring, Aerobic rice, Sunhemp, Yield

As the global population continues to escalate, achieving food security remains a critical challenge. Rice (*Oryza sativa* L.) stands as one of the principal staple crops, feeding a substantial proportion of the world's population. Aerobic rice cultivation, also known as upland rice or non-flooded rice, has emerged as a promising alternative to traditional flooded paddy fields, offering the potential for higher yields and reduced water requirements. In this innovative approach, rice is cultivated in well-drained, non-waterlogged soils, substantially mitigating water usage and environmental impact. However, the successful implementation of aerobic rice farming necessitates careful consideration of various factors that influence growth, yield and overall crop performance. In this context, this research delves into the effect of brown manuring, different Recommended Dose of Fertilizers (RDF) levels and herbicides on the growth and yield of aerobic rice, aiming to establish optimized strategies for maximizing productivity and sustainability.

Brown manuring, the practice of co-culture of rice + sunhemp, later sunhemp plants are sprayed with selective herbicides like 2, 4-D ester for desiccation of sunhemp plants after 20-25 days of sowing which holds significant potential in addressing nutrient deficiencies and enhancing soil health in aerobic rice cultivation. Incorporating organic matter through brown manuring enriches the soil with essential nutrients, improves its structure and water-holding capacity and promotes microbial activity. Fertilizers play a pivotal role in supplementing essential nutrients, including nitrogen, phosphorus and potassium, which are vital for rice growth. However, an excessive or inadequate application of fertilizers can lead to imbalances, negatively impacting both crop productivity and the environment. Therefore, a systematic investigation into varying RDF levels and their impact on growth and yield is essential for fine-tuning fertilizer management in aerobic rice farming. Furthermore, effective weed management is indispensable for maximizing the potential of aerobic rice cultivation. Weeds compete with rice plants for essential nutrients, sunlight and water which resulting nearly 40-60 per cent yield (Theerthana *et al*., 2022). Herbicides tailored to the weed spectrum of aerobic rice fields can aid in efficient weed control, ensuring the crop's unobstructed growth and optimal productivity. In this research paper, we endeavor to comprehensively analyze the impact of brown manuring, different RDF levels and herbicide applications on the growth and yield of aerobic rice. Through meticulous experimentation and data analysis, we seek to provide valuable insights into optimized practices that can contribute to enhanced rice yields, efficient nutrient management and sustainable weed control in aerobic rice cultivation.

Material and Methods

The field experiment was conducted at Agronomy field unit, ZARS, UASB, GKVK, Bengaluru. This site is located in Agro Climatic Zone V (Eastern Dry Zone) of Karnataka at a latitude of 13º 05' North, longitude of 77º 34' East and an altitude of 924 m above mean sea level. The soil of the experimental site was red sandy loam in texture and slightly acidic in reaction (pH 6.2) with normal electrical conductivity (0.35 dS m^{-1}) and low in organic carbon content (4.5 mg kg^{-1}). The initial soil nutrient status was medium with respect to available nitrogen (229.5 kg ha^{-1}), phosphorus (26.6 kg ha^{-1}) and potassium (219.5 kg ha^{-1}).

Study was conducted to know brown manuring - an effective technique for increasing productivity and profitability of aerobic rice during summer 2022 and 2023. The experiment was conducted with three different factors *viz.,* factor I: Brown manuring (C_1-Rice and C_2-Rice + Sunhemp), factor II: RDF levels (N_1- 75% RDF, N_2- 100% RDF and N_3- 125% RDF) and factor III: Herbicides [H_1- No herbicide, H_2- Pendimethalin (1000 g *a.i.* ha^{-1}) PE *fb* Pyrazosulfuron (25 g *a.i.* ha^{-1}) (POE at 25 DAS) and H_3: Bensulfuron methyl + Pretilachlor 6.6 % G (660 g *a.i.* ha^{-1}) PE *fb* Bispyribac sodium (25 g *a.i.* ha^{-1}) 25-30 DAS] and totally with 18 treatment combinations which were replicated thrice and laid out in completely randomised block design (RCBD) with factorial concept. Rice variety KMP 175 seeds (5 kg ha^{-1}) were sown with spacing of 25 cm × 25 cm at depth of 4-5 cm and simultaneously sunhemp seeds (25 kg ha^{-1}) were broadcasted in brown manuring plots (rice + sunhemp). Nutrients were applied as per the treatments in the form of urea, single super phosphate and murate of potash to supply nitrogen, phosphorus and potassium, respectively as per the treatments. The 50 per cent of nitrogen and total amount of phosphorus and potassium were applied at sowing time and remaining 50 per cent of nitrogen was applied as top dressing at 30 and 60 DAS in two equal splits (RDF used is 100: 50: 50 kg ha^{-1} NPK). Pre-emergent herbicides were sprayed at 2 days after sowing and post emergent herbicides were applied at 25-30 days after sowing. Brown manured plots were sprayed with 2, 4-D ester @ 600 ml ha^{-1} at 25 DAS for desiccation of sunhemp plants.

Biometric observations on growth parameters were recorded randomly on selected five plants at 30, 60, 90 days after sowing and at harvest in the net plot. Data related to yield was recorded at the time of harvest of the crop. The data recorded on various parameters were subjected to Fisher's method of analysis of variance and interpretation of the data was made as given by Gomez and Gomez (1984). The level of significance used in 'F' and 't' test was P = 0.05. Whenever F-test was significant for comparison amongst the treatments means an appropriate value of critical differences (CD) was worked out. Otherwise against CD values abbreviation 'NS' (Non-significant) is indicated.

Results and Discussion

Plant Height

The seasonal and pooled data of two seasons pertaining to plant height at different growth stages of aerobic rice as influenced by brown manuring, RDF levels and herbicides in rice - rice bean cropping system is presented in Table 1.

Pooled data indicated that rice + sunhemp has recorded significantly higher plant height of 13.07, 39.13, 63.81 and 77.75 cm at 30, 60, 90 DAS and at harvest, respectively over sole cultivation of rice (11.39, 33.51, 54.77 and 66.48 cm respectively at 30, 60, 90 and at harvest, respectively). Increased plant height in brown manured treatment might be due to more competition for light between rice and sunhemp plants during initial period leads to increased auxin concentration resulted taller plants (Gill and Wallia, 2014).

There was significant increase in plant height with increasing level of RDF. Among different RDF levels, 125 per cent RDF has recorded significantly higher plant height (12.86 cm) which was on par with 100 per cent RDF (38.05 cm) and significantly lower plant height was recorded with 75 per cent RDF (11.65 cm) at 30 DAS. Similar trend was followed at 60, 90 DAS and at harvest of the crop. Significantly higher plant height was recorded with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) (13.22 cm) which was on par with pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) (12.23 cm) and significantly lower plant height was observed in no herbicide treatment (H_1) (11.25 cm) at 30 DAS and similar trend was followed at 60, 90 DAS and at harvest of the crop. Adequate supply of nutrients and weed free environment due to herbicides at initial period helped for better accumulation and translocation of photosynthates which resulted in taller rice plants (Babu *et al*., 2013; Lakshmibai *et al*. 2014 and Bindu *et al*., 2023).

Overall interaction between brown manuring, RDF levels and herbicides was differed significantly in all growth stages of crop except 30 DAS. At 60 DAS the combination of rice + sunhemp with 125 per cent RDF along with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) has recorded significantly higher plant height (40.71 cm) whereas, significantly lower plant height was observed with combination of 75 per cent RDF + sole cultivation of rice without herbicides (24.63 cm). Similar trend was followed at 90 DAS and at harvest. Combined effect of brown manuring with increased RDF levels resulted in taller rice plants due to balanced nutrition to plants through both organic (brown manuring) and inorganic nutrients source (RDF) have enhanced cell division and cell elongation (Sarangi *et al.,* 2016).

