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Effect of planting methods, *Mycorrhiza* and zinc fertilization on growth and grain yield of pearl millet (*Pennisetum glaucum*)

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) seasons of 2020 and 2021 at research farm of Swami Keshwanand Rajasthan Agriculture University, Bikaner, Rajasthan to study the effect of planting methods, *Mycorrhiza* and zinc fertilization on growth and productivity of pearl millet [*Pennisetum glaucum* (L) R.Br.] in hot arid region. The experiment comprised 24 treatments combination having 3 planting methods (S_1, flat bed; S_2, ridge and furrow; S_3, pit technique) and two *Mycorrhiza* level (M_0, control; M_1, 8 kg/ha *Mycorrhiza* basal) in main plot and 4 zinc fertilization practices (Z_0, control; Z_1, 0.5% $ZnSO_4$ two foliar spray; Z_2, zinc sulphate @10 kg/ha basal + 0.5% foliar spray and Z_3, zinc sulphate @20 kg/ha basal) in sub plots were laid out in split-plot design and replicated thrice. It may be inferred that in pearl millet pit planting technique (S_3), *Mycorrhiza* (M_1) + fertilized with zinc sulphate (Z_2) practice gave significantly higher growth parameters, viz. plant stand (141.20 thousand/ha), plant height (171.1 cm), dry matter accumulation, crop growth rate, relative growth rate, chlorophyll content (4.3 mg/g), root dry weight (9.8 g/plant) and number of green leaves/plant (13.9 no./plant), quality parameters, viz. protein content (12.5%) and protein yield (384 kg/ha) in grain, ash (12.1%) and fibre content (44.3%) in stover and grain yield (3.1 t/ha) as compared to all other treatment combinations on pooled basis. The findings emphasize the potential of this technique for enhancing pearl millet productivity and quality in hot arid regions.

Keywords: *Mycorrhiza*, Planting method, Pit, Pearl millet, Ridge and furrow, Zinc

Pearl millet [*Pennisetum glaucum* (L). R. Br.] commonly known as bajri or bajara, is renowned for its remarkable resilience to high temperatures and moisture stress during critical growth stages, setting it apart from other cereal crops (Bana *et al.* 2023). Its exceptional nutritional composition has earned it the nickname "nutri cereal." The edible portion of the grain contains approximately 12.4% moisture, 11.6% protein, 3–5% fat, 67% carbohydrates, 1.5–3% fiber, and 2.7% minerals (Sharma and Burark 2015). Pearl millet plays a vital role in arid regions, providing quick sustenance for impoverished communities. It is often cultivated by economically disadvantaged farmers who have limited access to technology or practice suboptimal farming methods (Ankit *et al.* 2023). This versatile crop covers 30 million ha in semi-arid tropical environments and is primarily produced in India and Africa (Bana *et al.* 2023), contributing to 93.2% of global production. India, in particular, dominates with 9.3 million ha under cultivation and an annual production of 8.3 million tonnes, averaging 1436 kg/ha (ICRISAT 2022). Key pearl millet cultivating states in India include Rajasthan, Uttar Pradesh, Haryana, Gujarat, and Maharashtra. Rajasthan alone covers 4.32 million ha, yielding 4.53 million tonnes with a productivity of 1049 kg/ha (Anonymous 2021). Efficient planting techniques are crucial for maximizing resource utilization and yield (Bamboriya *et al.* 2017a). Pit planting technology, inspired by its success in sugarcane cultivation, is being explored for various crops, including pearl millet. However, its advantages require further standardization. Traditional planting methods present challenges to yield improvement (Bamboriya *et al.* 2017b). Pit planting can boost pearl millet productivity, while *Mycorrhizal* fungi enhance nutrient uptake and soil stability by efficiently transporting phosphorus and forming symbiotic relationships with most plant species (Grover *et al.* 2022). Zinc deficiency in plants can hinder crop yield and quality, as zinc is essential for structural components and enzymatic cofactors in key biochemical pathways (Choudhary *et al.* 2014, Yogi *et al.* 2023). Foliar zinc application has shown promise in

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enhancing zinc uptake efficiency, as supported by previous studies (Ning *et al.* 2009).

