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Effect of Brown Manuring through Sunhemp and Nitrogen Levels on Weed Suppression, Growth and Yield of Aerobic Rice

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Abstract

The field experiment was conducted at the Agronomy Field Unit, ZARS, GKVK, Bengaluru during summer and *rabi* 2023 using a factorial randomized block design. The study evaluated the influence of sunhemp seed rates (0, 50 and 75 kg ha^{-1}) and nitrogen levels (0%, 75%, 100% and 125% RDN) on growth, yield and weed dynamics in aerobic rice. Among sunhemp seed rates, 50 kg ha^{-1} recorded significantly higher plant height at harvest (81.87 cm), tillers plant^{-1} at harvest (19.22), leaf area at 90 DAS (1510 cm^2 plant^{-1}), dry matter production at harvest (101.38 g plant^{-1}), panicles plant^{-1} (19.22), panicle weight (3.60 g), grains panicle^{-1} (171.45), grain and straw yield (4453 and 5608 kg ha^{-1}) and was statistically on par with 75 kg ha^{-1}. Application of 125 per cent RDN resulted in significantly higher plant height (85.98 cm), tiller plant^{-1} (20.12), leaf area (1784 cm^2 plant^{-1}), dry matter production (119.70 g plant^{-1}), panicle weight (4.02 g), grains panicle^{-1} (182.42) and grain and straw yields (5130 and 6148 kg ha^{-1}), outperforming other nitrogen levels. The interaction of 50 kg ha^{-1}+125 per cent RDN recorded the higher grain (5304 kg ha^{-1}) and straw yield (6545 kg ha^{-1}). Weed observations showed that at 15 and 45 DAS, the 75 kg ha^{-1} sunhemp rate recorded the lower weed density (27.11 and 42.73 m^{-2}) and weed dry weight (2.44 and 5.55 g m^{-2}). At 60 DAS and harvest, 50 kg ha^{-1} was more effective in reducing weed density (67.56 and 80.66 m^{-2}) and dry weight (14.19 and 42.75 g m^{-2}). Among nitrogen levels, no-nitrogen plots recorded the lower weed growth, while 125 per cent RDN had higher weed density and dry weight.

Keywords : Aerobic rice, Brown manuring, Sunhemp, Nitrogen, Weed

Since the advent of agriculture, cereals have been staple foods due to their high carbohydrate content, with rice (*Oryza sativa* L.) being the most dominant globally. Rice contributes 21 per cent of global per capita energy and 15 per cent of protein intake. Asia, home to 60 per cent of the world's population, produces 92 per cent and consumes 90 per cent of global rice (Poornima, 2020). In India, rice is the staple for over 70 per cent of the population, grown on 47.83 million ha with a production of 137.82 million tonnes,while Karnataka cultivates 9.53 lakh ha producing 31.27 lakh tonnes (Anonymous, 2024). Rice, a semi-aquatic crop, requires 3,000-5,000 L of water per kg and traditional cultivation uses about 40 per cent of global irrigation water. Challenges such as groundwater depletion, labour shortages and climate-driven water scarcity threaten its sustainability. Hence, water-saving alternatives like AWD, SRI and aerobic rice are increasingly important, with aerobic rice showing promising yields. Aerobic rice is grown in well-drained, non-puddled soils, but severe weed pressure limits its adoption, with potential yield losses up to 53-90 per cent (Nyarko and De-Datta, 1991). Effective weed management is critical as weeds emerge with the crop.

Brown manuring has emerged as an efficient practice to suppress early weeds and improve soil health. Intercropped green manure crops like dhaincha or sunhemp are knocked down with 2,4-D at 25-30 DAS, forming a brown mulch that enriches soil nitrogen, conserves moisture and reduces weed growth through shading and allelopathy (Tanwar *et al.,* 2014). Nitrogen remains a critical nutrient for rice growth, yet its use efficiency in aerobic systems is low due to nutrient losses and fluctuating soil moisture. Therefore, balancing nitrogen application with brown manuring becomes essential for sustainable productivity. Hence, the present study titled 'Effect of Brown Manuring through Sunhemp and Nitrogen Levels on Weed Suppression, Growth and Yield of Aerobic Rice' was undertaken to explore viable and sustainable production practices.

Material and Methods

The field experiment was conducted during the summer and *rabi* seasons of 2023 at the Agronomy Field Unit, Zonal Agricultural Research Station, UASB, GKVK, Bengaluru. The experimental soil was red sandy loam in texture with a neutral soil reaction (pH 6.57). The experiment was conducted with two different factors *viz.,* factor I: sunhemp seed rate (S_0 -Rice+ no sumhemp, S_1- Rice + sunhmep 50 kg ha^{-1} and S_2 -Rice + sunhemp 75 kg ha^{-1}) and factor II: RDN levels (N_0- 0%, N_1 - 75%, N_2 - 100% and N_3 - 125%). Totally 12 treatment combinations which were replicated thrice and laid out in Completely Randomised Block Design. Rice variety KMP 175 seeds were sown with spacing of 25 cm × 25 cm at depth of 4-5 cm and simultaneously sunhemp seeds were broadcasted in brown manuring plots (rice + sunhemp). Nutrients were applied as per the treatments in the form of urea, single super phosphate and muriate of potash to supply nitrogen, phosphorus and potassium, respectively as per the treatments. Half of the nitrogen and full amount of phosphorus and potassium were applied at the time of sowing and remaining 50 per cent of nitrogen was applied as top dress at 30 and 60 DAS in two equal splits (RDF used is 100: 50: 50 kg ha^{-1} NPK). Brown manured plots were sprayed with 2,4-D ester at 600 ml ha^{-1} at 20-25 DAS for desiccation of sunhemp plants.

