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Short communication

Performance of grain sorghum in summer rice fallows of Southern Kerala

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Abstract

Sorghum is a major millet crop, renowned for its adaptability to various cropping systems and harsh environmental conditions typical of semi-arid regions. Sorghum in paddy fallows is gaining popularity among the farmers in South India. An experiment was conducted at College of Agriculture, Vellayani, from January 2024 to May 2024 to standardize the tillage, plant population and nutrient management for grain sorghum in summer rice fallows. The experimental design was RCBD replicated thrice and the treatments comprised of 12 combinations of two tillage methods (t_1-zero tillage, t_2-conventional tillage), two spacings (p_1 – 45x15 cm, p_2- 60x15 cm) and three NPK levels (n_1 – 45:25:25 kg NPK ha^{-1}, n_2 – 50:25:75 kg NPK ha^{-1} and n_3 – 50:25:50 kg NPK ha^{-1}).Sorghum grown under conventional tillage with spacing 45x15 cm and a nutrient dose of 50:25:75 NPK kg ha^{-1} recorded taller plants at harvest (288.03 cm) and higher leaf area index (LAI) at 30 DAS (3.13). Sorghum grown under zero tillage with spacing 45x15 cm and a nutrient dose of 50:25:50 NPK kg ha^{-1} recorded higher dry matter production (DMP)(11.72 t ha^{-1}) at harvest. Higher grain yield (5.14 t ha^{-1}) was obtained when sorghum was grown under zero tillage with spacing 45x15 cm and a nutrient dose of 50:25:50 NPK kg ha^{-1}, and higher stover yield (8.10 t ha^{-1}) was obtained in sorghum grown under zero tillage with spacing 45x15 cm and a nutrient dose of 50:25:75 NPK kg ha^{-1}. The net income(₹ 98676) as well as B-C ratio (2.77) was the highest in sorghum grown under zero tillage with 45 cm x 15 cm spacing and 50:25:50 kg NPK ha^{-1}nutrient dose followed by sorghum grown under zero tillage with 45 cm x 15 cm spacing and 50:25:75 kg NPK ha^{-1}nutrient dose (₹ 94263). Hence, grain sorghum can be profitably cultivated in summer rice fallows with zero tillage planted at a spacing of 45 cm x 15 cm and application of nutrient dose of 50:25:50 kg NPK ha^{-1} along with 5 t ha^{-1} FYM.

Key words: Conservation tillage, Nutrient management, Spacing

Sorghum is a versatile crop, renowned for its adaptability to various cropping systems and harsh environmental conditions typical of semi-arid regions. Sorghum cultivation in paddy fallows is becoming increasingly popular among farmers, as the crop is typically grown under zero-tillage conditions (Mishra and Chapke, 2013). Zero-tillage offers several economic and environmental advantages compared to conventional tillage, including reduced labour and fuel requirements, minimized soil erosion and runoff, enhanced soil organic carbon status, and improved soil biological activity.

Altering plant density is one of the strategies to promote water use efficiencyby the crop. Plants grown with a closer row spacing and with a higher density led to a more efficient use of solar radiation, nutrients andwater (McGowan et al.,1991). Sorghum responds well to nutrient application, with higher yields being achieved through a balanced application of NPK. In rice- fallows of Andhra Pradesh farmers use higher dose of fertilizers (150-200 kg N, 75-80 kg P_2O, and 75 kg K_2O ha^{-1}) (Chapke and Babu, 2016). For rainfed sorghum NPK recommendation is 45:25:25 kg/ha (KAU, 2024). Karthik (2021) reported that a modified fertilizer dose of 50:25:75 kg ha^{-1} NPK with N and K in two equal split doses, half of each at basal and at 30DAS and entire P as basal dose for high yielding sorghum as rainfed crop in laterite soils of southern Kerala.

In this background the present study was conducted with the objective to standardize tillage, plant population and nutrient management for cultivation of grain sorghum in summer rice fallows.

The study was undertaken in wetlands of the Instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram. The experimental field is located at 8° 25' 47" N latitude and 76° 59' 04" E longitude at an altitude of 24.15 m above MSL. The mean maximum temperature recorded between 32.2^0 C to 34.4^0 C and mean minimum temperature recorded between 20.0^0 C to 25.8^0 C, mean maximum relative humidity recorded between 85.14 per cent to 94.40 per cent, and mean minimum relative humidity

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recorded between 64.42 per cent to 76.10 per cent. A total rainfall of 343.20 mm was received during the cropping period.Composite soil sample was taken from the field before the experiment and analysed for its mechanical composition and chemical properties. The soil was sandy clay loam with strong acidity, safe electrical conductivity and high organic carbon content. The soil was medium in available nitrogen and high in available phosphorus and medium in available potassium.

