



Effect of Methods of Establishment and Zinc Management on Growth and Yield of Rice (*Oryza sativa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The field experiment was conducted at Shradhay Bhagwati Singh Agriculture Research Farm (Hajipur), Chandra Bhanu Gupta Krishi Snatkottar Mahavidyalaya, B.K.T., Lucknow (Uttar Pradesh) during *Kharif* (rainy) season in 2023-24. The treatment consisted of three methods of establishment (M1 – Direct seeding in lines after pre-irrigation, M2 -Broadcast of sprouted seed on puddled soil, M3 – System of Rice intensification (SRI) of (25 x 25cm) 12 days old seedling.) and five Zinc management practices (Zn0- Without zinc (control), Zn1- Zinc Sulphate ZnSO₄@20kg ha⁻¹ (Basal), Zn2- Foliar spray of Zn@0.5% at tillering and panicle initiation stage, Zn3- Seedling dipping in 2% ZnSO₄+ 2 Foliar of Zn@0.5% at tillering and Panicle stage, Zn4- Seedling dipping in 2 % ZnSO₄

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solution+ Foliar spray of Zn@0.2% at tillering and panicle initiation stage) were tested in split-plot design with 3 replications. The Experimental site was silty loam having medium organic carbon (0.70%) and available nitrogen (270 kg ha⁻¹), phosphorous (27 kg ha⁻¹) and Potassium (262 kg ha⁻¹). All the growth parameters, yield attributes, yield, Zinc content and uptake of Zn into grains and straw, were increased significantly with SRI method (M3) followed by direct seeding in Lines after pre-irrigation (M2). Amongst zinc management, all the growth parameters and yield attributes of rice were maximum under Seedling dipping in 2% ZnSO₄+ 2 Foliar of Zn@0.5% at tillering and panicle initiation stage, followed by Seedling dipping in 2 % ZnSO₄ solution+ Foliar spray of Zn@0.2% at tillering and panicle initiation stage the maximum gross income of Rs 158938.18 ha⁻¹ was accrued with (SRI method + T4) treatment combination. However, a combination of SRI method along with T3 treatment accrued the maximum net profit of Rs 107981.21 ha⁻¹ and benefit: cost ratio of 2.08 which was followed by a combination of SRI method along with T4 with net income of Rs 107234.99 ha⁻¹ and benefit cost ratio of 2.07.

Keywords: Zinc management; aquatic condition; food crop; organic carbon.

1. INTRODUCTION

“Rice (*Oryza sativa* L.) belongs to family Poaceae (Gramineae) and is a most important staple food crop in India as well as in the world. It is the major source of calories for 40 percent of the world population” [1]. “It is a most important cereal crop grown under aquatic condition and mostly under submergence or variable ponding conditions. The slogan RICE IS LIFE is especially relevant in India as this crop plays a vital role in national food security and is the livelihood of millions of rural households. It is a high-caloric diet, consisting of 75% starch, 6-7% Protein, 2-2.5% fat, 0.8% cellulose and 5-9% ash. Therefore, it is used as a staple food crop and is eaten as cooked rice and is used in various preparations and has commercial and industrial value. At the end of fiscal year 2021, India had the largest acreage under rice of 45.0 million ha with production of 120 million tonnes and average productivity of about 2.7 thousand kg ha⁻¹. In addition to having the greatest rice harvest area, India was the leading rice exporter in the fiscal year 2022–2023. 18.75 million metric tonnes of rice were exported from India at that time. In India rice is grown over an area of about 46.37 million ha which produces 130.83 million tonnes with an average productivity of 2809 kg ha⁻¹ [2].

“Different methods of crop establishment viz. conventional transplanting, direct Seeding, drum seeded under puddled condition and broadcasting of sprouted seed under puddled condition are adopted for the cultivation of rice. Method of crop establishment Largely affects the performance of rice as a result of its growth and development. The Scarcity of water for agriculture production is becoming a major

concern in many Countries, particularly in world's leading rice-producing countries like China and India” [3].