Number of Tillers

The number of tillers $plant^{-1}$ were significantly influenced by brown manuring, RDF levels and herbicides and data is presented in Table 2. Rice + sunhemp (1.87) recorded significantly higher number pf tillers $plant^{-1}$ compared to sole rice (1.30 $plant^{-1}$). Among different RDF levels, 125 per cent has recorded significantly higher number of tillers (1.88 $plant^{-1}$) which was on par with 100 per cent RDF (1.58) whereas, significantly lower number of tillers observed under 75 per cent RDF (1.29 $plant^{-1}$). At 30 DAS pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) has recorded significantly higher number of tillers (1.86 $plant^{-1}$) which was on par with and pre-emergent

TABLE 1

Effect of brown manuring, RDF levels and herbicides on plant height (cm) of aerobic rice

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
C_1	10.96	11.82	11.39	33.10	33.92	33.51	54.43	55.10	54.77	66.20	66.76	66.48
C_2	12.08	14.06	13.07	38.45	39.80	39.13	63.23	64.39	63.81	76.90	78.59	77.75
S.Em.±	0.20	0.24	0.21	0.28	0.31	0.30	0.46	0.47	0.46	0.56	0.59	0.57
CD at 5%	0.57	0.68	0.60	0.80	0.90	0.85	1.31	1.35	1.33	1.60	1.75	1.68
RDF level (N)												
N_1	10.94	12.36	11.65	33.28	34.36	33.82	54.72	55.64	55.18	66.55	67.68	67.12
N_2	11.47	12.89	12.18	36.54	37.62	37.08	60.09	61.00	60.54	73.08	74.20	73.64
N_3	12.15	13.57	12.86	37.51	38.60	38.05	61.68	62.60	62.14	75.02	76.15	75.58
S.Em.±	0.24	0.26	0.25	0.34	0.35	0.34	0.56	0.59	0.56	0.68	0.69	0.68
CD at 5%	0.70	0.74	0.72	0.98	1.01	0.99	1.61	1.70	1.66	1.96	1.99	1.97
Herbicides (H)												
H_1	10.54	11.96	11.25	33.70	34.78	34.24	55.41	56.33	55.87	67.40	68.52	67.96
H_2	11.52	12.94	12.23	36.36	37.45	36.91	59.80	60.71	60.25	72.73	73.85	73.29
H_3	12.51	13.93	13.22	37.27	38.35	37.81	61.28	62.19	61.74	74.53	75.66	75.09
S.Em.±	0.24	0.25	0.24	0.34	0.35	0.34	0.56	0.59	0.56	0.68	0.69	0.68
CD at 5%	0.70	0.73	0.72	0.98	1.01	0.99	1.61	1.70	1.66	1.96	1.99	1.97
Interaction C×N												
$C_1 N_1$	10.12	10.98	10.55	29.32	30.14	29.73	48.21	48.88	48.55	58.64	59.20	58.92
$C_1 N_2$	11.03	11.89	11.46	34.13	34.95	34.54	56.12	56.79	56.46	68.26	68.82	68.54
$C_1 N_3$	11.74	12.60	12.17	35.85	36.67	36.26	58.96	59.63	59.30	71.71	72.27	71.99
$C_2 N_1$	11.76	13.74	12.75	37.24	38.59	37.91	61.23	62.39	61.81	74.47	76.16	75.32
$C_2 N_2$	11.90	13.88	12.89	38.95	40.30	39.62	64.05	65.20	64.63	77.90	79.59	78.74
$C_2 N_3$	12.57	14.55	13.56	39.17	40.52	39.84	64.41	65.56	64.98	78.33	80.02	79.18
S.Em.±	0.34	0.36	0.35	0.48	0.50	0.49	0.79	0.80	0.79	0.96	0.99	0.98
CD at 5%	NS	NS	NS	1.38	1.45	1.42	2.27	2.30	2.28	2.77	2.86	2.82
$C_1 H_1$	10.38	11.24	10.81	30.29	31.11	30.70	49.81	50.48	50.14	60.58	61.14	60.86
$C_1 H_2$	10.96	11.82	11.39	33.77	34.59	34.18	55.53	56.20	55.86	67.53	68.09	67.81

Continued....

Table 1 Continued

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
$C_1 H_3$	11.55	12.41	11.98	35.25	36.07	35.66	57.96	58.63	58.30	70.49	71.05	70.77
$C_2 H_1$	10.70	12.68	11.69	37.11	38.46	37.78	61.02	62.18	61.60	74.21	75.90	75.06
$C_2 H_2$	12.07	14.05	13.06	38.96	40.31	39.63	64.07	65.22	64.64	77.92	79.61	78.76
$C_2 H_3$	13.47	15.45	14.46	39.28	40.63	39.96	64.60	65.76	65.18	78.57	80.26	79.41
S.Em.±	0.32	0.34	0.33	0.48	0.50	0.49	0.79	0.80	0.79	0.96	0.99	0.98
CD at 5%	NS	NS	NS	1.38	1.45	1.42	2.27	2.30	2.28	2.77	2.86	2.82
Interaction N×H												
$N_1 H_1$	9.69	11.11	10.40	30.06	31.14	30.60	49.43	50.34	49.89	60.12	61.24	60.68
$N_1 H_2$	11.08	12.50	11.79	34.37	35.46	34.92	56.52	57.44	56.98	68.75	69.87	69.31
$N_1 H_3$	12.06	13.48	12.77	35.40	36.48	35.94	58.21	59.13	58.67	70.80	71.92	71.36
$N_2 H_1$	10.41	11.83	11.12	34.47	35.55	35.01	56.68	57.59	57.13	68.93	70.06	69.49
$N_2 H_2$	11.39	12.81	12.10	37.04	38.13	37.58	60.91	61.83	61.37	74.08	75.21	74.65
$N_2 H_3$	12.60	14.02	13.31	38.11	39.19	38.65	62.67	63.58	63.12	76.22	77.34	76.78
$N_3 H_1$	11.52	12.94	12.23	36.57	37.65	37.11	60.13	61.05	60.59	73.14	74.26	73.70
$N_3 H_2$	12.08	13.50	12.79	37.67	38.76	38.22	61.95	62.87	62.41	75.35	76.47	75.91
$N_3 H_3$	12.86	14.28	13.57	38.29	39.37	38.83	62.96	63.88	63.42	76.58	77.70	77.14
S.Em.±	0.42	0.45	0.42	0.59	0.62	0.60	0.97	0.99	0.98	1.18	1.19	1.18
CD at 5%	NS	NS	NS	1.69	1.78	1.74	2.79	2.85	2.82	3.39	3.42	3.40
Interaction C×N×H												
$C_1 N_1 H_1$	9.38	10.24	9.81	24.22	25.04	24.63	39.83	40.50	40.17	48.45	49.01	48.73
$C_1 N_1 H_2$	10.11	10.97	10.54	30.85	31.67	31.26	50.72	51.39	51.06	61.69	62.25	61.97
$C_1 N_1 H_3$	10.86	11.72	11.29	32.88	33.70	33.29	54.08	54.75	54.41	65.77	66.33	66.05
$C_1 N_2 H_1$	10.27	11.13	10.70	31.33	32.15	31.74	51.51	52.18	51.85	62.65	63.21	62.93
$C_1 N_2 H_2$	11.05	11.91	11.48	34.75	35.57	35.16	57.14	57.81	57.47	69.49	70.05	69.77
$C_1 N_2 H_3$	11.78	12.64	12.21	36.32	37.14	36.73	59.72	60.39	60.06	72.63	73.19	72.91
$C_1 N_3 H_1$	11.49	12.35	11.92	35.31	36.13	35.72	58.07	58.74	58.41	70.63	71.19	70.91
$C_1 N_3 H_2$	11.71	12.57	12.14	35.71	36.53	36.12	58.72	59.39	59.06	71.42	71.98	71.70

Continued....

Table 1 Continued

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
$C_1 N_3 H_3$	12.00	12.86	12.43	36.54	37.36	36.95	60.09	60.76	60.43	73.08	73.64	73.36
$C_2 N_1 H_1$	10.00	11.98	10.99	35.90	37.25	36.57	59.03	60.18	59.61	71.79	73.48	72.64
$C_2 N_1 H_2$	12.04	14.02	13.03	37.90	39.25	38.57	62.32	63.48	62.90	75.80	77.49	76.64
$C_2 N_1 H_3$	13.25	15.23	14.24	37.91	39.26	38.59	62.35	63.50	62.93	75.83	77.52	76.67
$C_2 N_2 H_1$	10.56	12.54	11.55	37.61	38.96	38.28	61.84	63.00	62.42	75.21	76.90	76.06
$C_2 N_2 H_2$	11.73	13.71	12.72	39.34	40.69	40.01	64.69	65.84	65.27	78.68	80.37	79.52
$C_2 N_2 H_3$	13.42	15.40	14.41	39.90	41.25	40.58	65.62	66.77	66.19	79.80	81.49	80.65
$C_2 N_3 H_1$	11.54	13.52	12.53	37.82	39.17	38.50	62.20	63.35	62.77	75.64	77.33	76.49
$C_2 N_3 H_2$	12.45	14.43	13.44	39.64	40.99	40.31	65.19	66.34	65.76	79.28	80.97	80.12
$C_2 N_3 H_3$	13.73	15.71	14.72	40.04	41.39	40.71	65.84	66.99	66.41	80.07	81.76	80.92
S.Em.±	0.59	0.63	0.61	0.83	0.85	0.84	1.37	1.38	1.37	1.67	1.69	1.68
CD at 5%	NS	NS	NS	2.40	2.46	2.43	3.94	3.97	3.96	4.79	4.85	4.82

Factor-I: Brown manuring	Factor-II: RDF levels	Factor-III: Herbicides
C_1-Rice	N_1-75 % RDF	H_1-No herbicides
C_2-Rice+sunhemp	N_2-100 % RDF	H_2- Pendimethalin (1000 g a.i. ha^{-1}) PE *fb* Pyrazosulfuron (25g a.i. ha^{-1}each) (POE at 25 DAS)
	N_3-125 % RDF	H_3- Bensulfuron methyl + pretilachlor 6.6 % G (660 g a.i. ha^{-1}) PE *fb* Bispyribac sodium (25 g a.i. ha^{-1}) 25-30 DAS