The experiment was laid out in Randomized complete block design (RCBD) with 2 x 2 x 3 treatments, replicated thrice and the treatments included of combinations of two tillage methods (t_1-zero tillage, t_2-conventional tillage), two spacing (p_1 – 45x15 cm, p_2- 60x15 cm) and three NPK levels (n_1 – 45:25:25 kg NPK ha^{-1}, n_2 – 50:25:75 kg NPK ha^{-1} and n_3 – 50:25:50 kg NPK ha^{-1}).High-yielding grain sorghum variety Co-32 (TNS 648), released by Tamil Nadu Agricultural University, was used for the study. Co-32 is a derivative of APK 1 x M35-1, having a duration of 105-110 days. Season of the study was summer 2023-24. Plots of 4.5 m × 4.5 m were prepared with 30 cm wide bunds on all four sides. Then plots with conventional tillage treatment was ploughed and the clods were crushed, levelled and brought to a fine tilth and plots with zero tillage treatment was left as such. Irrigation and drainage channels were also provided.Seeds were sown according to the treatments, with row spacings of 45 cm and 60 cm, and a plant-to-plant spacing of 15 cm in line sowing method. Thinning and gap filling were done at 20 DAS.Irrigation was given daily up to crop establishment stage and subsequently as and when required. Five plants were selected and tagged in each plot, and growth and yield parameters were observed. Net income and B:C ratio were also worked out based on existing input and labour costs and cost of grain and stover.

Application of a higher nutrient dose of 50:25:75 kg NPK ha^{-1} led to a plant height of 266.17 cm and 269.76 cm at 90 DAS and harvest respectivelywhich was on par with a nutrient dose of 50:25:50 kg NPK ha^{-1} with a height of 263.56 cm and 266.54 cm at 90 DAS and harvest respectively. The interaction t_2n_2 resulted in significantly superior plant height at 30 DAS (109.17 cm). Significantly taller plants (270.14 cm) were produced by treatment p_1n_3 which was on par with p_1n_2 (269.76 cm), p_2n_2 (262.58 cm), p_2n_3 (256.97 cm) and p_2n_1 (254.97 cm) at 90 DASwhereas treatment p_1n_2 led to superior plant height of 273.79 cm which was on par with p_1n_3 (272.92 cm), p_2n_2 (265.73 cm), p_2n_3 (260.15 cm) and p_2n_1 (258.48 cm) at harvest.Sorghum grown under conventional tillage with a spacing of 45x15 cm and nutrient dose of 50:25:50 kg NPK ha^{-1}led to superior plant height of 285.36 cm at 90 DAS whereas sorghum grown under conventional tillage with a spacing of 45x15 cm and nutrient dose of 50:25:75 kg NPK ha^{-1}led to superior plant height of 288.03 cm at harvest.

Conventional tillage recorded statistically higher number of functional leaves per plant at 60 DAS and harvest respectively. Planting at a wider spacing of 60x15 cmresulted significantly higher number of leaves at all stages of growth NPK application rate of 50:25:50 kg NPK $ha^{-1}$was on par with 50:25:75 kg NPK ha^{-1} with respect to number of leaves and produced significantly higher number of leaves at 90 DAS.Widely spaced sorghum plants had access to more resources, such as light, nutrients, and water, allowing for the development of more leaves per plant compared to closely spaced plants. This is particularly relevant for sorghum, a crop known for its high nutrient demand and significant light requirements, as noted by Evans (1975).