Sommer and **Lipman** as early as 1926 first recognized zinc as an essential plant nutrient. The deficiency of zinc in India was first reported by Nene [4]. “Zinc is an imperative micronutrient and has a number of essential functions in the plant system such as the maintenance of structural and functional integrity of biological membranes and facilitation of protein synthesis and gene expression. Zinc is one of the most important micronutrients essential for plant growth especially for rice grown under submerged condition. Zinc deficiency continues to be one of the key factors in determining rice production in several parts of the country” [3]. Zn deficiency is the most wide spread micronutrient disorder in lowland rice and application of Zn along with NPK fertilizer increases the grain yield dramatically in most cases [5], (Singh *et al.*, 2011).

2. MATERIALS AND METHODS

A field experiment was conducted at the Shradhay Bhagwati Singh Agriculture Research Farm (Hajipur), Chandra Bhanu Gupta Krishi Snatkottar Mahavidyalaya, B.K.T., Lucknow (Uttar Pradesh) during *Kharif* season 2023. The soil of experimental field was silty loam texture, slightly alkaline in reaction (8.00pH), medium in organic carbon (0.70%), nitrogen (270 kg ha⁻¹), phosphorous (27 kg ha⁻¹) and potassium (262 kg ha⁻¹).

The Experiment was laid out in Split Plot Design with 15 treatment combination. The main plot treatments consisted of three methods

establishment (M₁ - Direct seeding in Lines after pre-irrigation, M₂ - Broadcast of sprouted seed on puddled soil, M₃ - System of Rice intensification (SRI) of (25 x 25cm) 12 days old seedling.) and five Zinc management practices (Zn₀- Without zinc (control), Zn₁- Zinc Sulphate ZnSO₄@20kg ha⁻¹ (Basal), Zn₂- Foliar spray of Zn@0.5% at tillering and panicle initiation stage, Zn₃- Seedling dipping in 2% ZnSO₄+ 2 Foliar of Zn@0.5% at tillering and Panicle stage, Zn₄- Seedling dipping in 2 % ZnSO₄ solution+ Foliar spray of Zn@0.2% at tillering and panicle initiation stage) in sun plot. In addition to this a uniform dose of 120 kg N, 60 kg P₂O₅, and 40 kg K₂O ha⁻¹ was applied in all the plots through urea, DAP and MOP, respectively. Half of total N and full dose of P₂O₅, Zinc and K₂O were applied as basal. While, the rest amount of the nitrogen was top-dressed in two splits, first at 30 days (tillering stage) and second at 65 days (panicle initiation stage) respectively. 'SHIATS DHAN - 1' non aromatic rice seedlings of 12 days in SRI method transplanted keeping 1 seedling hill⁻¹ at 25x25cm spacing in SRI method, Direct seeding in lines at 20 cm apart, and Broadcast of sprouted seeds in puddled soil. The crop was harvested in ten October. The other agronomic practices were followed as per standard recommendations. The direct seeding of sprouted seeds, and broadcast of sprouted seeds in puddled soil treatment was done on 4 June 2023 using 60 kg and 80 kg ha⁻¹ seed, respectively. The sowing of seeds in nursery for seedlings raising was done on the same day i.e. 4 June 2023 using 6 kg ha⁻¹ seed. 12 days old seedling were transplanted on 16 June 2023 in well prepared puddled field using one seedling hill⁻¹. Pre-emergence spray of pretilachlor @ 1.5 litre ha⁻¹ was done 2-3 days after sowing/transplanting, The crop was irrigated as and when required irrigation. All improved cultural practices were used to raise the crop. The data on plant height and tillers were recorded from the area already marked and tagged. Sample for dry mater accumulation was recorded by cutting of plants 10 cm row length in direct seeded treatment and in SRI method, 4 hills were randomly selected from each plot, and the plants were cut close to the ground put in the paper bags. The samples for dry matter accumulation were first sun dried and then kept in hot air oven 72° C±0.5° C for 48 hours till the constant weight was achieved. Yield attributes were recorded from 5 spikes selected randomly from each plot at harvest of crop. Grain and straw yield of rice were recorded at harvest, and harvest index (%) was calculated as grain yield divided by total biological yield and multiplied by

hundred. The soil and plant analysis was done by using Standard laboratory methods. The uptake of zinc was calculated by multiply zinc content in grain and straw yield. Economics of different treatments was worked out on the basis of prevailing market prices.