TABLE 2

Effect of brown manuring, RDF levels and herbicides on number of tillers plant^{-1} of aerobic rice

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
C_1	1.20	1.39	1.30	10.61	10.73	10.67	18.02	18.14	18.08	20.08	20.20	20.14
C_2	1.72	2.02	1.87	12.81	13.46	13.13	22.42	23.06	22.74	24.54	25.19	24.87
S.Em.±	0.04	0.05	0.04	0.09	0.12	0.11	0.24	0.23	0.23	0.23	0.24	0.25
CD at 5%	0.11	0.13	0.12	0.32	0.35	0.33	0.69	0.66	0.67	0.67	0.68	0.70
RDF level (N)												
N_1	1.19	1.39	1.29	10.68	11.07	10.87	18.17	18.55	18.36	20.23	20.62	20.43
N_2	1.46	1.71	1.58	12.02	12.41	12.21	20.85	21.23	21.04	22.95	23.33	23.14
N_3	1.73	2.03	1.88	12.42	12.81	12.61	21.64	22.03	21.83	23.76	24.14	23.95
S.Em.±	0.05	0.06	0.05	0.13	0.15	0.14	0.29	0.28	0.29	0.24	0.31	0.30
CD at 5%	0.14	0.16	0.15	0.40	0.45	0.41	0.84	0.80	0.82	0.82	0.83	0.86
Herbicides (H)												
H_1	1.05	1.23	1.14	10.85	11.24	11.05	18.53	18.89	18.71	20.58	20.97	20.78
H_2	1.62	1.89	1.75	11.95	12.33	12.14	20.70	21.08	20.89	22.80	23.19	22.99
H_3	1.72	2.01	1.86	12.32	12.71	12.51	21.44	21.83	21.63	23.55	23.94	23.74
S.Em.±	0.05	0.06	0.05	0.13	0.16	0.14	0.29	0.28	0.29	0.28	0.29	0.30
CD at 5%	0.14	0.16	0.15	0.39	0.41	0.40	0.84	0.80	0.82	0.79	0.83	0.86
Interaction C×N												
$C_1 N_1$	1.00	1.16	1.08	9.05	9.17	9.11	14.93	15.03	14.98	16.93	17.06	17.00
$C_1 N_2$	1.14	1.33	1.24	11.03	11.15	11.09	18.86	18.98	18.92	20.94	21.06	21.00
$C_1 N_3$	1.45	1.69	1.57	11.74	11.86	11.80	20.28	20.40	20.34	22.38	22.50	22.44
$C_2 N_1$	1.38	1.62	1.50	12.31	12.96	12.63	21.42	22.07	21.74	23.53	24.18	23.85
$C_2 N_2$	1.77	2.08	1.93	13.01	13.66	13.34	22.83	23.47	23.15	24.96	25.60	25.28
$C_2 N_3$	2.02	2.37	2.19	13.10	13.75	13.43	23.00	23.65	23.33	25.14	25.79	25.46
S.Em.±	0.07	0.08	0.07	0.18	0.21	0.20	0.42	0.40	0.41	0.40	0.41	0.42
CD at 5%	NS	NS	NS	0.56	0.58	0.57	1.19	1.14	1.17	1.15	1.18	1.22

Continued....

Table 2 Continued

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Interaction C×H												
$C_1 H_1$	0.77	0.89	0.83	9.45	9.57	9.51	15.73	15.82	15.78	17.74	17.87	17.81
$C_1 H_2$	1.36	1.58	1.47	10.88	11.00	10.94	18.56	18.68	18.62	20.64	20.76	20.69
$C_1 H_3$	1.47	1.71	1.59	11.49	11.61	11.55	19.78	19.90	19.84	21.87	21.99	21.93
$C_2 H_1$	1.33	1.57	1.45	12.26	12.91	12.58	21.32	21.96	21.64	23.42	24.07	23.74
$C_2 H_2$	1.87	2.20	2.04	13.02	13.67	13.34	22.83	23.48	23.16	24.97	25.61	25.29
$C_2 H_3$	1.96	2.31	2.13	13.15	13.80	13.47	23.10	23.75	23.43	25.24	25.89	25.56
S.Em.±	0.07	0.08	0.06	0.18	0.21	0.20	0.42	0.40	0.41	0.40	0.41	0.42
CD at 5%	NS	NS	NS	0.52	0.58	0.57	1.19	1.14	1.17	1.15	1.18	1.22
Interaction N×H												
$N_1 H_1$	0.71	0.83	0.77	9.36	9.74	9.55	15.49	15.90	15.70	17.55	17.92	17.75
$N_1 H_2$	1.36	1.60	1.48	11.13	11.52	11.32	19.09	19.45	19.27	21.14	21.54	21.34
$N_1 H_3$	1.49	1.74	1.62	11.55	11.94	11.75	19.94	20.29	20.11	22.00	22.40	22.19
$N_2 H_1$	1.01	1.18	1.10	11.17	11.55	11.36	19.15	19.52	19.34	21.22	21.60	21.41
$N_2 H_2$	1.60	1.87	1.73	12.23	12.61	12.42	21.26	21.64	21.45	23.37	23.75	23.56
$N_2 H_3$	1.77	2.07	1.92	12.67	13.05	12.86	22.14	22.52	22.33	24.26	24.64	24.45
$N_3 H_1$	1.43	1.67	1.55	12.03	12.42	12.23	20.94	21.25	21.09	22.97	23.39	23.17
$N_3 H_2$	1.89	2.21	2.05	12.49	12.87	12.68	21.75	22.16	21.96	23.90	24.27	24.08
$N_3 H_3$	1.89	2.21	2.05	12.74	13.13	12.93	22.24	22.67	22.45	24.41	24.77	24.59
S.Em.±	0.08	0.10	0.09	0.24	0.26	0.25	0.51	0.48	0.50	0.49	0.50	0.52
CD at 5%	NS	NS	NS	0.66	0.70	0.72	1.46	1.39	1.43	1.41	1.44	NS
Interaction C×N×H												
$C_1 N_1 H_1$	0.48	0.56	0.52	6.96	7.08	7.02	10.69	10.84	10.76	12.69	12.79	12.72
$C_1 N_1 H_2$	1.16	1.35	1.25	9.68	9.80	9.74	16.20	16.28	16.24	18.21	18.34	18.27
$C_1 N_1 H_3$	1.36	1.58	1.47	10.52	10.64	10.58	17.90	17.96	17.93	19.90	20.04	19.99
$C_1 N_2 H_1$	0.71	0.82	0.76	9.88	10.00	9.94	16.56	16.68	16.62	18.60	18.72	18.66
$C_1 N_2 H_2$	1.27	1.47	1.37	11.28	11.40	11.34	19.37	19.49	19.43	21.46	21.57	21.51

Continued....

Table 2 Continued

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
$C_1N_2H_3$	1.46	1.70	1.58	11.93	12.05	11.99	20.67	20.78	20.72	22.76	22.88	22.82
$C_1N_3H_1$	1.12	1.30	1.21	11.52	11.64	11.58	19.95	19.96	19.95	21.93	22.09	22.05
$C_1N_3H_2$	1.66	1.93	1.79	11.68	11.80	11.74	20.12	20.28	20.20	22.26	22.36	22.30
$C_1N_3H_3$	1.59	1.84	1.72	12.02	12.14	12.08	20.77	20.97	20.87	22.95	23.04	22.97
$C_2N_1H_1$	0.94	1.11	1.02	11.76	12.41	12.08	20.30	20.96	20.63	22.41	23.05	22.77
$C_2N_1H_2$	1.57	1.85	1.71	12.58	13.23	12.91	21.98	22.61	22.30	24.08	24.74	24.40
$C_2N_1H_3$	1.62	1.90	1.76	12.59	13.24	12.91	21.98	22.62	22.30	24.10	24.75	24.39
$C_2N_2H_1$	1.31	1.55	1.43	12.46	13.11	12.79	21.74	22.37	22.06	23.84	24.48	24.16
$C_2N_2H_2$	1.93	2.27	2.10	13.17	13.82	13.50	23.14	23.79	23.47	25.28	25.93	25.60
$C_2N_2H_3$	2.07	2.44	2.26	13.40	14.05	13.73	23.62	24.26	23.94	25.75	26.40	26.08
$C_2N_3H_1$	1.74	2.04	1.89	12.55	13.20	12.87	21.92	22.55	22.23	24.02	24.68	24.30
$C_2N_3H_2$	2.12	2.49	2.30	13.30	13.95	13.62	23.38	24.04	23.71	25.53	26.18	25.87
$C_2N_3H_3$	2.19	2.58	2.39	13.46	14.11	13.78	23.71	24.37	24.04	25.86	26.50	26.21
S.Em.±	0.12	0.14	0.13	0.32	0.34	0.33	0.72	0.69	0.70	0.69	0.71	0.74
CD at 5%	NS	NS	NS	0.94	0.98	0.93	2.07	1.97	2.02	2.00	2.04	2.11