Biometric observations on growth parameters were recorded randomly on selected five plants at different growth stages 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

Growth Parameters

Growth parameters *viz.,* plant height, number of tillers, leaf area and dry matter production were significantly influenced sunhemp seed rate and nitrogen management (Table 1).

The pooled analysis of data revealed that among the sunhemp seed rates, seed rate of 50 kg ha^{-1} recorded significantly higher plant height (81.87 cm), number of tillers (19.22) and dry matter production at harvest (101.38 g plant^{-1}) and leaf area at 90 DAS (1510 cm^2 plant^{-1}) and which was on par with seed rate of 75 kg ha^{-1} (79.57 cm, 18.07, 96.09 g plant^{-1} and 1432 cm^2 plant^{-1} respectively), as compared to sole rice cultivation. In nitrogen management, application of 125 per cent RDN significantly increased plant height (85.98 cm), number of tillers (20.12) and dry matter production at harvest (119.70 g plant^{-1}) and leaf area at 90 DAS (1784 cm^2 plant^{-1}) over other treatments.

The interaction between sunhemp seed rate and nitrogen management practices significantly influenced growth parameters of rice crop. The treatment comprising 50 kg ha^{-1} sunhemp seed rate along with 125 per cent RDN recorded significantly

TABLE 1

Effect of sunhemp seed rates and nitrogen management on growth parameters in aerobic rice

Treatment	Plant height (cm) at harvest			Number of tillers at harvest			Leaf area (cm^2 $plant^{-1}$) at 90 DAS			Dry matter production (g $plant^{-1}$) at harvest		
	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled
Sunhemp seed rate (S)												
S_0: 0 kg ha^{-1}	75.33	70.05	72.69	16.80	15.29	16.05	1322	1218	1270	88.72	81.80	85.26
S_1: 50 kg ha^{-1}	84.79	78.94	81.87	18.70	18.44	19.22	1572	1449	1510	105.44	97.32	101.38
S_2: 75 kg ha^{-1}	82.37	76.77	79.57	20.00	17.45	18.07	1489	1376	1432	99.88	92.29	96.09
S.Em ±	1.64	1.53	1.59	0.47	0.43	0.45	28.74	26.51	27.63	1.93	1.78	1.85
CD (p=0.05)	4.82	4.49	4.66	1.39	1.27	1.33	84.29	77.75	81.02	5.66	5.22	5.44
Nitrogen management practices (N)												
N_0: 0% RDN	73.37	68.32	70.84	15.27	14.10	14.68	1087	1003	1045	72.93	67.33	70.13
N_1: 75% RDN	77.62	72.26	74.94	18.56	17.10	17.83	1417	1307	1362	95.08	87.75	91.42
N_2: 100% RDN	83.28	77.53	80.41	19.24	17.74	18.49	1484	1369	1426	99.55	91.89	95.72
N_3: 125% RDN	89.05	82.91	85.98	20.93	19.30	20.12	1856	1711	1784	124.50	114.91	119.70
S.Em ±	1.90	1.77	1.83	0.55	0.50	0.52	33.19	30.61	31.90	2.23	2.06	2.14
CD (p=0.05)	5.57	5.18	5.38	1.60	1.47	1.53	97.33	89.78	93.56	6.53	6.03	6.28
Interaction S x N												
S_0N_0	54.40	50.59	52.49	12.48	11.36	11.92	659	607	633	44.22	40.77	42.50
S_0N_1	80.96	75.29	78.13	17.47	15.90	16.68	1459	1344	1401	97.88	90.24	94.06
S_0N_2	83.03	77.22	80.12	18.53	16.87	17.70	1474	1357	1415	98.87	91.16	95.01
S_0N_3	82.92	77.11	80.01	18.73	17.04	17.89	1698	1564	1631	113.91	105.02	109.46
S_1N_0	81.34	75.73	78.53	18.13	14.01	14.61	1265	1166	1215	84.84	78.31	81.57
S_1N_1	77.17	71.84	74.50	17.60	18.99	19.80	1545	1425	1485	103.68	95.70	99.69
S_1N_2	86.40	80.44	83.42	18.40	19.18	19.99	1372	1265	1319	92.06	84.97	88.51
S_1N_3	94.26	87.76	91.01	20.67	21.57	22.49	2104	1940	2022	141.18	130.31	135.75
S_2N_0	84.38	78.64	81.51	15.20	16.92	17.53	1338	1236	1287	89.74	82.92	86.33
S_2N_1	74.72	69.64	72.18	20.60	16.42	17.01	1247	1152	1200	83.67	77.31	80.49
S_2N_2	80.42	74.95	77.68	20.80	17.17	17.78	1606	1484	1545	107.72	99.53	103.63
S_2N_3	89.98	83.86	86.92	23.40	19.28	19.97	1765	1631	1698	118.40	109.40	113.90
S.Em ±	3.29	3.06	3.18	0.95	0.87	0.91	57.48	53.02	55.25	3.86	3.56	3.71
CD (p=0.05)	9.65	8.98	9.31	2.78	2.54	2.66	168.58	155.51	162.04	11.31	10.44	10.88

higher plant height (91.01 cm), number of tillers (22.49) and dry matter production at harvest (135.75 g $plant^{-1}$) and leaf area at 90 DAS (2022 cm^2 $plant^{-1}$). Statistically on par plant height was recorded with 75 kg ha^{-1} sunhemp seed rate with 125 per cent RDN (86.92 cm), whereas, for number of tillers at harvest, 50 kg ha^{-1} sunhemp seed rate + 100 per cent RDN (19.99) and 75 kg ha^{-1} sunhemp seed rate + 125 per cent RDN (19.97).