Leaf Area Index (LAI) was found to be significantly superior (2.10) at 30 DAS for plants grown under conventional tillage. Sorghum grown with 45x15 cm spacing resulted in significantly higher LAI (2.32, 5.40and 3.99) at 30, 60 and 90 DAS.Plants applied with a nutrient dose of 50:25:75 kg NPK ha^{-1} recorded statistically superior LAI (2.17) which was on par with a nutrient dose of 50:25:50 kg NPK ha^{-1} having LAI of 1.95 at 30 DAS. Plants applied with a nutrient dose of 50:25:75 kg NPK ha^{-1} recorded statistically superior LAI (3.90) at 90 DAS. The treatment t_2p_1 recorded significantly superior LAI (2.73)at 30 DAS. At 90 DASt_2p_1 recorded significantly superior LAI (4.13) which was on par with t_1p_1 (3.84). The treatment t_2n_2 evinced significantly superior LAI of 2.40 which was on par with t_2n_3 (2.17) at 30 DAS. The treatment p_1n_3 resulted in significantly superior LAI of 2.72 at 30 DAS and the treatment p_1n_2 produced significantly superior LAI of 4.52 at 90 DAS.The deeper tillage would have resulted in more aerated root zone, facilitating better root expansion and deeper growth. This enhanced root system allowed the plants to absorb water and nutrients more effectively from the soil. As a result, the plants exhibited increased height and overall vigour (Muhsin et al., 2021). Also improved availability of nutrients encourages apical branching, leading to a greater total number of leaves on each plant (Biemond, 1995). Conventional tillage led to increased soil porosity and reduced penetration resistance, when compared to plots under zero tillage (Lasisi, 2008). These facilitates plant roots to develop more efficiently and improve nutrient absorption from the soil. This improved root growth and nutrient uptake ultimately promoted better overall plant growth i.e., plant height, number of leaves and dry matter production (Tsegaye and Mullins, 1994). Closer spacing leads to more plants per unit area, which results in a denser canopy that intercepts more sunlight. The increased plant density causes faster

Table 1a. Effect of nutrient management on plant height of sorghum

Treatments	Plant height (cm)			
	30 DAS	60 DAS	90 DAS	At harvest
Nutrient management(n)				
n_1 (45:25:25 kg NPK ha^{-1})	81.96	226.60	246.84	250.37
n_2 (50:25:75 kg NPK ha^{-1})	91.08	246.94	266.17	269.76
n_3 (50:25:50 kg NPK ha^{-1})	83.41	234.52	263.56	266.54
SEm (±)	3.327	5.91	3.75	3.82
CD (0.05)	NS	NS	11.0	11.201

Table 1b. Effect of tillage, spacing and nutrient management on plant height of sorghum

Interactions	Plant height (cm)			
	30 DAS	60 DAS	90 DAS	At harvest
Tillage (t) x NPK Levels (n)				
t_1n_1	85.83	231.43	245.06	248.64
t_1n_2	72.98	244.01	262.27	265.71
t_1n_3	78.16	229.47	258.39	261.91
t_2n_1	78.10	221.76	248.61	252.09
t_2n_2	109.17	249.88	270.07	273.81
t_2n_3	88.68	239.58	268.72	271.16
SEm (±)	4.77	8.36	5.30	5.40
CD (0.05)	13.801	NS	NS	NS
Spacing (p) x NPK Levels (n)				
p_1n_1	79.36	221.24	238.70	242.26
p_1n_2	90.21	243.17	269.76	273.79
p_1n_3	88.68	246.97	270.14	272.92
p_2n_1	84.56	231.95	254.97	258.48
p_2n_2	91.95	250.71	262.58	265.73
p_2n_3	78.15	222.08	256.97	260.15
SEm (±)	4.77	8.35	5.304	5.40
CD (0.05)	NS	NS	15.556	15.841

Table 1c. Effect of T X P X N interaction on plant height of sorghum

Treatment combinations	Plant height (cm)			
	30 DAS	60 DAS	90 DAS	At harvest
Tillage (t) x Spacing (p) x NPK Levels (n)				
$t_1p_1n_1$	86.73	230.42	244.69	248.25
$t_1p_1n_2$	71.90	236.46	255.94	259.55
$t_1p_1n_3$	75.73	239.15	254.93	258.49
$t_1p_2n_1$	84.93	232.43	245.44	249.04
$t_1p_2n_2$	74.06	251.56	268.60	271.88
$t_1p_2n_3$	80.58	219.78	261.86	265.33
$t_2p_1n_1$	71.99	212.05	232.72	236.27
$t_2p_1n_2$	108.51	249.89	283.57	288.03
$t_2p_1n_3$	101.63	254.78	285.36	287.36
$t_2p_2n_1$	84.20	231.48	264.50	267.92
$t_2p_2n_2$	109.83	249.86	256.56	259.58
$t_2p_2n_3$	75.72	224.39	252.09	254.97
SEm (±)	6.66	11.82	7.50	7.64
CD (0.05)	NS	NS	21.999	22.402

canopy closure, leading to higher LAI. A higher LAI boosts the plant's photosynthetic capacity by maximizing the use of available light, enhancing growth. The application of higher fertility levels led to a significant increase in LAI, number of leaves and dry matter production. The underlying reason for this effect is the rapid cell division and elongation stimulated by higher fertility, resulting in an increase in dry