Factor-I: Brown manuring	Factor-II: RDF levels	Factor-III: Herbicides
C_1-Rice	N_1-75 % RDF	H_1-No herbicides
C_2-Rice+sunhemp	N_2-100 % RDF	H_2- Pendimethalin (1000 g a.i. ha^{-1}) PE *fb* Pyrazosulfuron (25g a.i. ha^{-1}each) (POE at 25 DAS)
	N_3-125 % RDF	H_3- Bensulfuron methyl + pretilachlor 6.6 % G (660 g a.i. ha^{-1}) PE *fb* Bispyribac sodium (25 g a.i. ha^{-1}) 25-30 DAS

application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) (1.75 plant^{-1}) and no herbicide treatments recorded significantly lower number of tillers (1.14 plant^{-1}). Similar trend was followed at 60, 90 and at harvest. Tiller production, being a vegetative attribute demands liberal supply of nutrients which might have been provided due to slow and steady decomposition of brown manuring crops and this release synchronized with physiological activities of rice crop resulted in maximum tiller production Ramesh *et al*. (2007), Lakshmibai *et al.* (2014) and Raj *et al.* (2014) also reported similar findings.

Interaction effect of all three factors differed significantly at 60 DAS, the combination of rice + sunhemp with 125 per cent RDF along with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) showed significantly higher number of tillers (2.39 plant^{-1}) and significantly lower number of tillers observed under combination of 75 per cent RDF with sole cultivation of rice without herbicides (0.52 plant^{-1}). Similar trend was followed at 90 DAS and at harvest. The crop has more favorable environment due to proper availability of growth factors and less crop-weed competition. It resulted in maximum number of tillers production. These results are supported by Payman and Singh (2008).

Brown manuring plots were sprayed with 2, 4-D ester at 20-25 DAS for knock downing the sunhemp plants thereafter the sunhemp residue on the soil serves as dead mulch throughout the crop season and reduced weed infestation in later stages of the crop. The decomposition of brown manured plants released significant amount of nutrients in slow and steady manner which helps in development of auxin, promoting growth of lateral buds, ultimately leading to formation of tillers. The similar observations were also made by Harishankar (2013) and Nawaz *et al*. (2017).

Dry Matter Production

There was significantly higher dry matter production found in rice + sunhemp (0.65 g plant^{-1}) compared to sole cultivation of rice (0.44 g plant^{-1}) (Fig. 1a). Among different levels of RDF 125 per cent has recorded significantly higher dry matter production (0.58 g plant^{-1}) which was on par with 100 per cent RDF (0.55 g plant^{-1}) whereas, lower dry matter production resulted under 75 per cent RDF (0.50 g plant^{-1}). Bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) recorded significantly higher dry matter production (0.59 g plant^{-1}) which was on par with and application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) (0.55 g plant^{-1}) and significantly lower dry matter

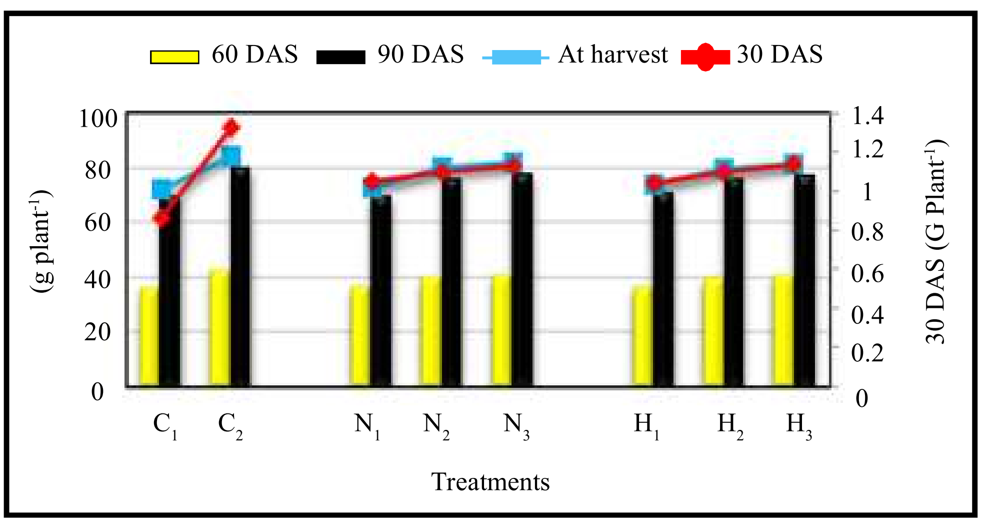

Fig. 1a : Effect of brown manuring, RDF levels and herbicides on dry matter production of aerobic rice

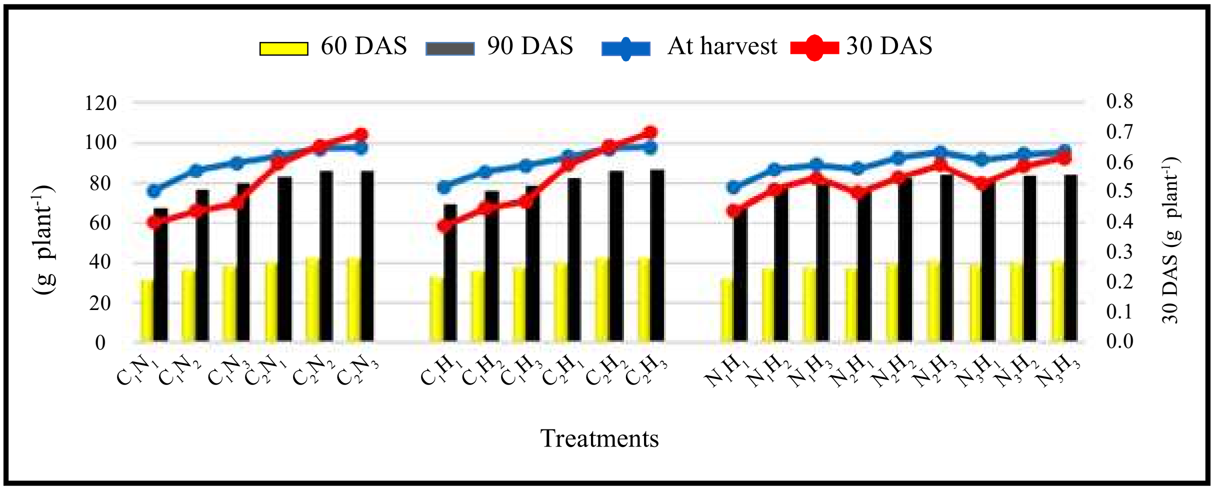

Fig. 1b : Effect of brown manuring, RDF levels and herbicides on dry matter production of aerobic rice

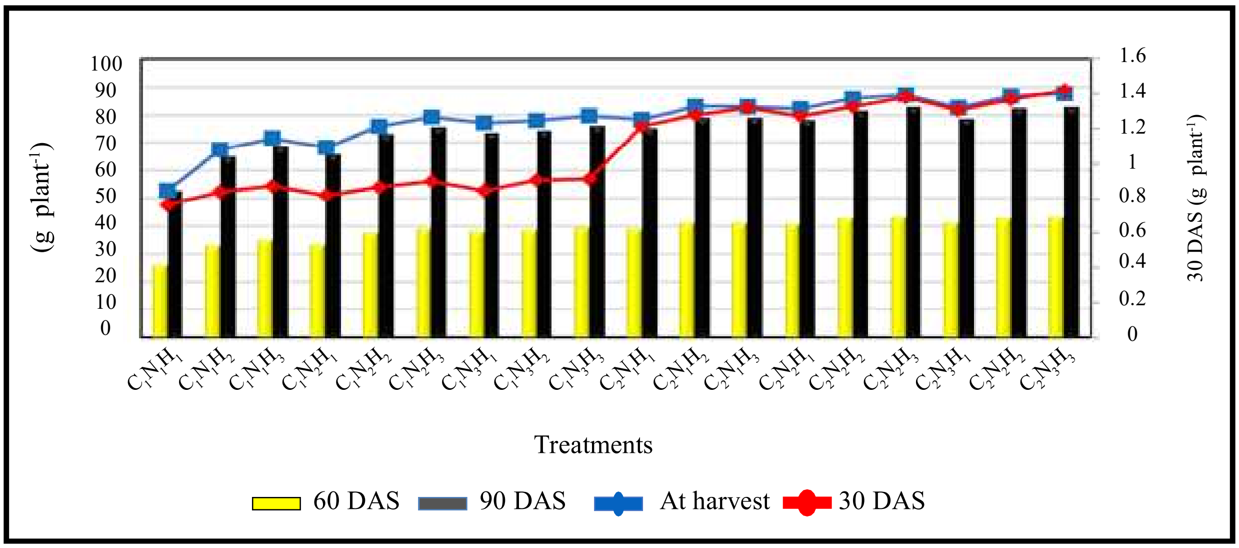

Fig. 1c : Effect of brown manuring, RDF levels and herbicides on dry matter production of aerobic rice

production (0.49 g plant^{-1}) observed under without herbicides treatments. Same trend followed at 60, 90 DAS and at harvest.