An optimum seed rate of 50 kg ha^{-1} ensured adequate population and vigorous growth, whereas 75 kg ha^{-1} caused excessive competition, reducing per-plant biomass (Balkcom *et al.,* 2011). The steady nutrient release from decomposed sunhemp might have matched the crop's physiological demand, enhancing plant height, tiller initiation and overall vegetative growth. Enhanced cytokinin and auxin activity under adequate nitrogen further supported tiller bud activation (Jong *et al.,* 2014). Increased leaf area resulted from better nutrient availability and reduced weed pressure due to sunhemp smothering. Higher nitrogen levels strengthened these effects by supporting vigorous growth, nutrient translocation and dry matter accumulation (Bhavya and Basavaraja, 2021). Synchronized nutrient supply from sunhemp residues and nitrogen fertilization improved resource use efficiency, lead to higher biomass and enhanced growth attributes of rice. Similar results are reported by Jyoti *et al.* 2024.

Weed Parameters

Weed Density

At 15 and 45 DAS, weed density was significantly influenced by sunhemp seed rate and nitrogen management (Table 2). Sowing sunhemp at the

Table 2

Effect of sunhemp seed rates and nitrogen management on total number of weeds (m^{-2}) in aerobic rice

Treatment	15 DAS (total no. m^{-2})			45 DAS (total no. m^{-2})			60 DAS (total no. m^{-2})			At harvest (total no. m^{-2})		
	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled
Sunhemp seed rate (S)												
S_0: 0 kg ha^{-1}	38.62	35.53	37.08	75.1	69.09	72.09	99.77	91.79	95.78	123.37	113.50	118.43
S_1: 50 kg ha^{-1}	29.03	26.65	27.84	45.34	41.62	43.48	70.45	64.67	67.56	84.11	77.21	80.66
S_2: 75 kg ha^{-1}	28.21	26.01	27.11	44.46	40.99	42.73	70.89	65.36	68.13	84.63	78.03	81.33
S.Em ±	0.39	0.36	0.38	0.46	0.42	0.44	0.65	0.6	0.62	0.61	0.56	0.58
CD (p=0.05)	1.15	1.06	1.11	1.35	1.24	1.3	1.9	1.75	1.82	1.79	1.64	1.71
Nitrogen management practices (N)												
N_0: 0% RDN	28.12	25.87	26.99	50.78	46.71	48.74	75.39	69.36	72.38	90.67	83.42	87.04
N_1: 75% RDN	30.09	27.68	28.88	51.94	47.78	49.86	76.46	70.35	73.41	91.99	84.63	88.31
N_2:100% RDN	34.01	31.29	32.65	56.02	51.54	53.78	82.05	75.49	78.77	99.40	91.45	95.42
N_3:125% RDN	35.6	32.75	34.18	61.13	56.24	58.68	87.57	80.57	84.07	107.42	98.83	103.12
S.Em ±	0.45	0.42	0.44	0.53	0.49	0.51	0.75	0.69	0.72	0.70	0.65	0.67
CD (p=0.05)	1.33	1.23	1.28	1.56	1.44	1.50	2.19	2.02	2.11	2.06	1.90	1.98
Interaction (S x N)												
S_0N_0	36.29	33.39	34.84	68.67	63.18	65.92	91.88	84.53	88.21	116.91	107.56	112.24
S_0N_1	37.85	34.82	36.33	69.84	64.25	67.04	92.57	85.17	88.87	118.00	108.56	113.28
S_0N_2	39.34	36.19	37.77	76.45	70.34	73.40	102.65	94.44	98.54	127.25	117.07	122.16
S_0N_3	41.01	37.73	39.37	85.42	78.59	82.01	111.99	103.03	107.51	131.31	120.8	126.06
S_1N_0	24.64	22.62	23.63	41.92	38.49	40.20	67.36	61.84	64.60	77.08	70.76	73.92
S_1N_1	26.56	24.39	25.48	44.47	40.83	42.65	66.54	61.09	63.82	78.05	71.65	74.85
S_1N_2	31.72	29.12	30.42	45.07	41.37	43.22	73.51	67.48	70.49	87.56	80.38	83.97
S_1N_3	33.18	30.46	31.82	49.90	45.80	47.85	74.38	68.28	71.33	93.75	86.06	89.9
S_2N_0	23.42	21.60	22.51	41.73	38.48	40.11	66.93	61.71	64.32	78.02	71.93	74.98
S_2N_1	25.85	23.83	24.84	41.5	38.26	39.88	70.28	64.79	67.53	79.91	73.68	76.79
S_2N_2	30.97	28.56	29.77	46.54	42.91	44.73	70.00	64.54	67.27	83.40	76.89	80.15
S_2N_3	32.61	30.07	31.34	48.07	44.32	46.19	76.35	70.4	73.37	97.20	89.61	93.40
S.Em ±	0.79	0.72	0.76	0.92	0.85	0.88	1.3	1.19	1.24	1.22	1.12	1.17
CD (p=0.05)	2.31	2.12	2.21	2.7	2.49	2.59	3.8	3.49	3.65	3.57	3.29	3.43

rate of 75 kg ha^{-1} recorded significantly lower weed densities at 15 DAS (27.11 m^{-2}) and 45 DAS (42.73 m^{-2}), and was on par with 50 kg ha^{-1} at both stages (27.84 and 43.48 m^{-2}, respectively). In contrast, no sunhemp sowing resulted in higher weed densities (37.08 and 72.09 m^{-2}, respectively). Among nitrogen management practices, no nitrogen application recorded significantly lower weed densities at 15 DAS (26.99 m^{-2}) and 45 DAS (48.74 m^{-2}),it was on par with 75 per cent RDN (49.86 m^{-2}) at 45 DAS. However, 125 per cent RDN resulted in higher weed densities (34.18 and 58.68 m^{-2} at 15 and 45 DAS, respectively). The interaction effects also revealed similar trend, with the lower weed density at 15 DAS (22.51 m^{-2}) and 45 DAS (40.11 m^{-2}) in the combination of 75 kg ha^{-1} sunhemp seed rate and no nitrogen application.