Table 2. Effect of tillage, spacing and nutrient management on number of leaves per plant of sorghum

Treatments	Number of leaves			
	30 DAS	60 DAS	90 DAS	At harvest
Tillage (t)				
t_1 (Zero tillage)	5.00	8.24	3.58	1.60
t_2 (Conventional tillage)	4.99	9.04	3.72	2.44
SEm (±)	0.11	0.15	0.14	0.11
CD (0.05)	NS	0.434	NS	0.323
Spacing (p)				
p_1 (45 cm x 15 cm)	4.80	8.32	3.17	1.84
p_2 (60 cm x 15 cm)	5.19	8.96	4.13	2.19
SEm (±)	0.13	0.15	0.14	0.11
CD (0.05)	0.333	0.434	0.422	0.323
Nutrient management(n)				
n_1 (45:25:25 kg NPK ha^{-1})	4.98	8.50	3.04	1.87
n_2 (50:25:75 kg NPK ha^{-1})	5.00	8.88	3.82	1.96
n_3 (50:25:50 kg NPK ha^{-1})	5.00	8.54	4.09	2.23
SEm (±)	0.14	0.18	0.18	0.14
CD (0.05)	NS	NS	0.517	NS

matter accumulation per unit time as fertility levels rise. These findings are consistent with the observations made by Gawai and Pawar (2006). Nutrient management influenced the days to 50 per cent flowering and a lesser number of days required for 50 per cent flowering (64.08 days) with a nutrient dose of 50:25:75 kg NPK ha^{-1} which was on par with NPK rate 50:25:50 kg NPK ha^{-1}. Nutrients when applied at a higher dose resulted in higher concentration and uptake of nutrients by plants which in turn led to greater synthesis of protein and earlier flower primordia development which would have ultimately resulted in earlier flowering (Patidar and Mali, 2004).

Sorghum grown under zero tillage resulted in significantly superior (8.18 t ha^{1}) dry matter production (DMP) at harvest. Plants grown with 45x15 cm spacing produced significantly superior DMP of 8.82 t ha^{1} at harvest. Application of NPK at rate of 50:25:75 kg NPK ha^{-1} resulted in statistically higher DMP (8.92 t ha^{-1}) at harvest. The combination of zero tillage with a 45x15 cm spacing (t_1p_1) resulted in significantly superior DMP (9.34 t ha^{-1}) at harvest. The treatment t_1n_2 i.e., zero tillage with a nutrient dose of 50:25:75 kg NPK ha^{-1} resulted in higher DMP (9.53 t ha^{-1}), which was on par with t_1n_3 (8.59 t ha^{-1}) at harvest. The combination of 45x15 cm spacing and a nutrient dose of 50:25:75 kg NPK ha^{-1} (p_1n_2) having the highest value (10.15 t ha^{-1}) which was comparable with p_1n_3 (9.27 t ha^{-1}) at harvest. Sorghum grown under zero tillage with a spacing of 45x15 cm and a nutrient dose of 50:25:50 kg NPK ha^{-1} resulted in significantly superior DMP (11.72 t ha^{-1}) which was comparable with $t_1p_1n_2$ (11.37 t ha^{-1}). Zero tillage may slow down early growth due to the lack of soil disturbance, it improves soil moisture retention and enhances the soil's organic matter content over time. These benefits become more significant in the later

Table 3a. Effect of tillage, spacing and nutrient management on leaf area index (LAI) of sorghum