At 60 DAS, the combination of rice + sunhemp with 125 per cent RDF along with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) resulted significantly higher dry matter production (43.49 g plant^{-1}) and significantly lower dry matter production observed under combination of sole cultivation of rice with 75 per cent RDF without herbicide application (43.07 g plant^{-1}) and 90 DAS and harvest also followed same trend (Fig. 1c). The augmented accumulation of dry matter was correlated with sunhemp brown manuring, likely attributed to the consistent and sufficient nitrogen release, along with essential macro and micronutrients resulting from gradual decomposition of sunhemp into the soil solution. This nutrient release pattern synchronized well with rice's nitrogen absorption rates throughout its growth cycle. This continuous enhancement in crop growth rate substantially increased dry matter accumulation due to increased NPK fertilizers (Bhavya and Basavaraja, 2021). The same result was supported by Tuteja *et al.* (1995), Majhi *et al.* (2009) and Mandal *et al.* (2011).

Weed Control Efficiency

Weed control efficiency indicates the relative efficacy of weed management practices over weedy check. Overall interaction of brown manuring, RDF levels and herbicides positively influenced the weed control efficiency. Among different combinations, combination of rice + sunhemp with 75 per cent RDF along with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) has recorded higher weed control efficiency (83.95%) at harvest of crop followed by combination of rice + sunhemp with 75 per cent RDF along with pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) (83.16%) over combination of sole rice with 75 per cent RDF without herbicide application (Fig. 2).

Higher weed control efficiency in case of rice + sunhemp combined with herbicide application over sole rice might be due to high efficacy of the applied herbicides coupled with smothering effect of sunhemp through allelopathic effect or biotic interference against different weed flora during early stage of crop growth (Singh *et al.,* 2014). At later growth stages, sunhemp acted as live mulch causing better suppression of late emerged weeds which resulted lower weed density and weed dry weight, ultimately resulting in higher weed control efficiency. The findings are in agreement with the findings of Gupta *et al*. (2006), Mishra and Singh (2007) and Anitha and Mathew (2010).

Apparent Recovery Efficiency

Combination of rice + sunhemp with 75 per cent RDF + pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) recorded higher apparent recovery efficiency of nitrogen, phosphorous and potassium (85.25, 55.50 and 189.18 per cent, respectively) (Fig. 3) which was on par with combination of rice + sunhemp with pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) and 75 per cent RDF in case of nitrogen (79.48%) compared to other combinations whereas, lower

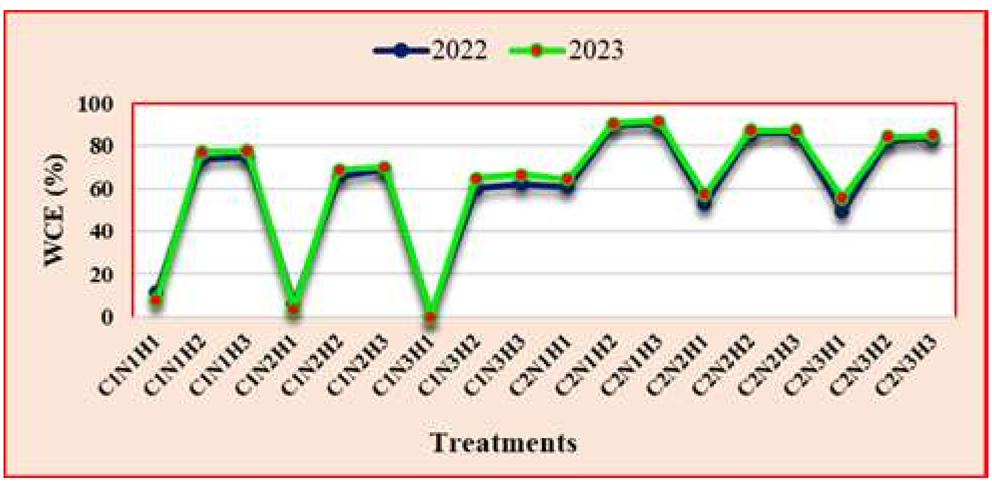

Fig. 2 : Effect of brown manuring, RDF levels and herbicide on weed control efficiency (%) in rice in aerobic rice-rice bean cropping system

Factor - I : Brown manuring
C_1-Rice
C_2-Rice+sunhemp

Factor - II : RDF levels
N_1-75 % RDF
N_2-100 % RDF
N_3-125 % RDF

Factor - III : Herbicides
H_1-No herbicides
H_2- Pendimethalin (1000 g a.i. ha^{-1}) PE *fb* Pyrazosulfuron (25g a.i. ha^{-1}each) (POE at 25 DAS)
H_3- Bensulfuron methyl + pretilachlor 6.6 % G (660 g a.i. ha^{-1}) PE *fb* Bispyribac sodium (25 g a.i. ha^{-1}) 25-30 DAS

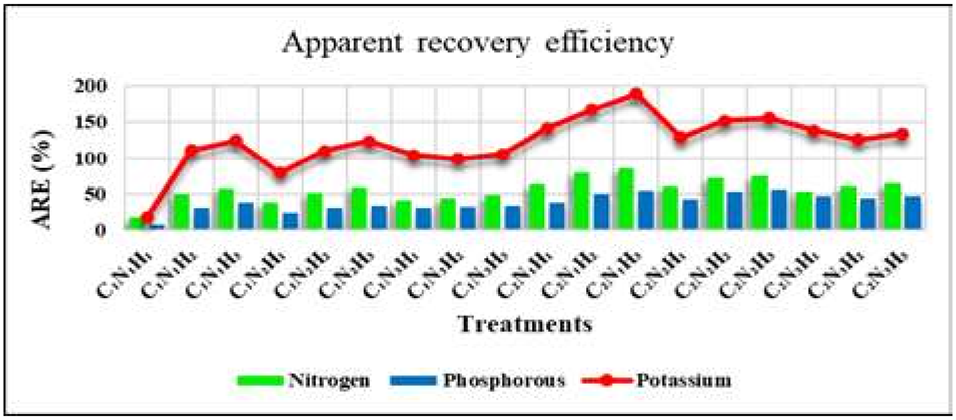

Fig. 3 : Effect on brown manuring, RDF levels and herbicides on apparent recovery efficiency of rice in aerobic rice-rice bean cropping system

Factor - I : Brown manuring
C_1 - Rice
C_2 - Rice+sunhemp

Factor - II : RDF levels
N_1 - 75 % RDF
N_2 - 100 % RDF
N_3 - 125 % RDF

Factor - III : Herbicides
H_1 - No herbicides
H_2 - Pendimethalin (1000 g a.i. ha^{-1}) PE *fb* Pyrazosulfuron (25g a.i. ha^{-1}each) (POE at 25 DAS)
H_3 - Bensulfuron methyl + pretilachlor 6.6 % G (660 g a.i. ha^{-1}) PE *fb* Bispyribac sodium (25 g a.i. ha^{-1}) 25-30 DAS

apparent recovery efficiency of nitrogen, phosphorous and potassium observed under combination of sole rice + 75 per cent RDF without herbicide application (17.71, 6.93 and 17.43%, respectively). The increased apparent recovery efficiency of rice might be due to added biomass from sunhemp increased the organic matter in soil enhancing the availability and uptake of essential nutrients by plants and it acts as a reservoir for nutrients, preventing their leaching and making them available to plants over an extended period. This result was in agreement with the finding of Moe *et al*. (2017). Lower RDF encourages efficient nutrient uptake by roots, maximizing the utilization of applied fertilizers and minimizing excess application. These results were also supported by Islam *et al*. (2015), Amrutha *et al*. (2016) and Sarangi *et al*. (2016). By controlling weeds through herbicide application, the nutrients that would have been taken up by the weeds are conserved in the soil and made available for the rice crop, resulting in increased nutrient utilization in-turn improved nutrient use efficiency.

Number of Panicles, Number of Grains and Test Weight

Rice + sunhemp recorded significantly higher number of panicles (19.82 plant^{-1}) and number of grains (172.56 panicle^{-1}) over sole cultivation of rice (16.93 plant^{-1} and 148.59 panicle^{-1}, respectively.) Among different RDF levels 125 per cent resulted significantly higher number of panicles (19.25 plant^{-1}) and number of grains (167.19 panicle^{-1}) which was on par with 100 per cent RDF and significantly lower number of panicles (17.12 plant^{-1}) and number of grains (151.02 panicle^{-1}) were observed in 75 per cent RDF. Pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) noticed significantly higher number of panicles (19.14 plant^{-1}) and number of grains (166.35 panicle^{-1}) which was on par with pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) over no herbicide application (17.33 plant^{-1} and 152.60 panicle^{-1}, respectively) (Table 3).