TABLE 3

Effect of sunhemp seed rates and nitrogen management on dry matter of weeds (g m^{-2}) in aerobic rice

Treatment	15 DAS (g m^{-2})			45 DAS (g m^{-2})			60 DAS (g m^{-2})			At harvest (g m^{-2})		
	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled
Sunhemp seed rate (S)												
S_0: 0 kg ha^{-1}	3.48	3.20	3.34	9.76	8.98	9.37	20.95	19.28	20.11	65.39	60.15	62.77
S_1: 50 kg ha^{-1}	2.61	2.40	2.51	5.89	5.41	5.65	14.79	13.58	14.19	44.58	40.92	42.75
S_2: 75 kg ha^{-1}	2.54	2.34	2.44	5.78	5.33	5.55	14.89	13.73	14.31	44.85	41.36	43.10
S.Em ±	0.04	0.03	0.03	0.06	0.06	0.06	0.14	0.13	0.13	0.32	0.3	0.31
CD (p=0.05)	0.10	0.10	0.10	0.18	0.16	0.17	0.40	0.37	0.38	0.95	0.87	0.91
Nitrogen management practices (N)												
N_0: 0% RDN	2.53	2.33	2.43	6.60	6.07	6.34	15.83	14.57	15.20	48.06	44.21	46.13
N_1: 75% RDN	2.71	2.49	2.60	6.75	6.21	6.48	16.06	14.77	15.42	48.75	44.85	46.80
N_2:100% RDN	3.06	2.82	2.94	7.28	6.70	6.99	17.23	15.85	16.54	52.68	48.47	50.58
N_3:125% RDN	3.20	2.95	3.08	7.95	7.31	7.63	18.39	16.92	17.66	56.93	52.38	54.65
S.Em ±	0.04	0.04	0.04	0.07	0.06	0.07	0.16	0.14	0.15	0.37	0.34	0.36
CD (p=0.05)	0.12	0.11	0.12	0.2	0.19	0.19	0.46	0.42	0.44	1.09	1.01	1.05
Interaction (S x N)												
S_0N_0	3.27	3.00	3.14	8.93	8.21	8.57	19.3	17.75	18.52	61.96	57.01	59.49
S_0N_1	3.41	3.13	3.27	9.08	8.35	8.72	19.44	17.89	18.66	62.54	57.54	60.04
S_0N_2	3.54	3.26	3.40	9.94	9.14	9.54	21.56	19.83	20.69	67.44	62.05	64.74
S_0N_3	3.69	3.40	3.54	11.10	10.22	10.66	23.52	21.64	22.58	69.59	64.03	66.81
S_1N_0	2.22	2.04	2.13	5.45	5.00	5.23	14.15	12.99	13.57	40.85	37.50	39.18
S_1N_1	2.39	2.19	2.29	5.78	5.31	5.54	13.97	12.83	13.40	41.37	37.97	39.67
S_1N_2	2.85	2.62	2.74	5.86	5.38	5.62	15.44	14.17	14.80	46.41	42.60	44.51
S_1N_3	2.99	2.74	2.86	6.49	5.95	6.22	15.62	14.34	14.98	49.69	45.61	47.65
S_2N_0	2.11	1.94	2.03	5.43	5.00	5.21	14.06	12.96	13.51	41.35	38.12	39.74
S_2N_1	2.33	2.15	2.24	5.39	4.97	5.18	14.76	13.61	14.18	42.35	39.05	40.70
S_2N_2	2.79	2.57	2.68	6.05	5.58	5.81	14.7	13.55	14.13	44.2	40.75	42.48
S_2N_3	2.93	2.71	2.82	6.25	5.76	6.01	16.03	14.78	15.41	51.51	47.50	49.50
S.Em ±	0.07	0.07	0.07	0.12	0.11	0.11	0.27	0.25	0.26	0.65	0.59	0.62
CD (p=0.05)	0.21	0.19	0.2	0.35	0.32	0.34	0.8	0.73	0.77	1.89	1.74	1.82

At 60 DAS and at harvest, weed density was significantly influenced by sunhemp seed rate and nitrogen management (Table 2). Sunhemp at 50 kg ha^{-1} recorded the lower weed density at 60 DAS and at harvest (67.56 m^{-2} and 80.66 m^{-2}), which was on par with 75 kg ha^{-1} (68.13 m^{-2} and 81.33 m^{-2}) and significantly lower than no sunhemp treatment (95.78 m^{-2} and 118.43 m^{-2}). Among nitrogen levels, no nitrogen application resulted in significantly lower weed density at both stages (72.38 and 87.04 m^{-2} at 60 DAS and at harvest, respectively) and was on par with 75 per cent RDN (73.41 and 88.31 m^{-2} at 60 DAS and at harvest, respectively), whereas, 125 per cent RDN recorded higher weed density (84.07 and 103.12 m^{-2}, respectively). The interaction effects also followed a similar pattern, at 60 DAS, the combination of 50 kg ha^{-1} sunhemp with 75 per cent RDN recorded the lower weed density (63.82 m^{-2}), while at harvest, the lower weed density was observed with 50 kg ha^{-1} sunhemp combined with no nitrogen application (73.92 m^{-2}), closely followed by 75 kg ha^{-1} sunhemp with no nitrogen application (74.98 m^{-2}).