2.1 Statistical Analysis

The observations recorded during the course of investigation were tabulated analyzed statistically to draw a valid conclusion. The data were analyzed as per the standard procedure for "Analysis of Variance" (ANOVA) as described by Gomez and Gomez (1984). The significance of treatment was tested by 'F' test (variance ratio). Standard error of mean was computed in all cases. The difference in the treatment mean were tested by using Least Significant Difference (LSD) at 5% level of probability where 'F' test showed significant

3. RESULTS AND DISCUSSION

3.1 Growth Attributes

A perusal of data presented in Table 1 revealed that plant height (cm), number of tillers (m⁻²), leaf area index and dry matter accumulation (q ha⁻¹) of rice were affected significantly due to different methods of crop establishments and Zinc management. Crop transplanted with 12 days old seedling recorded significantly tallest plant (129.67cm), higher number of tillers (524.13 m⁻²), dry matter accumulation (129.85 q ha⁻¹) and leaf area index (5.46) over rest methods of establishment. The maximum growth parameter under SRI methods was mainly because of availability of optimum space, more light inception and higher availability of plant nutrients and it's uptake by crop improved the metabolic activities and higher meristematic activity enhanced the cell multiplication and cell enlargement and finally higher growth in terms of plant height, dry matter accumulation, no. of tillers and leaf area index as compared to higher intra row competition leading to poor availability of nutrients and poor metabolic activity in direct seeded crop. Similar finding was obtained by Ghoneim [6].

The highest plant height (cm), no. of tillers m⁻², dry matter accumulation m⁻² and leaf area index was recorded when rice seedling were dipped in 2% ZnSO₄ solution + 2 Foliar spray of Zn@0.5% at tillering and panical initiation stage at all stage of crop growth which was followed by seed

dipping in 2% ZnSO₄ solution + 2 Foliar spray of Zn@0.2% at tillering and panical initiation stage. The smallest growth parameter was registered with no zinc application (control) treatment at all stages of crop growth.

3.2 Yield Attributes and Yield Studies

The maximum values of yield attributes like effective panicle (m²), panicle length (cm), panicle weight (gm), number of grains panicle⁻¹ and test weight (g) were recorded with transplanting of rice seedling by SRI method followed by direct seeding in lines at 20 cm apart. Significantly the maximum grain yield (q ha⁻¹), straw yield (q ha⁻¹), biological yield (q ha⁻¹) and harvest index (%) was obtained with transplanting of rice seedling by SRI method followed by to direct seeded rice at 20 cm apart. The lowest grain yield (q ha⁻¹), straw yield (q ha⁻¹), biological yield (q ha⁻¹) and harvest index (%) was recorded with broadcast of sprouted seeds in puddled soil.

Crop fertilized seed dipping in 2% ZnSO₄ solution + 2 Foliar spray of Zn@0.5% at tillering and panical initiation stage recorded significantly the maximum values of yield attribute like effective panicle (m²), panicle length (cm), panicle weight (g), number of grains panicle⁻¹ and test weight (g) and maximum value of grain yield (q ha⁻¹), straw yield (q ha⁻¹), biological yield (q ha⁻¹) and harvest index (%). followed by seed dipping in 2% ZnSO₄ solution + 2 Foliar spray of Zn@0.2% at tillering and panical initiation stage. Significantly the lowest value of all yield attributes was registered with No zinc application (control) treatment.

Maximum value of all yield attributes and yield was found under transplanting of 12 days old seedling but being at par with direct seeding in lines and significantly superior to broadcast of sprouted seed. This was mainly due to the facts that the transplanted crop had the higher tillering ability as compared to direct seeded crop and thus, recorded profuse growth in terms of tillers m², more leaf area, higher dry matter production which enhanced the synthesis of higher photosynthates and its translocation to reproductive parts of crop (sink) enhance the all yield attributes. Similar higher yield attributes and yield with transplanted crop was reported by Ghasal et al. [7], Kumhar et al. [8] and Kumar et al. [9]. Significantly higher grain and straw yield with transplanted crop was mainly attributed to higher growth and yield attributes.