Among different combinations 125 per cent RDF with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) recorded significantly higher number of panicles (19.66 plant^{-1}) and number of grains (169.82 panicle^{-1}) which was on par with application of

TABLE 3

Effect of brown manuring, RDF levels and herbicides on number of panicles, number of grains and test weight of aerobic rice

Treatment	Number of panicles plant^{-1}			Grains panicle^{-1}			Test weight (g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Brown manuring (C)									
C_1	16.55	17.31	16.93	148.03	149.16	148.59	15.91	16.50	16.20
C_2	19.24	20.40	19.82	168.05	177.07	172.56	16.62	17.29	16.95
S.Em.±	0.12	0.14	0.13	1.18	1.20	1.19	0.25	0.29	0.26
CD at 5%	0.40	0.41	0.39	3.38	3.41	3.39	NS	NS	NS
RDF level (N)									
N_1	16.64	17.60	17.12	148.48	153.55	151.02	15.84	16.45	16.14
N_2	18.28	19.24	18.76	160.98	166.06	163.52	16.11	16.73	16.42
N_3	18.77	19.73	19.25	164.66	169.73	167.19	16.85	17.51	17.17
S.Em.±	0.17	0.19	0.18	1.44	1.39	1.40	0.31	0.35	0.31
CD at 5%	0.49	0.50	0.48	4.14	4.09	4.11	NS	NS	NS
Herbicides (H)									
H_1	16.85	17.81	17.33	150.06	155.14	152.60	16.09	16.72	16.39
H_2	18.18	19.14	18.66	160.24	165.32	162.78	16.29	16.92	16.60
H_3	18.66	19.62	19.14	163.81	168.88	166.35	16.42	17.06	16.73
S.Em.±	0.17	0.19	0.18	1.44	1.39	1.40	0.31	0.35	0.31
CD at 5%	0.49	0.50	0.48	4.14	4.09	4.11	NS	NS	NS
Interaction C×N									
C_1N_1	14.66	15.42	15.04	132.72	133.85	133.28	15.63	16.21	15.92
C_1N_2	17.06	17.82	17.44	152.32	153.45	152.88	15.87	16.45	16.16
C_1N_3	17.93	18.69	18.31	159.05	160.18	159.62	16.24	16.83	16.53
C_2N_1	18.62	19.78	19.20	164.24	173.26	168.75	16.04	16.69	16.36
C_2N_2	19.50	20.66	20.08	169.64	178.66	174.15	16.35	17.01	16.68
C_2N_3	19.61	20.77	20.19	170.26	179.28	174.77	17.46	18.18	17.81
S.Em.±	0.24	0.26	0.23	1.99	2.04	2.13	0.43	0.50	0.44
CD at 5%	0.69	0.70	0.68	5.13	5.86	5.45	NS	NS	NS
Interaction C×H									
C_1H_1	15.15	15.91	15.53	137.18	138.31	137.74	15.72	16.31	16.01
C_1H_2	16.88	17.64	17.26	150.70	151.83	151.26	15.95	16.53	16.24
C_1H_3	17.62	18.38	18.00	156.21	157.34	156.78	16.06	16.66	16.36
C_2H_1	18.55	19.71	19.13	162.95	171.97	167.46	16.45	17.12	16.78
C_2H_2	19.48	20.64	20.06	169.79	178.81	174.30	16.63	17.30	16.96
C_2H_3	19.70	20.85	20.27	171.40	180.42	175.91	16.78	17.46	17.11
S.Em.±	0.24	0.26	0.23	1.99	2.04	2.13	0.43	0.50	0.44
CD at 5%	0.69	0.70	0.68	5.13	5.86	5.45	NS	NS	NS

Continued....

Table 3 Continued

Treatment	Number of panicles plant^{-1}			Grains panicle^{-1}			Test weight (g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Interaction N×H									
N_1H_1	15.02	15.98	15.50	135.64	140.72	138.18	123.60	16.30	15.98
N_1H_2	17.19	18.15	17.67	152.61	157.68	155.14	141.30	16.48	16.18
N_1H_3	17.70	18.67	18.19	157.19	162.26	159.72	146.35	16.57	16.26
N_2H_1	17.23	18.19	17.71	153.13	158.20	155.66	141.69	16.58	16.25
N_2H_2	18.52	19.48	19.00	162.86	167.93	165.40	152.28	16.73	16.42
N_2H_3	19.09	20.05	19.57	166.96	172.03	169.49	156.67	16.89	16.57
N_3H_1	18.29	19.26	18.78	161.42	166.50	163.96	150.33	17.28	16.95
N_3H_2	18.83	19.79	19.31	165.27	170.34	167.80	154.89	17.53	17.21
N_3H_3	19.19	20.13	19.66	167.28	172.36	169.82	157.41	17.71	17.37
S.Em.±	0.26	0.30	0.29	2.48	2.53	2.50	2.42	0.61	0.54
CD at 5%	0.85	0.86	0.83	7.16	7.21	7.19	6.95	NS	NS
Interaction C×N×H									
$C_1N_1H_1$	12.11	12.86	12.48	112.24	113.37	112.80	15.41	15.99	15.69
$C_1N_1H_2$	15.43	16.19	15.81	138.89	140.02	139.46	15.70	16.28	15.99
$C_1N_1H_3$	16.45	17.21	16.83	147.02	148.15	147.58	15.78	16.37	16.07
$C_1N_2H_1$	15.66	16.42	16.04	141.56	142.69	142.13	15.68	16.26	15.97
$C_1N_2H_2$	17.37	18.13	17.75	154.80	155.93	155.37	15.86	16.45	16.16
$C_1N_2H_3$	18.16	18.92	18.54	160.58	161.71	161.15	16.05	16.65	16.35
$C_1N_3H_1$	17.67	18.44	18.05	157.73	158.86	158.29	16.08	16.68	16.38
$C_1N_3H_2$	17.85	18.60	18.23	158.39	159.52	158.96	16.27	16.87	16.57
$C_1N_3H_3$	18.27	19.01	18.64	161.04	162.17	161.60	16.35	16.95	16.65
$C_2N_1H_1$	17.94	19.09	18.52	159.05	168.07	163.56	15.95	16.60	16.27
$C_2N_1H_2$	18.95	20.12	19.54	166.32	175.34	170.83	16.04	16.69	16.36
$C_2N_1H_3$	18.96	20.12	19.54	167.36	176.38	171.87	16.13	16.78	16.45
$C_2N_2H_1$	18.80	19.96	19.38	164.69	173.71	169.20	16.22	16.90	16.54
$C_2N_2H_2$	19.67	20.83	20.25	170.91	179.93	175.42	16.36	17.02	16.69
$C_2N_2H_3$	20.02	21.19	20.60	173.33	182.35	177.84	16.47	17.13	16.80
$C_2N_3H_1$	18.92	20.09	19.50	165.12	174.14	169.63	17.17	17.88	17.51
$C_2N_3H_2$	19.82	20.97	20.39	172.14	181.16	176.65	17.49	18.20	17.84
$C_2N_3H_3$	20.11	21.24	20.68	173.52	182.54	178.03	17.73	18.46	18.08
S.Em.±	0.39	0.42	0.40	3.49	3.53	3.50	0.75	0.86	0.77
CD at 5%	1.20	1.22	1.17	9.89	10.14	10.05	NS	NS	NS

Legend :

Factor-I: Brown manuring
C_1-Rice
C_2-Rice+sunhemp

Factor-II: RDF levels
N_1-75 % RDF
N_2-100 % RDF
N_3-125 % RDF

Factor-III: Herbicides
H_1-No herbicides
H_2- Pendimethalin (1000 g a.i. ha^{-1}) PE *fb* Pyrazosulfuron (25g a.i. ha^{-1}each) (POE at 25 DAS)
H_3- Bensulfuron methyl + pretilachlor 6.6 % G (660 g a.i. ha^{-1}) PE *fb* Bispyribac sodium (25 g a.i. ha^{-1}) 25-30 DAS

pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) + 125 per cent RDF, 100 per cent RDF with application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) and pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) + 100 per cent RDF. Significantly lower number of panicles (15.50 plant^{-1}) and number of grains (138.18 panicle^{-1}) noticed in combination of 75 per cent RDF without herbicides at harvest.

Combination of rice + sunhemp with 125 per cent RDF along with application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) recorded significantly higher number of panicles (20.68 plant^{-1}) and number of grains (178.03 panicle^{-1}) whereas, lower number of panicles (12.48 plant^{-1}) and number of grains (112.80 panicle^{-1}) observed under the combination of sole rice with 75 per cent RDF without herbicides. Effect of brown manuring, RDF levels and herbicides on test weight of rice was found non-significant.