Weed Dry Weight

Weed dry weight at 15 DAS and 45 DAS was significantly influenced by sunhemp seed rate, nitrogen management and their interaction (Table 3). Across both stages, sowing sunhemp at 75 kg ha^{-1} recorded significantly lower weed dry weight (2.44 g m^{-2} at 15 DAS and 5.55 g m^{-2} at 45 DAS) and was on par with 50 kg ha^{-1} (2.51 and 5.65 g m^{-2}, respectively), while the no sunhemp resulted in the higher weed dry weight (3.34 and 9.37 g m^{-2}, respectively). Among nitrogen management practices, the control treatment registered lower weed dry weight at both stages (2.43 g m^{-2} at 15 DAS and 6.34 g m^{-2} at 45 DAS), whereas 125 per cent RDN produced the higher values (3.08 and 7.63 g m^{-2}, respectively). The sunhemp seed rate at 75 kg ha^{-1} with the control recorded the lower weed dry weight at 15 DAS (2.03 g m^{-2}), while sunhemp at 75 kg ha^{-1} with 75 per cent RDN resulted in the lower value at 45 DAS (5.18 g m^{-2}). The higher weed dry weight at both stages was observed under no sunhemp with 125 per cent RDN (3.54 g m^{-2} at 15 DAS and 10.66 g m^{-2} at 45 DAS).

Weed dry weight at both 60 DAS and harvest was significantly influenced by sunhemp seed rate, nitrogen management and their interaction (Table 3). Across both stages, sowing sunhemp at 50 kg ha^{-1} recorded significantly lower weed dry weight (14.19 g m^{-2} at 60 DAS and 42.75 g m^{-2} at harvest) and was on par with 75 kg ha^{-1} (14.31 and 43.10 g m^{-2}, respectively), while the sole rice cultivation resulted in the higher weed dry weight (20.11 and 62.77 g m^{-2}, respectively). Among nitrogen management practices, the control treatment recorded lower weed dry weight at both stages (15.20 g m^{-2} at 60 DAS and 46.13 g m^{-2} at harvest), whereas 125 per cent RDN produced the higher values (17.66 and 54.65 g m^{-2}, respectively). The combination of sunhemp at 50 kg ha^{-1} with 75 per cent RDN recorded the lower weed dry weight at 60 DAS (13.40 g m^{-2}) and at harvest 75 kg ha^{-1} sunhemp seed rate with the control treatment resulted in the lower value (39.18 g m^{-2}). The higher weed dry weight at both stages was observed under no sunhemp with 125 per cent RDN (22.58 g m^{-2} at 60 DAS and 66.81 g m^{-2} at harvest).

Concurrent cultivation of sunhemp with rice reduced weed density and weed dry weight at all crop growth stages compared to sole rice. This was mainly because sunhemp acted as a cover crop, suppressing the initial flush of weeds through its smothering effect, these results re in line with Mann *et al.* (2007), Walia *et al.* (2009) and Gaire *et al.* (2013). Higher seed rate increased sunhemp population, which further reduced weeds by enhancing competition for resources (Jalali and Falahzadah, 2021). Sunhempposed competition with weeds for water, nutrients and space, while its shading reduced light availability and weed seed germination. After sunhemp was terminated at 20-25 DAS, the desiccated biomass formed a mulch that further suppressed weed emergence. These results are in agreement with Anitha and Mathew (2010) and Maity and Mukherjee (2011). Weed density and dry weight increased with higher nitrogen levels due to enhanced nitrogen availability andhigher nutrient removal by weeds. Similar findings were also reported by Pysek and Leps (1991) and Anurag *et al.* (2018).

Weed Control Efficiency

Weed control efficiency (WCE) at 15 and 45 DAS were presented in the Fig. 1. At 15 DAS, a higher seed rate of sunhemp at 75 kg ha^{-1} recorded higher WCE (31.06%), followed by 50 kg ha^{-1} (29.23%), while no sunhemp recorded the lower values. A similar trend was observed at 45 DAS, where WCE was slightly higher with 75 kg ha^{-1} (47.89%) than 50 kg ha^{-1} (46.97%). Interaction effects revealed that at 15 DAS, a higher WCE (42.77%) was recorded with sunhemp at 75 kg ha^{-1} combined with 0 per cent RDN, which was closely followed by 50 kg ha^{-1} + 0 per cent RDN (39.93%). The lower WCE at this stage (3.98%) occurred in no sunhemp + 100 per cent RDN. At 45 DAS, a higher WCE (51.37%) was obtained in sunhemp at 75 kg ha^{-1} + 75 per cent RDN, followed by 75 kg ha^{-1} + 0 per cent RDN (51.09%) and 50 kg ha^{-1} + 0 per cent RDN (50.97%). The lower WCE at this stage (10.49%) was observed in no sunhemp + 100 per cent RDN.