MATERIALS AND METHODS

The experiment conducted during the rainy (*kharif*) seasons of 2020 and 2021 at research farm of Swami Keshwanand Rajasthan Agriculture University, Bikaner (28°4'21" North and 73°20'17" East, with an altitude of 235 mvamsl), Rajasthan. Bikaner falls under Agro-climatic zone XIV (Western Dry Region) of India. In 2020, the maximum and minimum temperatures ranged from 30.4 to 41.8°C, while in 2021, they ranged from 25.5 to 42.3°C. Relative humidity fluctuated from 19.7 to 91.9% in 2020 and 32.4 to 93.6 % in 2021. Rainfall during the *kharif* seasons was 287.4 mm in 2020 and 246 mm in 2021, with 14 and 15 rainy days, respectively. Evaporation from an open pan evaporimeter Class A was 126.8 mm in 2020 and 202.2 mm in 2021 during the crop growing period. Bright sunshine hours ranged from 4.0 to 9.9 and 3.4 to 10.4 hours, with wind velocities of 2.8 to 12.7 and 2.8 to 17.9 km/hr in 2020 and 2021, respectively. The potential evapotranspiration (PET) in this region typically ranges from 1500-2000 mm annually. The soil in the experimental field was loamy sand, low in organic carbon and available nitrogen, medium in available phosphorus, and rich in available potassium. It had an alkaline *p*H and a low electrical conductivity. The experiment followed a split plot design with 24 treatment combinations, replicated thrice, using plot sizes of 3.60 m × 4.50 m. Pearl millet variety MPMH-17 was used, initially sown in a nursery with a seed rate of 2 kg/ha, and then directly sown in the field at a rate of 4 kg/ha. Sowing in flat bed through the pora method and transplanting was done on 20 July 2020 and 29 July 2021, respectively. In flat bed seed sowing keep space between row to row and plant to plant (R × P) at 45 cm × 15 cm, ridge and furrow (R × P) at 60 cm × 22.5 cm and in pit technique (R × P) at 60 cm × 45 cm. Nearly three-week-old healthy seedlings were transplanted in experimental plots. Well decomposed FYM @9 t/ha was applied along with fertilizers (60 kg N: 40 kg P: 20 K). Half dose of nitrogen and full dose of phosphorus and potassium were applied as basal dose through urea, DAP and MOP just before sowing/treatment. The remaining half dose of nitrogen through urea was top dressed into two splits, first $1/4^{th}$ at 30 DAS and remaining $1/4^{th}$ dose at 50 DAS/DAT with rains/irrigation.

The biometric observation was recorded on five randomly selected plants from net plots of each treatment. Crop growth rate (CGR) was estimated using the formula reported by Brown (1984) and expressed as g/m^2/day. Relative growth rate (RGR) was calculated using the formula given by Radford (1967) and expressed as g/g/day.

Number of green leaves: The number of leaves per plant of the five plant randomly selected in each plot was counted at 60 DAS/DAT and average was worked out for further study.

Root dry weight: Root dry weight was observed from taken 5 randomly tagged plant root dug out from each plot followed by washing in water, airdrying and then oven drying. Weight of dry plant root was recorded individually.

