1. Optimal Drip Irrigation Configurations for Rice: A Study on Yield and Economic Returns

~~**Drip Design and Crop Geometry for Drip Irrigated Rice Cultivation**~~

ABSTRACT

The effectiveness of drip irrigation systems and the potential for increased productivity and water use efficiency are determined by the selection of dripper spacing, dripper discharge rate, suitable crop variety, and crop geometry. The study found that using a 90 cm lateral spacing and 60 cm dripper spacing with a 4 lph discharge rate is optimal for rice cultivation in direct-seeded raised beds with a medium-duration variety. This setup, with a spacing of 20x40x10 cm (paired row), resulted in a higher grain yield of 7075 kg~~/~~ha^{-1}, a net return of Rs. 82526/ha, a benefit-cost ratio (BCR) of 2.76, and water use efficiency of 7.69 kg/ha-mm during the *rabi* season. Direct seeding in raised beds with a medium-duration variety ~~at a spacing of~~spaced at 20x40x10 cm, combined with other agronomic practices, is the most effective method for achieving higher yield parameters, increased yield, greater net return, and improved water use efficiency and water productivity in drip-irrigated rice cultivation during the Samba (Rabi) season

Key words: *Drip design, Direct seeded, Water use efficiency and Water productivity*.

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INTRODUCTION

Rice (Oryza sativa L.) is the world's most crucial food crop, cultivated in at least 114 countries, with over 50 countries producing at least 100,000 tons annually. Globally, ~~around~~ approximately 491.4 million tons of rough rice are harvested from 160.6 million hectares of land(1). The diminishing availability of water for agriculture poses a threat to the productivity of irrigated rice systems, necessitating strategies to conserve water and enhance rice water productivity. Rice's daily water consumption ranges from 6-10 mm, with total water usage varying from 1100 to 1250 mm depending on agro-climatic conditions, variety duration, and soil characteristics. As per a 2010 UNESCO report, India's rice production water footprint is 2020 m³ per tonne, compared to the global average of 1325 m³ per tonne. Irrigated rice has a low water use efficiency, requiring up to 6667 liters of water to produce one kilogram of rice (0.15 kg of milled rice per m³ of water)

The growing water scarcity and low water productivity in irrigated dry lands are pushing farmers to implement resource conservation technologies like dry-seeded and non-flooded rice. Water productivity can be improved through various water-saving practices, including better irrigation management(2). Enhancing water productivity at the field level can be achieved by increasing yield per unit of cumulative evapotranspiration (ET), reducing unproductive water outflow and depletion (SP, E), or making more effective use of rainfall alongside efficient irrigation systems in direct-seeded rice (DSR) cultivation. Water use efficiency can be boosted either by increasing yield or by conserving water(3).

To optimize crop production with limited water resources, it is crucial to understand the relationship between the amount of water applied and the resulting yield, yield attributes, and biomass produced. While a drip irrigation system for rice cultivation can increase production costs, its expense depends on the number of laterals and drippers/emitters per unit area, along with the main system components. For rice, a closely spaced crop, the cost of a drip irrigation system ranges from Rs. 1.10 lakhs to 1.25 lakhs per hectare. The effectiveness of the drip layout can be optimized using the wetting diameter parameter, which varies based on soil conditions, crop spacing, and geometry. The diameter and depth of wetting are crucial factors in designing an efficient drip irrigation system.

Choosing dripper spacing and discharge rate depends on the crop type, root spread, and soil type. Often, suboptimal methods are used for this selection. An efficient drip irrigation system should have a low investment cost and high productivity. Costs can be reduced by designing the system based on soil characteristics and crop root spread. Drip irrigation delivers water to the root zone in frequent, low volumes, aiming to meet the plants' consumptive use with higher uniformity compared to other irrigation methods. More data on rice's agronomic response to drip irrigation is necessary to assess its technical and economic feasibility and to identify the best management practices for rice cultivation. With this context, the research aimed to determine the optimal crop geometry to reduce production costs and increase rice yield with higher water productivity.