Weed control efficiency at 60 DAS and at harvest were presented in the Fig. 1. At 60 DAS, sunhemp seed rate of 50 kg ha^{-1} recorded a higher weed control efficiency (37.17%), followed by 75 kg ha^{-1} (36.64%). A similar trend was observed at harvest, where weed control efficiency was higher with 50 kg ha^{-1} (36.01%) than 75 kg ha^{-1} (35.48%). Interaction effects revealed that at 60days after sowing, a higher weed control efficiency (40.65%) was recorded with sunhemp at 50 kg ha^{-1} combined with 75 per cent RDN, which was closely followed by 75 kg ha^{-1} + 0 per cent RDN (40.18%). The lower WCE at this stage (8.35%) occurred in no sunhemp + 100 per cent RDN. At harvest, a higher WCE (41.36%) was obtained

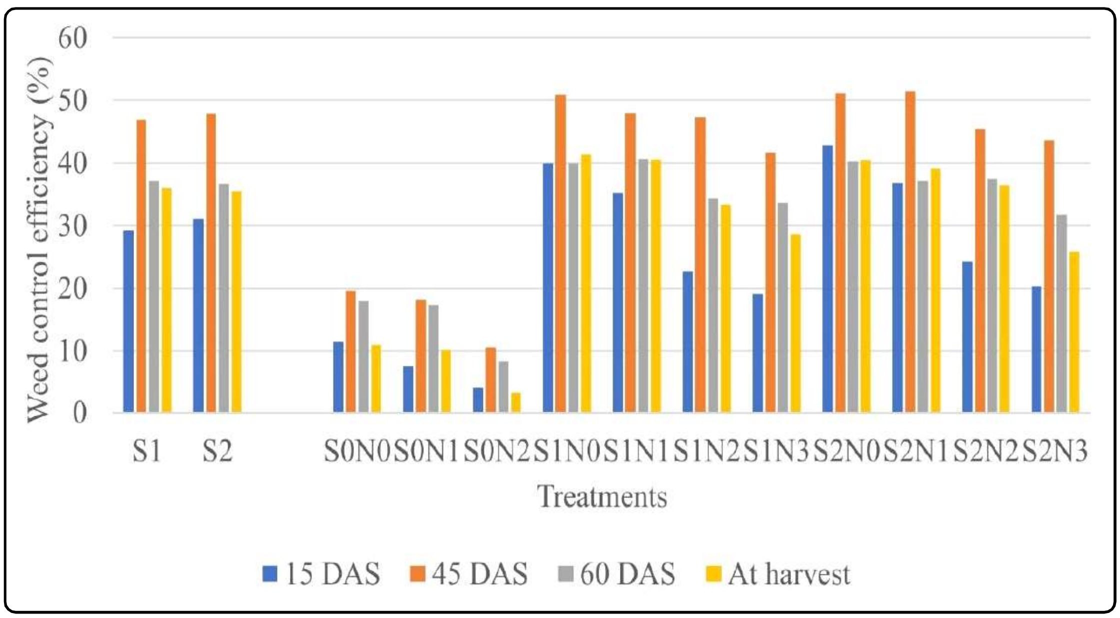

Fig. 1 : Effect of sunhep seed rates and nitrogen management on weed control efficiency in aerobic rice

Legend:

Factor I: Seed rates

S_0: Sunhemp (0 kg ha^{-1})

S_1: Sunhemp (50 kg ha^{-1})

S_2: Sunhemp (75 kg ha^{-1})

Factor II: RDN levels

N_0: Control

N_1: 75 % RDN

N_2: 100 % RDN

N_3: 125 % RDN

in sunhemp at 50 kg ha^{-1} + 0 per cent RDN, followed by 50 kg ha^{-1} + 75 per cent RDN (40.62%) and 75 kg ha^{-1} + 0 per cent RDN (40.52%). The lower WCE at this stage (3.09%) was observed in no sunhemp + 100 per cent RDN.

Yield Attributes

The data on yield attributes of aerobic rice in response to varied sunhemp seed rates and nitrogen levels are presented in Table 4. Significantly higher number of panicles per plant (19.22), panicle weight (3.60 g) and total number of grains panicle^{-1} (171.45) compared to with 50 kg ha^{-1}sunhemp seed rate as compared to without sunhemp treatment. It was statistically on par with 75 kg ha^{-1} of sunhemp (18.07 and 3.46 g and 167.39, respectively). Application of 125 per cent RDN recorded significantly higher number of panicles per plant (20.12), panicle weight (4.02 g) and total number of grains panicle^{-1} (182.42) compared to other nitrogen levels.

TABLE 4

Effect of sunhemp seed rates and nitrogen management on yield attributes in aerobic rice