Treatments	LAI		
	30 DAS	60 DAS	90 DAS
Tillage (t)			
t_1 (Zero tillage)	1.88	4.79	3.61
t_2 (Conventional tillage)	2.10	4.75	3.56
SEm (±)	0.05	0.11	0.07
CD (0.05)	0.138	NS	NS
Spacing (p)			
p_1 (45 cm x 15 cm)	2.32	5.40	3.99
p_2 (60 cm x 15 cm)	1.67	4.15	3.18
SEm (±)	0.05	0.11	0.07
CD (0.05)	0.138	0.313	0.216
Nutrient management(n)			
n_1 (45:25:25 kg NPK ha^{-1})	1.86	4.65	3.44
n_2 (50:25:75 kg NPK ha^{-1})	2.17	4.88	3.90
n_3 (50:25:50 kg NPK ha^{-1})	1.95	4.78	3.42
SEm (±)	0.06	0.13	0.09
CD (0.05)	0.169	NS	0.264

Table 3b. Interaction effects of tillage, spacing and nutrient management on leaf area index (LAI) of sorghum

Interactions	LAI		
	30 DAS	60 DAS	90 DAS
Tillage(t) x Spacing (p)			
t_1p_1	1.90	5.41	3.84
t_1p_2	1.87	4.16	3.38
t_2p_1	2.73	5.38	4.13
t_2p_2	1.46	4.13	2.98
SEm(±)	0.07	0.15	0.10
CD(0.05)	0.195	NS	0.305
Tillage(t) x NPK Levels(n)			
t_1n_1	1.99	4.91	3.54
t_1n_2	1.94	4.72	3.80
t_1n_3	1.73	4.75	3.50
t_2n_1	1.72	4.38	3.33
t_2n_2	2.40	5.06	4.00
t_2n_3	2.17	4.82	3.34
SEm(±)	0.08	0.18	0.13
CD(0.05)	0.238	NS	NS
Spacing(p) x NPK Levels(n)			
p_1n_1	2.00	5.17	3.76
p_1n_2	2.22	5.48	4.52
p_1n_3	2.72	5.54	3.69
p_2n_1	1.71	4.12	3.12
p_2n_2	2.12	4.29	3.27
p_2n_3	1.18	4.03	3.15
SEm(±)	0.08	0.18	0.13
CD(0.05)	0.238	NS	0.374

stages of sorghum growth, as improved soil structure leads to more stable moisture levels and greater long-term nutrient availability. As a result, dry matter production becomes higher in the later stages of growth under zero tillage. Additionally, reduced soil disturbance helps to preserve beneficial soil microorganisms that support nutrient cycling during the later stages.

The sorghum yield was significantly affected by tillage, spacing and nutrient management. Zero tillage treatment

Table 3c. Effect of t x p x n interaction on leaf area index (LAI) of sorghum

Treatment combinations	LAI		
	30 DAS	60 DAS	90 DAS
Tillage (t) x Spacing (p) x NPK Levels (n)			
$t_1P_1n_1$	1.91	5.43	4.03
$t_1P_1n_2$	1.48	5.26	3.91
$t_1P_1n_3$	2.32	5.55	3.59
$t_1P_2n_1$	2.07	4.38	3.06
$t_1P_2n_2$	2.40	4.17	3.68
$t_1p_2n_3$	1.14	3.94	3.40
$t_2p_1n_1$	2.09	4.92	3.48
$t_2p_1n_2$	2.97	5.70	5.13
$t_2P_1n_3$	3.13	5.52	3.79
$t_2P_2n_1$	1.35	3.86	3.19
$t_2P_2n_2$	1.83	4.41	2.86
$t_2P_2n_3$	1.22	4.12	2.90
SEm (±)	0.12	0.26	0.18
CD (0.05)	0.337	NS	0.529

Table 4a. Effect of tillage, spacing and nutrient management on grain yield, stover yield and harvest index of sorghum.

Treatments	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index	Dry matter production at harvest
Tillage (t)				
t_1 (Zero tillage)	3.28	6.48	0.33	8.18
t_2 (Conventional tillage)	2.42	5.51	0.31	7.27
SEm (±)	0.06	0.10	0.007	0.24
CD (0.05)	0.172	0.283	0.019	0.72
Spacing (p)				
p_1 (45 cm x 15 cm)	3.08	6.52	0.31	8.82
p_2 (60 cm x 15 cm)	2.62	5.46	0.34	6.63
SEm (±)	0.06	0.10	0.007	0.24
CD (0.05)	0.172	0.283	NS	0.72
Nutrient management(n)				
n_1 (45:25:25 kg NPK ha^{-1})	2.27	5.17	0.32	6.61
n_2 (50:25:75 kg NPK ha^{-1})	3.13	7.09	0.30	8.92
n_3 (50:25:50 kg NPK ha^{-1})	3.15	5.72	0.36	7.64
SEm (±)	0.07	0.12	0.008	0.30