RESULTS AND DISCUSSION

The study revealed significant differences in plant height among planting techniques. Pit planting resulted in the tallest pearl millet plants (135.4 cm at 40 DAS/T and 171.1 cm at harvest), followed by ridge and furrow (107.4 cm and 161.4 cm) and flat bed sowing (86.9 cm and 142.8 cm) when analyzing pooled data. Application of *Mycorrhiza* treatment led to increased plant height, with taller plants (113.9 cm at 40 DAS/T and 162.7 cm at harvest) compared to the control in both 2020 and 2021, and on pooled data (Fig 1). Regarding zinc application, the Z_2 treatment resulted in the tallest plants at harvest (161.4 cm), on par with Z_3, both significantly exceeding the control. Table 1 showed that pearl millet transplanting in pits (S_3) yielded significantly higher Crop growth rate (CGR) values (21.2 and 21.7 g/m^2/day) and Relative growth rate (RGR) (6.01 and 6.56 g/g/day) at 20–40 and 60 DAS/T to harvest stages, surpassing ridge and furrow and flat-bed sowing. CGR was notably higher with *Mycorrhiza* treatment between 20–40 DAS/T, while RGR was maximum under *Mycorrhiza* treatment across growth stages. CGR at 20–40 DAS/T was highest with Z_3, while CGR at 60 DAS/T to harvest was statistically superior with Z_2. The highest relative growth rate at 20-40 DAS/T was found with Z_3, while at 60 DAS/T to harvest, it was with Z_2, both on pooled data. The pivotal role of planting methods in influencing pearl millet (*Pennisetum glaucum*) growth attributes was corroborated by Deshmukh and Patel (2013) in Navsari, Gujarat. Their study highlighted planting techniques' profound impact on plant height, attributing the increased growth with pit techniques to lower plant density, improved light penetration, and efficient soil moisture and nutrient utilization. These findings align with those of Fatondji (2002), who favored zai pit over flat-bed planting for millet growth. Additionally, Jayne and Quigley (2014) emphasized the efficiency of AM fungi in enhancing plant growth and arbuscular formation. Kanta (2019) reported increased growth parameters in *Mycorrhiza*-treated pearl millet, while Bamboriya *et al.* (2017a) observed improved growth rates in pearl millet with enhanced planting methods. Maqsood *et al.* (2006) and Fatondji *et al.* (2006) highlighted the benefits of pit techniques in nutrient application near roots, supporting crop growth and mitigating dry spells.

The mean maximum number of green leaves per plant (13.9/plant) was recorded with pit technique (S_3) which was significantly higher by 27.1 and 67.5%, over ridge and bed and flat-bed method, respectively on pooled basis. On pooled data, 2020 and 2021 basis maximum no. of green leaves was recorded under basal application of *Mycorrhiza* M_1 treatment (12.4, 11.5 and 13.3/plant) which was significantly higher over control M_0 treatment by 27.7, 26.5 and 28.2%, respectively. The highest number of green leaves per plant was recorded with Z_2 treatment (11.8/plant) and lowest number of green leaves/plant (10)

Table 1 Effect of planting technique, *Mycorrhiza* and zinc fertilization on crop growth rate and relative growth rate at 20–40 DAS/DAT and 60-harvest of pearl millet