2. MATERIALS AND METHODS

2.1. Description of Exprimental Site

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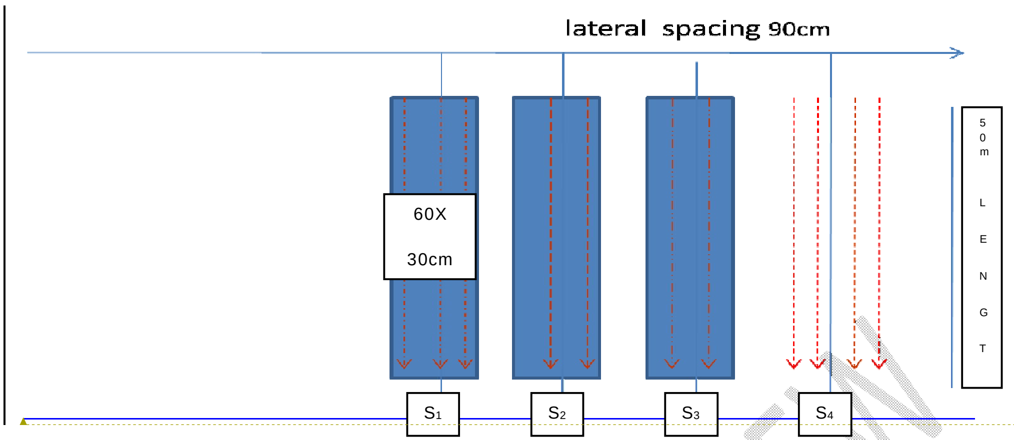
The experiment was conducted at the Central Farm (C-block) of the Agricultural Engineering College and Research Institute (TNAU) in Kumulur, Tamil Nadu, India, during the Samba season of 2019-20 and 2020-21. The location is at 10°92' North Latitude and 78°82' East Longitude, with an elevation of 62 meters above mean sea level. During the crop growth period, the average maximum temperature was 35.6°C and the minimum temperature was 24.2°C, with a mean annual rainfall of 864 mm. The soil texture of the experimental plot was sandy clay loam, with a field capacity of 25% and a bulk density of 1.63 g/cm^{-3}.

2.2. Crop husbandry

A field experiment was conducted ~~to evaluate the effectiveness of the selected dripper spacing and discharge rate by preparing the main field~~ under two conditions: dry and wet. In both conditions, beds and channels (60 cm x 30 cm) with a height of 25 cm were formed over a length of 50~~ meters~~.



~~Fig 1: Field layout of drip irrigation system~~

In the dry condition (M_1), treated seeds of three rice varieties were sown in the beds according to the spacing treatments. Pre-emergence herbicide Pretilachlor was applied 3 days after sowing (DAS) for direct-sown rice. Fertilizer recommendations of 150:60:60 NPK kg/ha^{-1} were followed, along with other agronomic practices and pest and disease management. Gap filling was done at 12 DAS to ensure full establishment. Similarly, in the wet condition (M^2), 18-day-old seedlings from the SRI nursery technique were planted in the dry-formed beds and channels, which were irrigated before transplanting. The same fertilizer recommendations, agronomic practices, and pest and disease management were followed, with gap filling done at 8 days after transplanting (DAT) to ensure full establishment.

In both conditions, drip laterals were spaced 90 cm apart with emitters placed 50 cm apart (4 lph) at the center of the beds. Irrigation was done at 100% PE on alternate days, and fertigation was applied at 100% RDF of 150:60:60 NPK kg/ha. A basal dose of phosphorus was applied using 375 kg/ha^{-1} of super phosphate, while nitrogen and potash were supplied using 326 kg of urea and 100 kg of muriate of potash through the drip irrigation system over 6 days. The quantity of NPK applied varied based on the growth stage of the rice crop

2.2. Experimental design

~~The aim of the study was to assess the effectiveness of selected dripper spacing (60 cm) and discharge rate (4 lph) on crop growth and yield parameters. Additionally, the study sought to identify the optimal variety and crop geometry for improved productivity and water use efficiency in drip irrigation systems for paddy during the 2019-2021 Samba seasons~~. The experiments were carried out using a strip plot design with the following treatments consisted of Direct seeded under raised bed(M_1), Transplanting under raised bed(M_2) as main plot treatment and varieties considered as sub plot treatments(ADT 54, TKM 13 and CR1009 sub 1),different spacing and geometry considered as sub- sub plot treatments viz., 20 x 10 cm (Rectangular) (50 hills/m^2)(S_1), 20 x 20 cm (Square) (25 hills/ m^2) (S_2), 25 x 25 cm (Square) (16 hills/ m^2) (S_3) and 20 x 40 x 10 cm (Paired row) (33 hills/ m^2) (S_3).