Brown manuring effectively manages late weed growth, limiting their nutrient consumption and ensuring better nutrient availability for the crop which resulted higher yield attributes. These findings align with those of Pooniya *et al*. (2012) and Gaire *et al*. (2013). Adjusted supply of N, P and K was liable for higher photosynthesis, metabolic action and cell division, which therefore increased the number of panicles along with this adequate supply of phosphorus resulted higher grain filling in turn increased number of grains as detailed by Vijayakumar *et al*. (2017) and Reddy *et al*. (2022).

Grain Yield, Straw Yield and Harvest Index

Rice + sunhemp recorded significantly higher grain yield (4579 kg ha^{-1}) and straw yield (6283 kg ha^{-1}) over sole cultivation of rice (3940 and 5342 kg ha^{-1}, respectively.) Among different RDF levels 125 per cent resulted significantly higher grain yield (4455 kg ha^{-1}) and straw yield (6143 kg ha^{-1}) which was on par with 100 per cent RDF and significantly lower grain yield (3976 kg ha^{-1}) and straw yield (5362 kg ha^{-1}) were observed in 75 per cent RDF. Pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) noticed significantly higher grain yield (4437 kg ha^{-1}) and straw yield (6120 kg ha^{-1}) which was on par with pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) over no herbicide application (4018 and 5368 kg ha^{-1}, respectively) (Table 4).

Combination of rice + sunhemp with 125 per cent RDF along with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) recorded significantly higher grain yield (4774 kg ha^{-1}) and straw yield (6747 kg ha^{-1}) which was on par with combination of rice + sunhemp with 125 per cent + pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS), 125 per cent RDF with rice + sunhemp without application of herbicide, rice + sunhemp with 100 per cent RDF without application of herbicide, brown manuring with 100 per cent RDF + pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS), rice + sunhemp with 100 per cent RDF + pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS), 75 per cent RDF with rice + sunhemp in pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) and 75 per cent RDF with rice + sunhemp with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS). Significantly lower grain yield (2882 kg ha^{-1}) and straw yield (3551 kg ha^{-1}) were observed in combination of 75 per cent RDF + sole cultivation of rice without herbicides.

During decomposition of sunhemp, release of organic acids and allelochemicals helped in suppression of weed seeds from germination thus providing a weed

TABLE 4

Effect of brown manuring, RDF levels and herbicides on grain yield, straw yield and harvest index of aerobic rice

Treatment	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})			Harvest index		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Brown manuring (C)									
C_1	3938	3928	3940	5220	5465	5342	0.431	0.419	0.426
C_2	4532	4626	4579	6210	6356	6283	0.422	0.421	0.422
S.Em.±	30.9	38.1	33.0	62.45	72.24	68.45	0.002	0.003	0.002
CD at 5%	88.7	109.6	94.9	188.2	203.8	195.1	0.005	NS	NS
RDF level (N)									
N_1	3957	3995	3976	5265	5460	5362	0.431	0.423	0.427
N_2	4320	4354	4348	5833	6030	5932	0.426	0.419	0.423
N_3	4428	4482	4455	6046	6241	6143	0.423	0.418	0.421
S.Em.±	37.8	46.7	40.4	69.5	75.2	73.1	0.001	0.003	0.002
CD at 5%	108.7	134.2	116.2	199.7	218.5	209.3	NS	NS	NS
Herbicides (H)									
H_1	4004	4010	4018	5270	5465	5368	0.434	0.424	0.430
H_2	4300	4349	4325	5853	6048	5950	0.424	0.418	0.421
H_3	4401	4473	4437	6021	6218	6120	0.423	0.418	0.421
S.Em.±	37.8	46.7	40.4	69.5	75.2	73.1	0.002	0.003	0.002
CD at 5%	108.7	134.2	116.2	199.7	218.5	209.3	0.006	NS	0.005
Interaction C×N									
C_1N_1	3518	3481	3499	4603	4848	4725	0.436	0.420	0.428
C_1N_2	4052	4051	4074	5405	5650	5527	0.429	0.418	0.425
C_1N_3	4244	4251	4247	5651	5896	5774	0.429	0.419	0.424
C_2N_1	4397	4509	4453	5926	6071	5999	0.426	0.426	0.426
C_2N_2	4588	4657	4622	6262	6410	6336	0.423	0.421	0.422
C_2N_3	4612	4714	4663	6441	6586	6513	0.417	0.417	0.417
S.Em.±	53.5	66.1	57.2	107.8	143.23	122.1	0.003	0.005	0.004
CD at 5%	153.7	189.9	164.3	308.9	376.8	323.2	NS	NS	NS
Interaction C×H									
C_1H_1	3625	3560	3615	4611	4856	4734	0.443	0.424	0.435
C_1H_2	4012	4042	4027	5448	5693	5571	0.424	0.415	0.419
C_1H_3	4176	4182	4179	5599	5844	5722	0.428	0.417	0.422
C_2H_1	4383	4460	4421	5929	6074	6002	0.425	0.423	0.424
C_2H_2	4589	4656	4622	6257	6402	6329	0.423	0.421	0.422
C_2H_3	4625	4764	4694	6443	6592	6517	0.418	0.420	0.419
S.Em.±	53.5	66.1	57.2	107.8	143.23	122.1	0.003	0.005	0.004
CD at 5%	153.7	189.9	164.3	308.9	376.8	323.2	0.009	NS	NS

Continued....

Table 4 Continued

Treatment	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})			Harvest index		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Interaction N×H									
N_1H_1	3600	3576	3588	4527	4722	4624	0.446	0.431	0.439
N_1H_2	4079	4104	4092	5523	5718	5621	0.424	0.417	0.420
N_1H_3	4193	4304	4248	5744	5939	5841	0.423	0.421	0.422
N_2H_1	4090	4078	4117	5471	5666	5568	0.428	0.418	0.425
N_2H_2	4376	4452	4414	5961	6156	6058	0.424	0.420	0.422
N_2H_3	4494	4533	4514	6068	6268	6168	0.426	0.419	0.423
N_3H_1	4323	4375	4349	5813	6008	5910	0.427	0.422	0.425
N_3H_2	4446	4490	4468	6073	6268	6171	0.423	0.417	0.420
N_3H_3	4514	4582	4548	6251	6446	6349	0.420	0.416	0.418
S.Em.±	65.5	80.9	70.0	129.9	165.2	146.5	0.004	0.005	0.004
CD at 5%	188.2	232.5	201.2	368.5	432.87	413.5	NS	NS	NS
Interaction C×N×H									
$C_1N_1H_1$	2951	2812	2882	3429	3674	3551	0.463	0.434	0.448
$C_1N_1H_2$	3687	3646	3667	5151	5396	5274	0.417	0.403	0.410
$C_1N_1H_3$	3914	3985	3949	5228	5473	5351	0.429	0.422	0.426
$C_1N_2H_1$	3741	3686	3780	4951	5196	5074	0.431	0.415	0.427
$C_1N_2H_2$	4121	4232	4176	5522	5767	5644	0.427	0.423	0.425
$C_1N_2H_3$	4295	4236	4266	5741	5986	5863	0.428	0.414	0.421
$C_1N_3H_1$	4184	4180	4182	5453	5698	5576	0.435	0.424	0.430
$C_1N_3H_2$	4228	4247	4238	5672	5917	5794	0.427	0.418	0.422
$C_1N_3H_3$	4320	4325	4323	5828	6073	5951	0.426	0.416	0.421
$C_2N_1H_1$	4248	4341	4294	5624	5769	5697	0.430	0.429	0.430
$C_2N_1H_2$	4471	4563	4517	5895	6040	5968	0.431	0.430	0.431
$C_2N_1H_3$	4473	4622	4548	6259	6404	6332	0.417	0.419	0.418
$C_2N_2H_1$	4438	4469	4454	5990	6135	6063	0.426	0.422	0.424
$C_2N_2H_2$	4631	4672	4652	6400	6545	6472	0.420	0.417	0.418
$C_2N_2H_3$	4693	4830	4762	6396	6551	6473	0.423	0.425	0.424
$C_2N_3H_1$	4462	4569	4516	6173	6318	6245	0.420	0.420	0.420
$C_2N_3H_2$	4664	4733	4699	6475	6620	6547	0.419	0.417	0.418
$C_2N_3H_3$	4708	4839	4774	6675	6820	6747	0.414	0.415	0.414
S.Em.±	92.6	114.4	99.0	186.2	202.6	192.1	0.005	0.006	0.005
CD at 5%	266.2	328.8	284.6	534.2	598.3	576.8	0.015	NS	NS

Legend :