Treatment	No. panicles plant^{-1}			Total grains panicle^{-1}			Panicle weight (g)			Test weight (g)		
	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled
Sunhemp seed rate (S)												
S_0: 0 kg ha^{-1}	16.80	15.29	16.05	146.99	144.11	145.55	3.23	2.95	3.09	17.63	16.32	16.98
S_1: 50 kg ha^{-1}	20.00	18.44	19.22	175.63	167.26	171.45	3.75	3.46	3.60	18.72	17.49	18.10
S_2: 75 kg ha^{-1}	18.70	17.45	18.07	172.83	161.94	167.39	3.58	3.35	3.46	19.40	18.25	18.83
S.Em ±	0.47	0.43	0.45	1.63	2.02	1.70	0.11	0.10	0.10	0.60	0.56	0.58
CD (p=0.05)	1.39	1.27	1.33	4.79	5.93	4.98	0.31	0.29	0.30	NS	NS	NS
Nitrogen management practices (N)												
N_0: 0% RDN	15.27	14.10	14.68	138.49	131.86	135.18	2.98	2.76	2.87	15.78	14.74	15.26
N_1: 75% RDN	18.56	17.10	17.83	156.50	149.48	152.99	3.10	2.87	2.98	18.47	17.25	17.86
N_2: 100% RDN	19.24	17.74	18.49	179.31	171.21	175.26	3.81	3.52	3.66	18.97	17.72	18.34
N_3: 125% RDN	20.93	19.30	20.12	186.31	178.54	182.42	4.18	3.87	4.02	21.11	19.71	20.41
S.Em ±	0.55	0.50	0.52	1.89	2.34	1.96	0.12	0.11	0.12	0.69	0.65	0.67
CD (p=0.05)	1.60	1.47	1.53	5.53	6.85	5.76	0.36	0.34	0.35	2.03	1.90	1.97
Interaction (S x N)												
S_0N_0	12.48	11.36	11.92	97.07	95.16	96.12	3.41	3.12	3.26	14.50	13.43	13.96
S_0N_1	17.47	15.90	16.68	147.57	144.68	146.13	2.95	2.69	2.82	17.33	16.05	16.69
S_0N_2	18.53	16.87	17.70	165.20	161.96	163.58	3.04	2.78	2.91	17.68	16.37	17.03
S_0N_3	18.73	17.04	17.89	178.13	174.64	176.39	3.51	3.20	3.36	21.00	19.45	20.22
S_1N_0	15.20	14.01	14.61	160.27	152.63	156.45	2.05	1.90	1.98	16.17	15.10	15.63
S_1N_1	20.60	18.99	19.80	163.52	155.73	159.63	3.57	3.30	3.44	18.50	17.28	17.89
S_1N_2	20.80	19.18	19.99	186.99	178.08	182.53	4.91	4.54	4.73	19.22	17.95	18.59
S_1N_3	23.40	21.57	22.49	191.73	182.60	187.17	4.45	4.11	4.28	21.00	19.61	20.31
S_2N_0	18.13	16.92	17.53	158.13	147.79	152.96	3.48	3.26	3.37	16.67	15.68	16.18
S_2N_1	17.60	16.42	17.01	158.40	148.04	153.22	2.78	2.60	2.69	19.59	18.43	19.01
S_2N_2	18.40	17.17	17.78	185.73	173.58	179.66	3.47	3.24	3.36	20.00	18.82	19.41
S_2N_3	20.67	19.28	19.97	189.07	178.36	183.72	4.58	4.29	4.43	21.33	20.07	20.70
S.Em ±	0.95	0.87	0.91	3.27	4.05	3.40	0.21	0.20	0.21	1.20	1.12	1.16
CD (p=0.05)	2.78	2.54	2.66	9.58	11.86	9.97	0.63	0.58	0.60	NS	NS	NS

The combination of 50 kg ha^{-1} sunhemp with 125 per cent RDN recorded a significantly higher number of panicles per plant (22.49), which was statistically on par with the combinations of 75 kg ha^{-1} sunhemp with 125 per cent RDN (19.97) and 50 kg ha^{-1} sunhemp with 100 per cent RDN (19.99). Significantly higher panicle weight was recorded with 50 kg ha^{-1} sunhemp with 100 per cent RDN (4.73 g), which was statistically on par with the combinations of 50 kg ha^{-1} sunhemp with 125 per cent RDN (4.28 g) and 75 kg ha^{-1} sunhemp with 125 per cent RDN (4.43 g). The combination of 50 kg ha^{-1} sunhemp seed rate with 125 per cent RDN recorded the significantly higher total grains panicle^{-1} (187.17). Although it was on par with the combination of sunhemp seed rate of 75 kg ha^{-1} with 125 per cent RDN (183.72), seed rate of 50 kg ha^{-1} with 100 per cent RDN (182.53) and seed rate of 75 kg ha^{-1} with 100 per cent RDN (179.66).

Test weight was significantly influenced by nitrogen management, while the effect of sunhemp seed rate and the interaction between sunhemp seed rate and nitrogen management were found to be non-significant. Among nitrogen levels, the application of 125 per cent RDN recorded significantly higher test weight (20.41 g) than all other nitrogen levels. It was followed by 100 per cent RDN (18.34 g), which was statistically lower than 125 per cent RDN. The lower test weight (17.15 g) was observed under no nitrogen application.

The improvement in yield parameters under brown manuring with varied sunhemp seed rate can be attributed to enhanced nutrient availability during panicle initiation stage, led to improved grains per panicle. Similar effect also reported by Hemalatha *et al.* (2000) and Sraw *et al.* (2017). Brown manuring further suppresses late-emerging weeds, reducing nutrient competition and improving nutrient uptake by the crop. Brown manuring of sunhemp ensured a continuous supply of nutrients (N, P_2O_5 and K_2O) during key growth stages such as primordial initiation, flowering and grain filling. This steady nutrient release enhanced phosphorus uptake in the leaves, contributing to higher proportion of filled grains. Additionally, nitrogen supports protein and enzyme synthesis, while potassium aids enzyme activation and carbohydrate formation, both being vital for effective grain filling. Similar results were also documented by Aslam *et al.* (2008), Nalini *et al.* (2008) and Chaudhary *et al.* (2018).

Grain and Straw Yield

Among the sunhemp seed rates, sunhemp at 50 kg ha^{-1} recorded significantly higher grain (4453 kg ha^{-1}) and straw yield (5608 kg ha^{-1}), which was on par with 75 kg ha^{-1} (4133 and 5381 kg ha^{-1}, respectively), while the control recorded lower grain (3504 kg ha^{-1}) and straw yield (4648 kg ha^{-1}). In nitrogen management practices, application of 125 per cent RDN resulted in significantly higher grain (5130 kg ha^{-1}) and straw yield (6148 kg ha^{-1}), followed by 100 per cent RDN (4449 and 5696 kg ha^{-1}) and 75 per cent RDN, whereas, the control recorded lower grain (2964 kg ha^{-1}) and straw yield (4065 kg ha^{-1}). The treatment combination sunhemp 50 kg ha^{-1} + 125 per cent RDN recorded significantly higher grain (5304 kg ha^{-1}) and straw yield (6545 kg ha^{-1}), whereas no sunhemp + 0 per cent RDN recorded lower grain (1947 kg ha^{-1}) and straw yield (3864 kg ha^{-1}).