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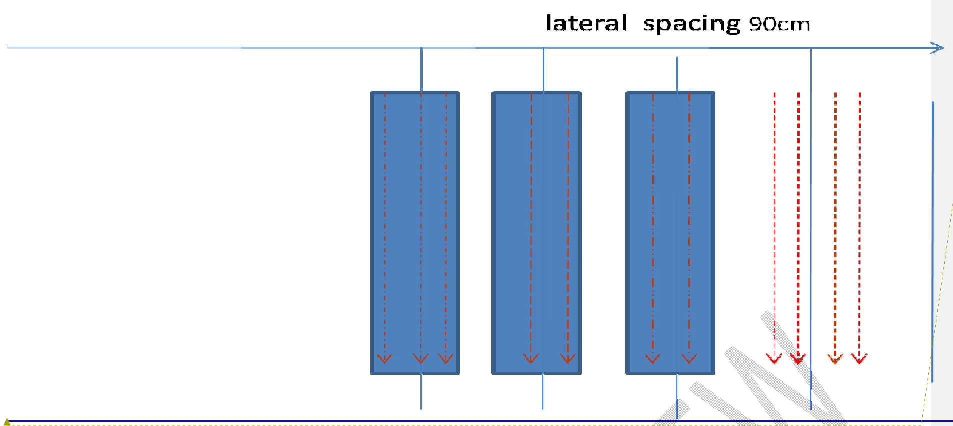

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Fig 1: Field layout of drip irrigation system

2.3. Crop growth and ~~yield~~ Yield ~~parameters~~Parameters

Growth parameters such as plant height and number of tillers, along with yield parameters including productivity tillers, number of filled grains, test weight, and both grain and straw yield, were measured. The data from the two years of field experiments were combined, and the average pooled values are presented in Tables 1 and 2. An economic analysis was conducted to evaluate the cost of cultivation, gross return, net return, and benefit-cost ratio (BCR). The net return values are shown in Fig. 2.

2.4. Water ~~use~~ Use ~~efficiency~~ Efficiency and ~~water~~ Water ~~productivity~~Productivity

Irrigation was applied at 100% of Potential Evapotranspiration (PET) on alternate days using meteorological data from AEC&RI, Kumulur. Water use efficiency and water productivity were assessed. The total water applied for direct-seeded rice was 920 mm (M_1), and 960 mm for transplanted rice (M2), with the same amount of water applied regardless of variety and spacing through the drip irrigation system.

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The scheduling of drip irrigation was done based on daily PE values during the crop growth period and the duration of irrigation was computed as follows:

$$\text{Irrigation hours (h)} = \frac{ET_c\,(mm)}{Application\ rate\ (mmh^{-1})} \times 100$$

~~ETc (mm)~~

~~Irrigation hours (h) = X 100~~

~~Application rate (mm h-1)~~

Whereas,

~~Actual evaporation or crop evapotranspiration~~ ~~(~~ETc~~)in~~ ~~(~~mm) = ET_0 x ~~Crop factor~~K_c

~~Reference evaporation or evapotranspiration~~ ~~(~~ET_0~~)in~~ ~~(~~mm) = Previous day evaporation x Pan factor.

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Crop factors for paddy at its initial, crop development, reproductive and maturity stages were used were 1.15, 1.23, 1.14, and 1.02 respectively, and a constant pan factor of 0.7 was used.

Water-use efficiency was measured by determining dry weight of grain (yield kg ~~/~~ ha^{-1}), and dividing that by irrigation plus rainfall(ha.mm).

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3. RESULTS AND DISCUSSION

~~The results indicated that a 90 cm lateral spacing and 60 cm dripper spacing with a 4 lph discharge rate is optimal for rice cultivation in sandy clay loam soil~~

3.1. Plant ~~growth~~ Growth and ~~yield~~ Yield ~~characters~~Parametrs

The results indicated that plant height did not significantly vary with the method of establishment or spacing. However, there was no variation among varieties, with the tallest plant at harvest (136 cm) being observed in CR 1009 sub 1. The highest number of productive tillers, 278, 344, and 314 per square meter, were recorded under direct-seeded (M_1), TKM 13 (V_2), and 20x40x10 cm (Paired row) (S4) treatments, respectively, compared to transplanted (M_2), other varieties, and different spacing treatments (Table 1). A similar pattern was observed in filled grains (32,272~~/~~m^{-2}, 39,416~~/~~m^{-2}, and 43,744~~/~~m^{-2}) and grain yield (5.31, 5.26, and 6.22 t~~/~~ha^{-1}). Soman et al., also reported that panicle number, grain number, and test weights were higher with water and fertilizer management through drip systems(4).