3.3 Development Studies

Days taken to 50% flowering: The data on number of days to 50% flowering of rice as influenced by method of establishment and zinc management are presented in Table 4.

Number of days to 50% flowering difference significantly due to methods of establishment and zinc management. SRI (M₃) took significantly more number of days to flowering (94.06 days) closely followed by direct seedling in line after pre- irrigation (M₂) 85.86 while broadcast of sprouted seeds in puddled soil took lesser days (77.60 days) to flowering. This was because of optimum nutrient supply to crop which increased the crop space.

Turing to the effect of zinc management on days taken to 50 % flowering seedling dipping 2 % zinc solution + foliar spray of zinc @0.5% at tillering and panical initiation stage (82.55 days) recorded significantly lesser days followed by seedling dipping in 2% zinc sulphate solution + foliar spray of zinc @0.2% at tillering and panicle initiation stage (84.22 days).the data further revealed that foliar spray of zinc @0.5% at tillering and panicle initiation stage T₃ was found statistically superior over ZnSO₄ applied @20 kg ha⁻¹ as basal. Crop without zinc recorded significantly late flowering (88.88 days). The higher no of days taken to 50 % flowering under (T₃) was due to continuous supply of nutrient to plant which delayed the flowering.

Days taken to maturity: The data on number of days taken to maturity of rice as influenced by method of establishment and zinc management are presented in Tables 4, 6.

Days taken to maturity difference significantly due to establishment of establishment and zinc management. SRI (M₃) took significantly more number of days to maturity (114.46 days) closely followed by direct seedling in line after pre-irrigation (M₂-111 days) while broadcast of sprouted seeds in puddled soil took lesser days (104.46 days) to maturity. The higher availability of nutrient under SRI delayed the maturity due to late senescence in plant.

Turing to the effect of zinc management on days taken to maturity seedling dipping 2 % zinc solution + foliar spray of zinc @0.5% at tillering and panicle initiation stage (108 days) recorded significantly lesser days followed by seedling dipping in 2% zinc sulphate solution + foliar

Table 1. Growth attributes of rice as affected by different methods of establishment and zinc management at different stages of crop

Treatment	DAS/DAT			
	Plant height (At harvest)	No. of tillers (At harvest)	Dry matter accumulation (At harvest)	Leaf area index (90 days)
Methods of establishment				
M ₁ -Direct seedling in lines after pre-irrigation	115.6	427.53	100.51	5.31
M ₂ -Broadcast of sprouted seeds in puddle soil	103.46	366.30	82.37	5.05
M ₃ -System of rice intensification (SRI) at (25×25) with 12 days old seedling	129.67	524.13	129.85	5.46
SE(m)±	0.22	0.95	0.059	0.003
C.D(P=0.05)	0.98	3.86	0.236	0.011
Zinc management				
T ₀ - Without zinc (control)	114.80	426.44	103.24	5.18
T ₁ - Zinc sulphate ZnSO ₄ @20 kg ha ⁻¹	116.61	432.77	104.95	5.23
T ₂ - Foliar spray of Zn@0.5% at tillering and panicle initiation stage	112.43	438.66	105.56	5.28
T ₃ - Seedling dipping in 2% ZnSO ₄ solution + Foliar spray of Zn@0.5% at tillering and panicle initiation stage	119.58	453.66	107.90	5.36
T ₄ -Seedlingdipping in 2% ZnSO ₄ solution + Foliar spray of Zn@0.2% at tillering and panicle initiation stage	118.98	445.0	106.23	5.32
SE(m)±	0.51	0.86	0.098	0.003
C.D(P=0.05)	0.83	2.52	0.287	0.011

Table 2. Yield attributes of rice as affected by methods of establishment and Zinc management