Treatment	CGR at 20–40 DAS (g/m^2/day)			CGR at 60-harvest (g/m^2/day)			RGR at 20–40 DAS (g/g/day)			RGR at 60-harvest (g/g/day)		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Sowing method												
S_1	9.8	11.6	10.7	10.1	16.0	13.1	5.2	5.4	5.3	6.0	6.1	6.0
S_2	15.8	19.0	17.4	15.6	20.7	18.1	5.8	5.9	5.8	6.3	6.5	6.4
S_3	19.3	23.1	21.2	18.5	24.9	21.7	5.9	6.1	6.0	6.5	6.6	6.6
SEm±	0.70	0.65	0.52	0.94	1.31	0.86	0.04	0.03	0.03	0.03	0.05	0.01
CD (P=0.05)	2.20	2.06	1.52	2.96	4.12	2.54	0.13	0.1	0.09	0.1	0.16	0.03
Mycorrhiza												
M_0	11.2	15.1	13.2	14.1	19.6	16.9	5.4	5.7	5.5	6.2	6.3	6.2
M_1	18.7	20.7	19.7	15.4	21.4	18.4	5.9	5.9	5.9	6.4	6.5	6.4
SEm±	0.57	0.53	0.42	0.77	1.07	0.7	0.0	0.0	0.0	0.0	0.0	0.0
CD (P=0.05)	1.80	1.68	1.25	NS	NS	NS	0.11	0.08	0.08	0.09	0.13	0.03
Zinc fertilization												
Z_0	13.3	14.8	14.1	8.9	14.5	11.7	5.5	5.6	5.6	6.1	6.2	6.2
Z_1	14.7	16.1	15.4	13.6	19.4	16.5	5.6	5.7	5.6	6.2	6.4	6.3
Z_2	15.9	19.6	17.8	18.8	24.6	21.7	5.7	5.9	5.8	6.4	6.5	6.4
Z_3	16.0	21.0	18.5	17.8	23.6	20.7	5.7	6.0	5.8	6.4	6.5	6.4
SEm±	0.19	0.19	0.14	0.75	0.76	0.53	0.02	0.01	0.01	0.05	0.05	0.01
CD (P=0.05)	0.56	0.54	0.38	2.15	2.18	1.49	0.05	0.04	0.03	0.15	0.15	0.3

Treatment details are given under Materials and Methods.

recorded with Z_0 (control) followed by Z_1 (11.4) and Z_3 (11.3) on pooled data basis. The highest leaf area (2785.6 cm^2) and root dry weight (9.8 g) was obtained maximum through pit planting technique during both years and on pooled data basis. *Mycorrhiza* (M_1) and zinc fertilization (Z_2) also play a vital role in increasing leaf area across in both season and pooled data basis (Table 2). *Mycorrhiza* inoculation significantly alters the growth and biochemical composition of host plants and soil. *Mycorrhizal* root systems can expand the root's absorbing area by 10 to 100 times, greatly enhancing the plant's ability to utilize soil resources. Jayne and Quigley (2014) found that AM fungi were particularly effective in increasing plant growth, leaf area, and active arbuscular formation. Studies by Tarafdar *et al.* (2014) and Dadhich and Gupta (2004) also demonstrated positive effects of zinc applications on root length, leaf number, leaf area, and overall growth parameters in pearl millet.

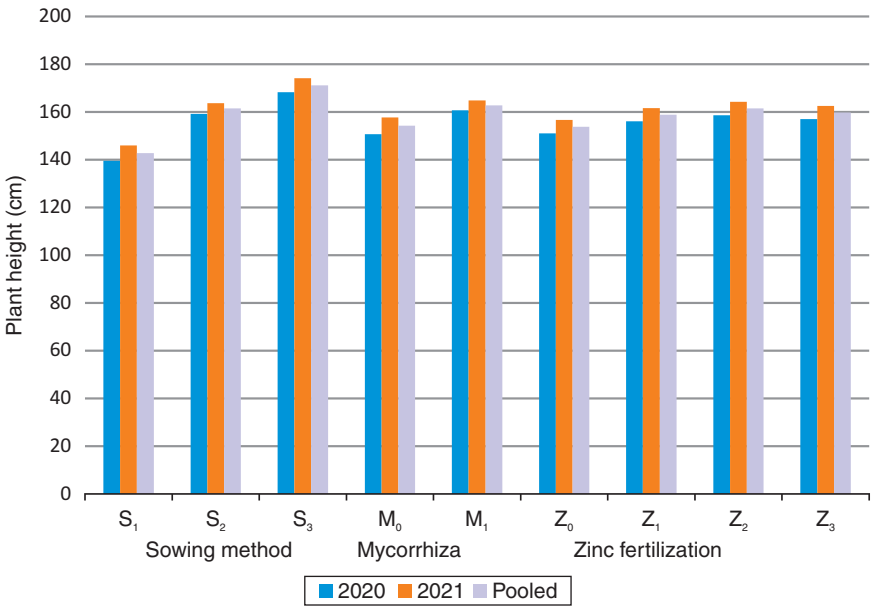

Fig 1 Effect of planting technique, *Mycorrhiza* and zinc fertilization on plant height at harvest.