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Table 1: Effects of individual treatments on yield parameters

Treatment	Productive tillers (Numbers/m^2)	Filled grains (Numbers/m^2)	Grain yield (t/ha)
Method of establishment			
M_1: Direct seeded	278	32272	5.31
M_2 : Transplanted	238	27525	4.59
Mean	258	29899	4.95
SED	12	964	0.26
CD(p=0.05)	27	1452	0.41
Varieties			
V_1 : ADT 54	253	29078	4.71
V_2 : TKM 13	344	39416	5.26
V_3: CR 1009 sub 1	177	21203	4.88
Mean	258	29899	4.95
SED	9.8	678	0.23
CD(p=0.05)	14	1242	0.38
Spacing			
S_1 : 20 x 10 cm (Rectangular)	275	27184	4.42
S_2 : 20 x 20 cm (Square)	246	30071	4.94
S_3: 25 x 25 cm (Square)	197	24896	4.22
S_4: 20 x 40 x 10 cm (paired row)	314	37444	6.22
Mean	258	29899	4.95
SED	10.4	864	0.14
CD(p=0.05)	19.6	1328	0.31

~~Treatment~~	~~Productive tillers (Numbers/m^2)~~	~~Filled grains (Numbers/m^2)~~	~~Grain yield (t/ha)~~
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~~SED~~	~~10.4~~	~~864~~	~~0.14~~
~~CD(p=0.05)~~	~~19.6~~	~~1328~~	~~0.31~~

The combination of the direct-seeded method (M_1) with the 'TKM 13' variety (V_2) at a spacing of 20 x 40 x 10 cm (paired row) (S_4) resulted in the highest number of productive tillers (429/m^{-2}), filled grains (53,196/m^{-2}), and grain yield (7.08 t/ ha^{-1}) (Table 2). High rice productivity in drip irrigation is likely due to the optimal amount of water applied during the reproductive stage, which enhances the number of productive tillers, filled grains, and overall yield. Similar findings have been reported by other researchers [5-9]. However, another study [10] found differing results, showing that transplanted rice irrigated through a drip system yielded significantly higher plant growth parameters and seed yield compared to direct-seeded rice irrigated by the same method.

Table 2: Effects of ~~combination~~ Combination ~~treatments~~ Treatments on ~~yield~~ Yield ~~parameters~~Parameters

Treatments	**Number of productive tillers (Nos./m^2)**	**Number of filled grains (Nos. m^2)**	**Grain yield (t/ha)**
$M_1V_1S_1$	300	29400	4.65
$M_1V_1S_2$	250	29500	4.78
$M_1V_1S_3$	224	27776	4.56
$M_1V_1S_4$	363	42108	6.86
$M_1V_2S_1$	400	40800	5.39
$M_1V_2S_2$	375	45375	6.08
$M_1V_2S_3$	256	32768	4.42
$M_1V_2S_4$	**429**	**53196**	**7.08**
$M_1V_3S_1$	200	18800	4.29
$M_1V_3S_2$	150	19800	4.55
$M_1V_3S_3$	160	20480	4.75
$M_1V_3S_4$	231	27258	6.30
$M_2V_1S_1$	200	20200	3.20
$M_2V_1S_2$	200	24400	3.95
$M_2V_1S_3$	192	24192	3.97
$M_2V_1S_4$	297	35046	5.71
$M_2V_2S_1$	350	34300	4.53
$M_2V_2S_2$	350	39900	5.35

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M_1V_2 S_3	224	26880	3.63
M_1V_2 S_4	363	42108	5.60
M_2V_3 S_1	200	19600	4.47
M_2V_3 S_2	150	21450	4.94
$M_2V_3S_3$	128	17280	4.01
M_2V_3 S_4	198	24948	5.76
Mean	258	29899	4.95
SED	14	988	0.16
CD(p=0.05)	29	1726	0.33

Treatments	Number of productive tillers (Nos./m^2)	Number of filled grains (Nos. m^2)	Grain yield (t/ha)
M_1V_1 S_1	300	29400	4.65
M_1V_1 S_2	250	29500	4.78
M_1V_1 S_3	224	27776	4.56
M_1V_1 S_4	363	42108	6.86
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M_1V_3 S_1	200	18800	4.29
M_1V_3 S_2	150	19800	4.55
$M_1V_3S_3$	160	20480	4.75
M_1V_3 S_4	231	27258	6.30
M_2V_1 S_1	200	20200	3.20
M_2V_1 S_2	200	24400	3.95
M_2V_1 S_3	192	24192	3.97
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M_2V_3 S_4	198	24948	5.76
Mean	258	29899	4.95
SED	14	988	0.16
CD(p=0.05)	29	1726	0.33