Treatment	Effective panicle m⁻²	Panicle length (cm)	Weight of panicle (gm)	Grain panicle⁻¹	Grain weight Panicle⁻¹	1000 grain weight
Methods of Establishment						
M₁ Direct seedling in line after pre-irrigation	425.60	22.83	4.28	151.93	2.77	18.73
M₂ Broadcast of sprouted seeds in puddled soil	361.86	20.01	3.49	119.80	2.12	17.77
M₃ System of rice intensification (SRI) at (25x25 cm) with 12 days old seedling	521.80	24.60	5.62	171.33	3.35	19.64
SEM±	0.41	0.04	0.01	0.46	0.03	0.01
C. D. =(P=0.05)	2.06	0.16	0.07	1.88	0.13	0.07
Zinc Management						
T₀ -Without zinc (control)	425.52	21.67	4.02	136.66	2.52	18.39
T₁ - Zinc sulphate ZnSO ₄ @20 kg ha ⁻¹	431.88	22.02	4.23	142.77	2.67	18.62
T₂ –Foliar spray of Zn@0.5% at tillering and panicle initiation stage	432.67	22.42	4.54	147.66	2.78	18.74
T₃ - Seedling dipping in 2% ZnSO ₄ solution + 2 foliar spray of Zn@0.5% at tillering and panicle initiation stage	450.66	23.36	4.81	158.44	3.00	18.98
T₄ - Seedling dipping in 2% ZnSO ₄ solution + foliar spray of 0.2%Zn at panicle initiation stage.	441.7	22.93	4.72	152.88	2.77	18.84
SEM±	0.40	0.04	0.01	0.69	0.01	0.05
C. D. =(P=0.05)	2.571	0.13	0.04	2.03	0.05	0.01

Table 3. Yield studies of rice as affected by different methods of establishment and zinc management

Treatment	Grain yield (qt/ha)	Straw yield (qt/ha)	Total biological yield (qt/ha)	Harvest Index (%)
Methods of establishment				
M₁ - Direct seedling in lines after pre-irrigation	40.72	60.18	100.88	40.35
M₂ - Broadcast of sprouted seeds in puddled soil.	31.55	51.16	82.72	38.12
M₃ - System of rice intensification (SRI) at (25x25cm) with 12 days old seedling	57.93	77.60	135.50	42.74
SE(m)±	0.07	0.07	0.02	0.07
C.D(P=0.05)	0.30	0.30	0.09	0.29
Zinc Management				
T₀ - Without zinc (control)	42.01	76.33	103.47	40.14
T₁ - Zinc sulphate ZnSO ₄ @20 kg ha ⁻¹ (Basal)	42.86	76.93	105.30	40.28
T₂ - Foliar spray of Zn@0.5% at tillering and panicle initiation stage.	43.47	77.66	106.50	40.44
T₃ - Seedling dipping in 2% ZnSO ₄ solution + Foliar spray of Zn@0.5% at tillering and panicle initiation stage	44.56	78.76	108.80	40.62
T₄ - Seedling dipping in 2% ZnSO ₄ solution + foliar spray of Zn@0.2% at tillering and panicle initiation stage	44.08	78.30	107.77	40.54
SE(m)±	0.07	0.06	0.10	0.06
C.D(P=0.05)	0.23	0.19	0.29	0.18

Table 4. Development studies of rice as affected by different methods of establishment and zinc management at different stages of crop

Methods of establishment	Days taken to 50% flowering	Days taken to maturity
Direct seedling in lines after pre-irrigation	85.86	111.0
Broadcast of sprouted seeds in puddled soil.	77.60	104.46
System of rice intensification (SRI) at (25x25cm) with 12 days old seedling	94.06	114.46
SE(m)±	0.07	0.14
C.D (P=0.05)	0.31	0.60
Zinc management		
Without zinc (control)	88.88	110.88
Zinc sulphate ZnSO ₄ @20 kg ha ⁻¹ (Basal)	87.55	110.77
Foliar spray of Zn@0.5% at tillering and panicle initiation stage.	86.00	110.33
Seedling dipping in 2% ZnSO ₄ solution + Foliar spray of Zn@0.5% at tillering and panicle initiation stage	82.55	108.00
Seedling dipping in 2% ZnSO ₄ solution + foliar spray of Zn@0.2% at tillering and panicle initiation stage	84.22	109.66
SE(m)±	0.29	0.27
C.D(P=0.05)	0.85	0.80