Factor-I: Brown manuring	Factor-II: RDF levels	Factor-III: Herbicides
C_1-Rice	N_1-75 % RDF	H_1-No herbicides
C_2-Rice+sunhemp	N_2-100 % RDF	H_2- Pendimethalin (1000 g a.i. ha^{-1}) PE *fb* Pyrazosulfuron (25g a.i. ha^{-1}each) (POE at 25 DAS)
		N_3-125 % RDF H_3- Bensulfuron methyl + pretilachlor 6.6 % G (660 g a.i. ha^{-1}) PE *fb* Bispyribac sodium (25 g a.i. ha^{-1}) 25-30 DAS

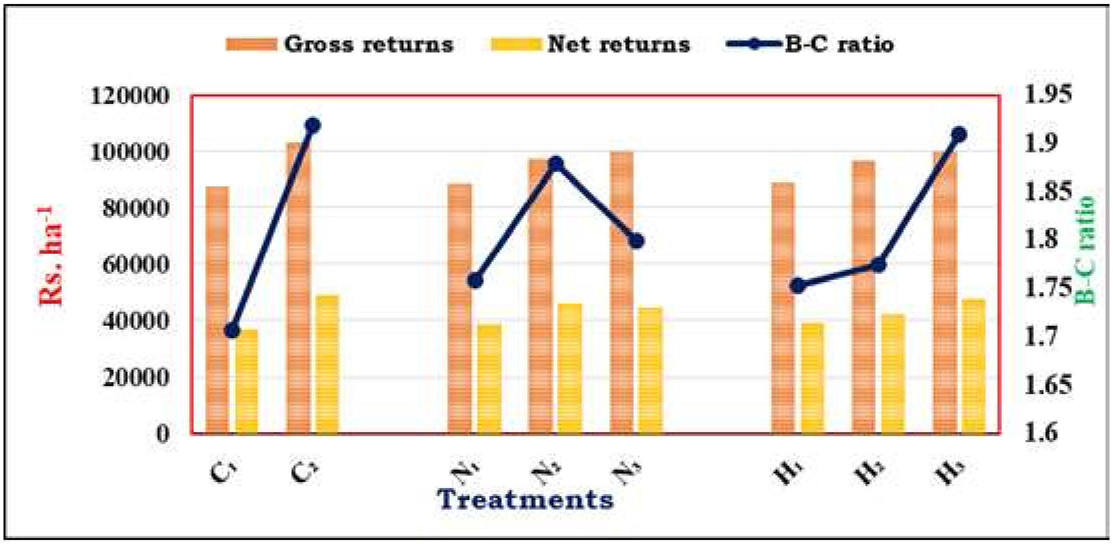

Fig. 4a : Effect of brown manuring, RDF levels and herbicides on economics of aerobic rice

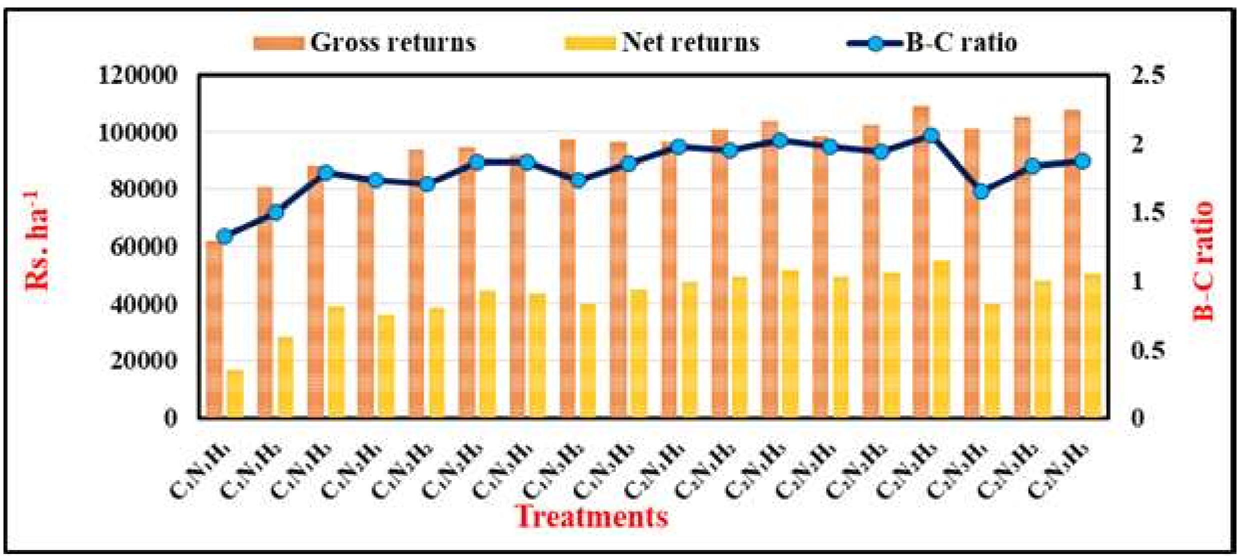

Fig. 4b : Effect of brown manuring, RDF levels and herbicides on economics of aerobic rice

free environment (Kamboj *et al*., 2012). Thus, ample supply of nutrients coupled with competition free environment resulted in higher rice yield. Comparable outcomes were observed by Singh *et al*. (2009) and Samant (2017). The most elevated estimations of growth characteristics acquired with the use of phosphorus showed signs of improvement in yield attributes and yield which might be likely because of more ingestion and usage of accessible phosphorous for absorption and utilization by plants, by and large improvement of 'source-sink relationship', which thus upgraded the yield of aerobic rice (Sharma *et al*., 2008). Utilization of K brought about better translocation of photosynthates which resulted higher yield.

Economics of Rice

Rice + sunhemp recorded significantly higher gross returns (102842 Rs.ha^{-1}), net returns (49050) and B-C ratio (1.92) compared to sole cultivation of rice (87537 Rs.ha^{-1}, 36807 Rs.ha^{-1} and 1.71, respectively). Among different levels of RDF 125 per cent resulted

TABLE 5

Correlation studies of number of panicles, number of grains and dry matter production with grain yield of aerobic rice

	Grain yield	Number of panicles	Grains per panicle	Dry matter production per plant
Grain yield	1.000			
No. of panicles	0.998 **	1.000		
Grains per panicle	0.997 **	0.999 **	1.000	
Dry matter production per plant	0.998 **	1.000 **	0.998 **	1.000

significantly higher gross returns (99892 Rs.ha^{-1}) whereas, higher net returns (45713) and B-C ratio (1.88) noticed under 100 per cent RDF and significantly lower gross returns (87537 Rs.ha^{-1}), net returns (38722) and B-C (1.76) ratio observed under 75 per cent RDF. Pre-emergent application bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) recorded significantly higher gross returns (99912 Rs.ha^{-1}), net returns (47500) and B-C ratio (1.91) which was on par with pre-emergent application of pendimethalin (1000 g *a.i.* ha^{-1}) *fb* pyrazosulfuron (25g *a.i.* ha^{-1} at 25 DAS) whereas, lower gross returns (88882 Rs.ha^{-1}), net returns (38877) and B-C ratio (1.75) recorded in no application of herbicides (Fig. 2a).

Combination of rice + sunhemp with 100 per cent RDF along with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) recorded significantly higher net returns (55094 Rs.ha^{-1}) and B-C ratio (2.06) whereas, lower net returns (16755 Rs.ha^{-1}) and B-C ratio (1.32) observed in combination of sole rice with 75 per cent RDF without herbicide application (Fig. 2b). The reason attributed to higher net returns and B:C ratio might be less cost of cultivation coupled with higher gross returns. Though higher yield was recorded in 125 per cent RDF but higher net returns and B-C ratio was obtained in 100 per cent RDF this is because of there was no significant yield difference between 100 and 125 per cent RDF whereas, reduced fertilizers cost in 100 per cent RDF. Efficient management of weeds by the combination of pre and post-emergence herbicides along with the brown manuring, which lowers the weed population, dry-biomass and nutrient depleting by weeds. It positively attributed the growth characteristics, yield attribute and yield of rice which resulted higher net returns and B-C ratio in herbicide treated along with rice + sunhemp treatments. These results were in confirmation with Ravisankar *et al.* (2008) and Maity and Mukherjee (2011) and Kumari and Kaur (2016).

Correlation

The correlation study indicated that there was strong positive correlation between grain yield of rice with number of panicles (r = 0.998**), number of grains (r = 0.997**) and dry matter production (r = 0.998**) of rice, hence number of panicles, number of grains and dry matter production should be higher as much as possible in order to increase the grain yield of rice (Table 5).

The results showed that the growth, yield and yield components of aerobic rice were significantly influenced by the treatments. Therefore, it is concluded that combination of rice + sunhemp with 100 per cent RDF along with pre-emergent application of bensulfuron methyl + pretilachlor 6.6 per cent G (660 g *a.i.* ha^{-1}) *fb* bispyribac sodium (25 g *a.i.* ha^{-1} at 25-30 DAS) recorded higher B-C ratio though the same combination with 125 per cent RDF recorded higher growth, yield and yield components.

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