The results showed that pit technique (S_3) recorded significantly higher grain yield (3.1 t/ha) over ridge and furrow and flat bed sowing method on pooled data basis (Table 3). Transplanting at ridge and furrow (S_2) technique gave significantly higher grain yield (2.4 t/ha) over flat bed seed sowing (1.6 t/ha) on pooled basis. The highest grain yield of 3.1 t/ha recorded by S_3 (pit technique) was higher by 27.9 and 95.7% over S_2 and S_1 respectively. The highest grain yield was realized in the treatment M_1 (2.6 t/ha), which was statistically superior over no *Mycorrhiza* control practice (M_0) on pooled analysis basis. The grain

Table 2 Effect of planting technique, *Mycorrhiza* and zinc fertilization on green leaves, leaf area and root dry weight of pearl millet

Treatment	Green leaves (Nos/plant)			Leaf area (cm^2/plant)			Root dry weight (g/plant)		
	2020	2021	2020	2020	2020	Pooled	2020	2021	Pooled
Sowing method									
S_1	7.5	9.0	8.3	1377.4	1569.4	1473.4	6.0	6.6	6.3
S_2	10.4	11.4	10.9	2135.2	2242.2	2188.7	8.2	9.3	8.8
S_3	12.9	14.9	13.9	2745.6	2825.6	2785.6	9.4	10.2	9.8
SEm±	0.40	0.44	0.09	70.71	79.08	57.24	0.14	0.16	0.11
CD (P=0.05)	1.27	1.38	0.24	222.80	249.18	169.19	0.44	0.51	0.32
Mycorrhiza									
M_0	10.3	9.7	1849.1	1987.1	1918.1	7.5	7.7	7.6	10.3
M_1	13.3	12.4	2323.1	2437.7	2380.4	8.2	9.7	8.9	13.3
SEm±	0.36	0.07	57.73	64.57	46.74	0.11	0.13	0.09	0.36
CD (P=0.05)	1.13	0.20	181.91	203.45	138.13	0.36	0.41	0.25	1.13
Zinc fertilization									
Z_0	10.7	10.0	1875.0	2001.3	1938.2	7.7	8.5	8.1	10.7
Z_1	11.8	11.0	2087.9	2214.3	2151.1	7.8	8.7	8.3	11.8
Z_2	12.6	11.8	2243.3	2369.7	2306.5	8.0	8.9	8.4	12.6
Z_3	12.0	11.3	2138.1	2264.4	2201.2	7.9	8.7	8.3	12.0
SEm±	0.15	0.10	32.80	36.23	24.44	0.07	0.07	0.05	0.15
CD (P=0.05)	0.42	0.28	94.06	103.92	68.17	0.19	0.20	0.14	0.42

Treatment details are given under Materials and Methods.

Table 3 Effect of planting technique, *Mycorrhiza* and zinc fertilization on grain yield and economics of pearl millet

Treatment	Grain yield (t/ha)			Net returns (₹/ha)			B:C		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Sowing method									
S_1	1.5	1.7	1.6	32653	44965	38809	2.21	2.63	2.42
S_2	2.1	2.7	2.4	47379	66227	56803	2.38	2.90	2.64
S_3	2.7	3.4	3.1	56916	79857	68386	2.36	2.81	2.59
SEm±	0.64	0.90	0.60	1083.9	1680.9	509.3	0.04	0.05	0.02
CD (P=0.05)	2.01	2.83	1.75	3415.5	5296.6	1435.3	0.13	0.14	0.06
Mycorrhiza									
M_0	1.9	2.4	2.1	38167	57312	47739	2.12	2.63	2.38
M_1	2.3	2.8	2.6	53132	70054	61593	2.51	2.93	2.72
SEm±	0.52	0.73	0.49	885.0	1372.4	415.8	0.03	0.04	0.01
CD (P=0.05)	1.64	2.31	1.44	2788.7	4324.6	1172.2	0.11	0.12	0.04
Zinc fertilization									
Z_0	1.5	2.0	1.7	30727	47874	39301	1.88	2.35	2.11
Z_1	2.0	2.5	2.3	42635	60576	51606	2.22	2.68	2.45
Z_2	2.5	3.0	2.8	56346	74879	65612	2.64	3.10	2.87
Z_3	2.4	2.9	2.6	52889	71404	62146	2.52	2.99	2.76
SEm±	0.24	0.37	0.22	739.8	914.2	588.0	0.02	0.03	0.02
CD (P=0.05)	0.68	1.06	0.62	2121.9	2622.2	16587.8	0.07	0.08	0.05