Table 5. Zinc content and uptake as affected by methods of establishment and zinc management

Treatment	Zinc content (mg kg ⁻¹) in		Zinc uptake (kg ha ⁻¹)	
	Grain	Straw	Grain	Straw
Methods of establishment				
M ₁ -Direct seedling in lines after pre-irrigation	30.95	31.99	0.126	0.192
M ₂ -Broadcast of sprouted seeds in puddled soil.	33.57	35.58	0.105	0.182
M ₃ -System of rice intensification (SRI) at (25x25cm) with 12 days old seedling	27.39	29.06	0.158	0.225
SE(m)±	0.017	0.02	0.04	0.21
C.D(P=0.05)	0.06	0.08	0.09	1.08
Zinc Management				
T ₀ -Without zinc (control)	31.30	32.87	0.133	0.253
T ₁ -Zinc sulphate ZnSO ₄ @20 kg ha ⁻¹ (Basal)	31.70	33.21	0.134	0.252
T ₂ -Foliar spray of Zn@0.5% at tillering and panicle initiation stage.	30.81	32.19	0.133	0.249
T ₃ -Seedling dipping in 2% ZnSO ₄ solution + Foliar spray of Zn@0.5% at tillering and panicle initiation stage	29.31	31.09	0.130	0.244
T ₄ -Seedling dipping in 2% ZnSO ₄ solution + foliar spray of Zn@0.2% at tillering and panicle initiation stage	30.06	31.69	0.132	0.248
SE(m)±	0.02	0.04	0.04	0.17
C.D(P=0.05)	0.07	0.13	0.13	0.52

spray of zinc @0.2% at tillering and panicle initiation stage (109.66 days).the data further revealed that foliar spray of zinc @0.5% at tillering and panicle initiation stage T₃ was found statistically superior over ZnSO₄ applied @20 kg ha⁻¹as basal. Crop without zinc recorded significantly late maturity (110.88 days). This was mainly because of the facts that (T₃) enhanced the supply of plant nutrients continuously which delayed the senescence in plant thus delayed the maturity.

3.4 Qualitative Studies

Zinc content: Data indicated that zinc content (mg kg⁻¹) in grain and straw was affected statically by crop establishment methods and Zinc management practices.

In general, the highest zinc content (%) in grain and straw (30.95 and 31.99 mg kg⁻¹) was recorded with broadcast of sprouted seeds in puddled soil. The results are confirmed with the close findings of Rani and Sukumari [10].

A Perusal of the data revealed that maximum zinc content in grains and straw (31.70 and 33.21 mg kg⁻¹) respectively with application of zinc sulphate ZnSO₄@20 kg ha⁻¹ (Basal). However, Minimum zinc content in grain and straw (29.31 and 31.09 mg kg⁻¹) respectively was recorded

under seedling dipping in 2% ZnSO₄ solution + foliar spray of Zn@0.5% at tillering and panicle initiation stage (T₃). Zinc plays main role in different plant metabolic processes and many enzymatic activities resulting to the efficient absorption and translocation of essential plant nutrients ultimately more biomass production. Similar finding has been reported by Saha et al. [11].

Zinc uptake: Data pertaining to zinc uptake by grains of rice as influenced by crop establishment methods and Zinc management practices has been presented in Table 5.

It is evident from the data that crop establishment methods had significant influence in respect of zinc uptake by grains and straw. The maximum zinc uptake by grains and straw (0.158 and 0.225 kg ha⁻¹) respectively was recorded with system of rice intensification (SRI) at (25 x 25) with 12 days old seedling method (M₃), which was at par with direct seedling in line after pre irrigation (M₁) while, significantly superior over rest of the treatments. The significantly maximum uptake (0.134 and 0.252 kg ha⁻¹) through grain and straw, respectively of Zinc was noted when crop received ZnSO₄@20 kg ha⁻¹as basal, however, the minimum uptake of Zn is (0.130 and 0.252 kg ha⁻¹) through grain and straw, respectively was observed with application of seedling dipping in

Table 6. Economics of each treatment as affected by methods of establishment and zinc management