resulted in grain yield (3.28 t ha^{-1}), stover yield of 6.48 t ha^{-1} and harvest index (0.33). Plants grown with a 45x15 cm spacing resulted in higher grain yield (3.08 t ha^{-1}) and stover yield (6.52 t ha^{-1}) whereas plants grown with a 60x15 cm spacing recorded higher harvest index (0.34). Application of nutrient dose of 50:25:50 kg NPK ha^{-1}recorded higher grain yield (3.15 t ha^{-1}) and harvest index (0.36) whereas nutrient dose of 50:25:75 kg NPK ha^{-1} resulted in highest stover yield of 7.09 t ha^{-1}. The t_1p_1 treatment (zero tillage and 45x15 cm spacing) produced the higher grain yield (3.96 t ha^{-1}) and stover yield (7.27 t ha^{-1}) whereas t_2p_2 treatment (conventional tillage and 60x15 cm spacing) shows the highest harvest index (0.35). The treatment t_1n_3 (zero tillage and 50:25:50kg NPK ha^{-1}) recorded the highest harvest index (0.39). The treatment t_1n_2 (zero tillage and 50:25:75kg NPKha^{-1}) produced the higher grain yield (4.00 t ha^{-1}) and stover yield (7.99 t ha^{-1}). p_1n_3 treatment (45 cm x 15 cm spacing and 50:25:50 kg NPK ha^{-1}) produced higher grain

Table 4b. Interaction effects of tillage, spacing and nutrient management on grain yield, stover yield and harvest index of sorghum.

Interactions	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index	Dry matter production at harvest
Tillage (t) x Spacing (p)				
t_1p_1	3.96	7.27	0.34	9.94
t_1p_2	2.60	5.69	0.33	6.43
t_2p_1	2.20	5.78	0.27	7.71
t_2p_2	2.65	5.23	0.35	6.83
SEm (±)	0.08	0.14	0.009	0.35
CD (0.05)	0.243	0.40	0.027	1.018
Tillage (t) x NPK Levels (n)				
t_1n_1	1.98	5.16	0.28	6.44
t_1n_2	4.00	7.99	0.33	9.53
t_1n_3	3.84	6.28	0.39	8.59
t_2n_1	2.55	5.18	0.35	6.79
t_2n_2	2.25	6.18	0.27	8.32
t_2n_3	2.46	5.16	0.32	6.70
SEm (±)	0.10	0.17	0.01	0.42
CD (0.05)	0.297	0.489	0.03	1.247
Spacing (p) x NPK Levels (n)				
p_1n_1	1.77	5.38	0.25	7.06
p_1n_2	3.45	7.34	0.30	10.15
p_1n_3	3.99	6.85	0.36	9.27
p_2n_1	2.76	4.96	0.38	6.17
p_2n_2	2.80	6.84	0.29	7.70
p_2n_3	2.30	4.58	0.35	6.02
SEm (±)	0.10	0.17	0.01	0.42
CD(0.05)	0.297	0.489	0.03	1.247

Table 4c. Effect of t x p x n interaction on grain yield, stover yield and harvest index of sorghum.

Treatment combination	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index	Dry matter production at harvest
Tillage(t) x Spacing(p) x NPK Levels (n)				
$t_1p_1n_1$	1.77	5.90	0.23	6.73
$t_1P_1n_2$	4.96	8.10	0.39	11.37
$t_1P_1n_3$	5.14	7.81	0.40	11.72
$t_1P_2n_1$	2.20	4.43	0.33	6.14
$t_1p_2n_2$	3.05	7.88	0.28	7.69
$t_1p_2n_3$	2.55	4.76	0.38	5.45
$t_2p_1n_1$	1.78	4.87	0.27	7.39
$t_2p_1n_2$	1.95	6.58	0.23	8.92
$t_2p_1n_3$	2.86	5.90	0.33	6.81
$t_2p_2n_1$	3.32	5.49	0.43	6.19
$t_2P_2n_2$	2.56	5.79	0.31	7.71
$t_2P_2n_3$	2.06	4.41	0.32	6.59
SEm (±)	0.14	0.24	0.02	0.60
CD (0.05)	0.42	0.692	0.05	1.763