The pooled mean harvest index (HI) of aerobic rice was significantly influenced by sunhemp seed rate, nitrogen management and their interaction. Among sunhemp seed rates, sowing sunhemp at 50 kg ha^{-1} recorded the higher harvest index (0.442), which was significantly superior to no sunhemp (0.419) and on par with 75 kg ha^{-1} (0.433). Application of 125 per cent RDN recorded the higher HI (0.455), followed by 100 per cent RDN (0.438), whereas the lower value was recorded under no nitrogen (0.415). The higher HI was observed in no sunhemp along with 125 per cent RDN(0.481), followed by 75 kg ha^{-1} + no sunhemp (0.460) and 50 kg ha^{-1} + no sunhemp (0.449). The lower HI was obtained under sunhemp 0 kg ha^{-1} + no sunhemp (0.335).

The decomposition, mineralization of sunhemp biomass resulted in release of essential nutrients at the critical physiological stage of the crop *i.e.,* panicle

TABLE 5

Effect of sunhemp seed rates and nitrogen management on grain yield, straw yield and harvest index of aerobic rice

Treatment	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})			Harvest Index (%)		
	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled	Summer	*Rabi*	Pooled
Sunhemp seed rate (S)									
S_0: 0 kg ha^{-1}	3647	3360	3504	4812	4485	4648	0.421	0.418	0.419
S_1: 50 kg ha^{-1}	4612	4294	4453	5779	5438	5608	0.443	0.441	0.442
S_2: 75 kg ha^{-1}	4256	4009	4133	5536	5226	5381	0.433	0.433	0.433
S.Em ±	122.01	114.48	118.24	85.91	80.75	83.33	0.006	0.006	0.006
CD (p=0.05)	357.85	335.74	346.80	251.98	236.84	244.41	0.017	0.018	0.017
Nitrogen management practices (N)									
N_0: 0% RDN	3066	2862	2964	4192	3937	4065	0.416	0.414	0.415
N_1: 75% RDN	3703	3449	3576	5097	4788	4942	0.418	0.416	0.417
N_2:100% RDN	4606	4292	4449	5874	5518	5696	0.439	0.437	0.438
N_3:125% RDN	5312	4949	5130	6340	5956	6148	0.456	0.455	0.455
S.Em ±	140.89	132.18	136.54	99.21	93.25	96.23	0.007	0.007	0.007
CD (p=0.05)	413.21	387.68	400.45	290.96	273.48	282.22	0.020	0.021	0.019
Interaction (S x N)									
S_0N_0	2027	1868	1947	4000	3728	3864	0.337	0.334	0.335
S_0N_1	3220	2967	3093	4489	4184	4337	0.418	0.416	0.417
S_0N_2	4182	3853	4018	5214	4859	5036	0.445	0.442	0.444
S_0N_3	5159	4753	4956	5544	5167	5356	0.482	0.479	0.481
S_1N_0	3479	3239	3359	4237	3987	4112	0.451	0.448	0.449
S_1N_1	4554	4240	4397	5782	5441	5612	0.440	0.437	0.439
S_1N_2	4923	4584	4754	6353	5978	6165	0.436	0.434	0.435
S_1N_3	5494	5115	5304	6744	6346	6545	0.447	0.446	0.446
S_2N_0	3692	3478	3585	4340	4097	4219	0.461	0.460	0.460
S_2N_1	3334	3141	3238	5018	4737	4878	0.396	0.396	0.396
S_2N_2	4713	4440	4576	6055	5716	5886	0.436	0.436	0.436
S_2N_3	5284	4978	5131	6732	6355	6543	0.440	0.439	0.439
S.Em ±	244.03	228.95	236.49	171.83	161.51	166.67	0.012	0.012	0.011
CD (p=0.05)	715.71	671.49	693.59	503.96	473.69	488.82	0.034	0.036	0.033

initiation stage of rice (Radhakrishnan and Mathew, 2010). Slow and steady supply of major nutrients helped in reducing losses through volatilization, leaching of major nutrients and loss of micronutrients by chelation process, increasing their availability to the plants. During decomposition of sunhemp, release of organic acids and allelochemicals helped in suppression of weed seeds from germination thus providing a weed free environment. Thus, ample supply of nutrients coupled with competition free environment resulted in higher rice yield. Comparable results were observed by Singh *et al.* (2009) and Samant (2017). The improvement in yield components under 125 per cent RDN might be due to good vegetative growth, higher leaf area and dry matter production. Increase in filled grain and thousand-grain weight with increased nutrient levels might be due to enhancement of photosynthetic activity resulting in the translocation of photosynthates and amino acids from the leaves and culms to the grain. These in turn might have favoured the development of large sink.This is evident from the report of Mahajan *et al.,* (1997).

The present study highlights that integrating brown manuring with appropriate nitrogen management can significantly enhance aerobic rice cultivation. This practice improved soil health, moderated weed pressure and supported better crop growth under water-limited conditions. Optimizing nitrogen application alongside sunhemp incorporation proved essential for achieving balanced growth and improved productivity.

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