Treatment details are given under Materials and Methods.

yield of Z_2 treatment (2.8 t/ha) was significantly higher by 4.5, 22.1 and 59.5 % over Z_3, Z_1 and Z_0, treatments, respectively on pooled data basis. The maximum net returns of 68386 ₹/ha were accrued in S_3 followed by S_2 (56803 ₹/ha), then S_1 (38809 ₹/ha) however, the first two named treatment S_3 and S_2 registered statistically superiority over flat bed (S_1) on pooled data basis (Table 3). The highest net return of 53132, 70054 and 61593 ₹/ha obtained with *Mycorrhiza* application @8 kg/ha (M_1) during 2020, 2021 and on pooled data basis which were significantly higher by 39.2, 22.2 and 29%, respectively over no *Mycorrhiza* control. The highest net returns of 56346, 74879 and 65612 ₹/ha obtained with Z_2 zinc fertilization during 2020, 2021 and pooled data basis. Result exhibit that ridge and furrow planting technique (S_2) was the maximum benefit cost ratio (2.38, 2.90 and 2.64) which was closely at par with pit planting technique S_3 (2.36, 2.81 and 2.58) during 2020, 2021 and on pooled data basis. Further, it was noticed pearl millet planting by ridge and furrow and pit technique, both these were significantly superior over flat bed sowing (S_1) to the tune of 9.1 and 7% on pooled basis, respectively. The highest benefit cost ratio was obtained with *Mycorrhiza* @8 kg/ha (2.51, 2.93 and 2.72) treatment with respective increase of 14.3% on pooled data basis over no *Mycorrhiza* control (M_0). The benefit cost ratio of pearl millet was the highest with Z_2 (2.87) followed by Z_3 (2.76) and Z_1 (2.45). Kumar *et al.* (2022) found that transplanting four plants per pit resulted in the highest pearl millet grain yield (3086 kg/ha), significantly surpassing ridge and furrow and direct seeding methods in Rajasthan's arid region. Ehsanullah *et al.* (2017) observed increased cotton yield attributes with pit planting. Pal and Pandey (2017) reported enhanced grain yield and biomass in pearl millet with AM fungi inoculation, along with improved plant height, chlorophyll content, and *mycorrhizal*-root colonization. Similarly, studies by Shekhawat and Kumawat (2017). Pit planting yielded the highest net return, while ridge and furrow had a favourable B: C ratio due to lower costs, echoing results from Ehsanulllah *et al.* (2017) in cotton.

Based above results it can be concluded that pit technique (S_3) helps to get higher plant height, maximum grain yield and net returns in arid environmental conditions. Further growth parameters, viz. plant height, No. of green leaves, leaf area, crop growth rate, relative growth rate at different intervals and grain yield also significantly increase with fertilized *Mycorrhiza* (M_1) + zinc dose @10 kg /ha + 0.5% foliar spray at 45 DAS/T (Z_2) compared to rest of treatments during both years and on pooled data basis. The B:C ratio was maximum with ridge and furrow planting method (2.64) and it was at par with pit planting technique (2.59).

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