yield (3.99 t ha^{-1}) whereas p_1n_2 treatment (45 cm x 15 cm spacing and 50:25:75 kg NPK ha^{-1}) produced highest stoveryield (7.34 t ha^{-1}) which was on par with p_1n_3 (6.85 t ha^{-1}). p_2n_1 treatment (60 cm x 15 cm spacing and 45:25:25 kg NPK ha^{-1}) produced highest harvest index (0.38) which was on par with p_1n_3 (0.36) and p_2n_3 (0.35). Sorghum grown under zero tillage with 45x15 cm spacing and 50:25:50 kg NPK ha^{-1} nutrient dose produced highest grain yield (5.14 t ha^{-1}) whereas Sorghum grown under zero tillage with 45x15 cm spacing and 50:25:75 kg NPK ha^{-1} nutrient dose produced highest stover yield (8.10 t ha^{-1}). Sorghum grown under conventional tillage with 60x15 cm spacing and nutrient dose of 45:25:25 kg NPK ha^{-1} produced highest harvest index (0.43). In zero tillage there will be better soil moisture retention, timely planting, and reduced soil disturbance that leads to enhanced yield components as a result of water conservation, better surface residue management, improved soil biological activity, and improved soil structure (Busari et al., 2015). The reduced disturbance of soil structure in zero tillage promotes better nutrient retention and availability, which can positively affect grain weight per panicle (Laxmi et al., 2007). Closer spacing may lead to better canopy coverage which enhances light interception and photosynthesis (Wang et al., 2023), also it improve water use efficiency by reducing evaporation of water from the soil surface and ensuring more water availability to plants (Ngidi et al., 2024) and also closer spacing can supress weed growth by shading the soil surface, reducing competition for resources and allowing sorghum plants to thrive (Nagesh Kumar et al., 2022). Higher N level (up to 120 kg N ha^{-1}) significantly increased grain yield, stover yield, and grain weight per panicle across various sorghum genotypes (Naik and Debbarma, 2022). Potassium is crucial for promoting optimal plant growth and it initiates various critical enzymes that play key roles in activities such as protein production, sugar movement, nitrogen and carbon metabolism, and photosynthesis, thereby making a substantial contribution to enhancing crop yields (Marschner, 2012).

Table 6. Effect of tillage, spacing, nutrient management and their interactionson net income and benefit-cost ratio

Treatment combination	Net income (₹ ha^{-1})	B:C ratio
$t_1p_1n_1$	11623	1.21
$t_1P_1n_2$	94263	2.65
$t_1P_1n_3$	98676	2.77
$t_1P_2n_1$	16070	1.30
$t_1P_2n_2$	47476	1.83
$t_1P_2n_3$	24426	1.44
$t_2p_1n_1$	4859	1.08
$t_2p_1n_2$	11208	1.18
$t_2p_1n_3$	31759	1.52
$t_2p_2n_1$	42667	1.72
$t_2P_2n_2$	22719	1.37
$t_2P_2n_3$	8909	1.15

The economic analysis revealed that, sorghum grown under zero tillage with 45x15 cm spacing and 50:25:50 kg NPK ha^{-1} nutrient doseresulted in higher net returns (98,676 ₹ ha^{-1}) and B:C ratio (2.77) followed by sorghum grown under zero tillage with 45x15 cm spacing and 50:25:75 kg NPK ha^{-1} nutrient dose with net income (₹ 94,263) and BCR

(2.65). Higher grain yield, stover yield and harvest index was recorded in zero tillage and low cost of cultivation for land preparation would have led to higher net income and benefit cost ratio under zero tillage (Chapke et al., 2017). Sorghum grown with a closer spacing 45 cm x 15 cm recorded higher grain yield and stover yield and led to higher net returns and benefit cost ratio (Kumar et al., 2012). Nutrient dose of 50:25:50 kg NPK ha^{-1} and 50:25:75 kg NPK ha^{-1} recorded higher grain yield and stover yield and considering the total cost of cultivation NPK ratio of 50:25:50 kg NPK ha^{-1} recorded higher net income and benefit cost ratio (Sumeriya et al., 2005).

Conclusion

Considering growth, yield and economics of cultivation, sorghum may be recommended for cultivation in summer rice fallows with zero tillage, spacing of 45 cm x 15 cm and application of 50:25:50 kg NPK ha^{-1} along with 5 t ha^{-1} of FYM.

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