Treatment	Cost of cultivation (Rs ha⁻¹)	Gross Income (Rs ha⁻¹)	Net income (Rs ha⁻¹)	B:C Ratio (Rs/Re invested)
M₁T₀	48,208.19	108,726.28	60,518.09	1.25
M₁T₁	50,608.19	111,554.09	60,945.9	1.20
M₁T₂	49,708.19	112,965.59	63,257.4	1.27
M₁T₃	49,198.19	116,302.68	67,104.49	1.36
M₁T₄	49,018.19	115,098.5	66,080.31	1.34
M₂T₀	46,033.19	85,321.19	39,288	0.85
M₂T₁	48,433.19	87,593.89	39,160.7	0.80
M₂T₂	47,533.19	89,836.08	42,302.89	0.88
M₂T₃	47,023.19	92,750.19	45,727	0.97
M₂T₄	46,843.19	91,174.9	44,331.71	0.94
M₃T₀	50,893.19	154,810.19	103,917	2.04
M₃T₁	53,293.19	156,359.99	103,066.8	1.93
M₃T₂	52393.19	157,525.19	105,132	2.00
M₃T₃	51883.19	159,864.4	107,981.21	2.08
M₃T₄	51703.19	158,938.18	107,234.99	2.07

2% ZnSO₄ solution + Foliar spray of Zn@0.5% at tillering and PIS. This was because of lower content (%) and poor grain and straw yield with this treatment.

However, the minimum amount of zinc uptake by grains and straw (0.105 and 0.182 kg ha⁻¹) was recorded with broadcasting of sprouted seed in puddle condition (M₂). This might be due to higher grain and straw recorded with system of rice intensification (SRI) at (25 x 25) with 12 days old seedling. These results are in line with the research findings of Yadav et al. [12] and Meena et al. [13].

3.5 Economics

A critical examination of the data in Table 6 revealed that the maximum gross income of Rs 158938.18 ha⁻¹ was accrued with (SRI method + T₄) treatment combination. However, a combination of SRI method along with T₃ treatment accrued the maximum net profit of Rs 107981.21 ha⁻¹ and benefit: cost ratio of 2.08 which was followed by a combination of SRI method along with T₄ with net income of Rs 107234.99 ha⁻¹ and benefit cost ratio of 2.07 [14].

The lowest gross return (Rs. 85321.19 ha⁻¹), net income (Rs 39160.7 ha⁻¹) and benefit: cost ratio of (0.08) was obtained with broadcast of sprouted seed in puddled soil + No Zinc application (control) treatment (M₂ T₁).

4. CONCLUSION

It can be concluded from the above results that:

1. Transplanting of rice seedling by SRI method 12 days old seedling recorded the highest values of growth, yield attributes and yield which was followed by Direct seeded rice at 20 cm.
2. Seed dipping in 2% ZnSO₄ solution + 2 Foliar spray of Zn@0.5% at tillering and panical initiation stage (T₃) recorded highest values of growth, yield attributes and yield which was followed by Seed dipping in 2% ZnSO₄ solution + 2 Foliar spray of Zn@0.2% at tillering and panicle initiation stage (T₄).
3. The maximum Zinc content (mg/kg) in grain and straw was recorded with Broadcast of sprouted seeds in puddle soil, but uptake of Zn was highest with SRI method.

4. Application of ZnSO₄@20 kg ha⁻¹ (Basal) recorded the highest Zn content and its uptake by grain and straw.
5. The maximum net income and benefit: cost ratio was recorded with treatment combination SRI +T₃ (System of rice intensification (SRI) at (25 x 25) with 12 days old seedling + Seed dipping in 2% ZnSO₄ solution + 2 Foliar spray of Zn@0.5% at tillering and panicle initiation stage.)

On the basis of above conclusion, the recommendation in follows:

Rice crop should be establishment by SRI method with 12 days old seedling along with Seedling dipping in 2% ZnSO₄ solution + 2 Foliar spray of Zn@0.5% at tillering and panical initiation stage to obtained maximum yield and net profit under central plain zone conditions of Uttar Pradesh.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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