~~Economics~~3.2. Partial Budget Analysis

Higher net returns of Rs. 51,976ha^{-1}~~/ha~~, Rs. 51,161ha^{-1}~~/ha~~, and Rs. 69,959~~/~~ha^{-1} were achieved with the direct-seeded method (M_1), 'TKM 13' variety (V_2), and 20x40x10 cm paired row spacing (S_4), respectively, compared to the transplanted method (M_2), other varieties, and different spacing treatments. A similar pattern was observed in the benefit-cost ratio (BCR), with values of 2.11, 2.10, and 2.46. Among the various treatment combinations of establishment method, variety, and spacing, the direct-seeded raised bed with TKM 13 at a

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spacing of 20x40x10 cm yielded the highest net return of Rs. 82,526~~/~~ha^{-1} and a BCR of 2.76, compared to other combinations (Fig. 2).According to the researcher [11], a higher net income of Rs. 58,104ha^{-1} ~~/ha~~ was achieved compared to the conventional cultivation methods.

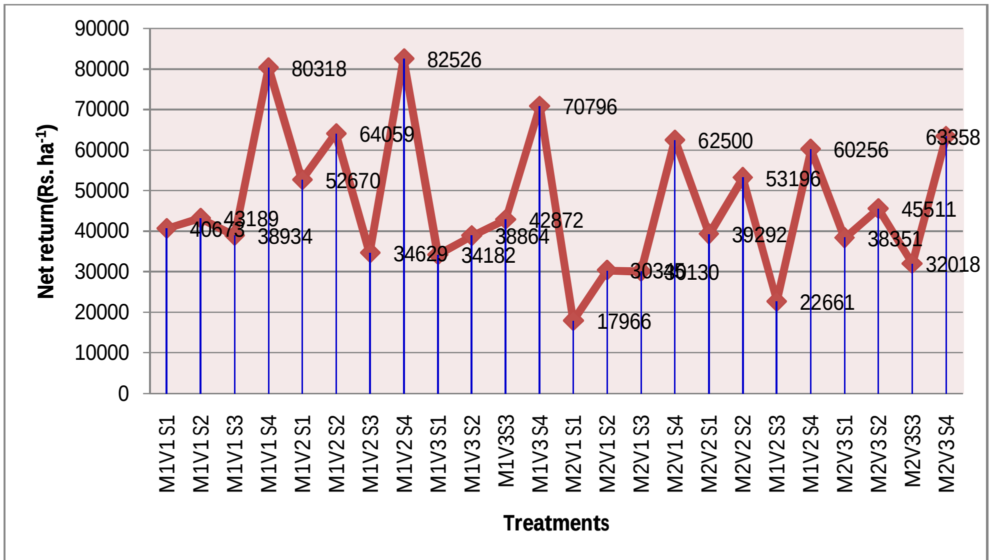

Fig 2: Effect of treatments on net return (Rs./ha)

3.3. Water ~~use~~ Use ~~efficiency~~ Efficiency and Water ~~productivity~~Productivity

Higher water use efficiency of 5.77, 5.62, and 6.63 kgtha^{-1}cm~~kg/ha.~~mm was observed with the direct-seeded method (M_1), 'TKM 13' variety (V_2), and 20x40x10 cm paired row spacing (S^4) compared to other treatments. A similar trend was seen in water productivity, with values of Rs. 9.23, 8.97, and 10.61/m^{-3}. Soman et al. (2018) also reported water savings and increased water productivity and grain yields in drip-irrigated aerobic rice systems. Among the treatment combinations, the direct-seeded raised bed with TKM 13 at a spacing of 20x40x10 cm showed the highest water use efficiency (7.69 tha^{-1}cm~~kg/ha~~-mm) and water productivity (Rs. 12.30~~/~~m^{-3}) compared to other combinations (Fig. 3 ~~&~~and4). Rakesh Sharda et al., noted that micro irrigation in direct-seeded rice can enhance irrigation water use efficiency by better matching crop water requirement, reducing runoff and deep drainage losses, and saving energy(5). Technologies like drip irrigation and fertigation are seen as solutions to address water challenges and improve overall efficiency and production(4b).
According to researcher [12] also suggested that the use of micro irrigation in DSR has the potential to increase irrigation WUE by matching the water requirement of the crop, reducing runoff, deep drainage losses and energy saving [5]. Technologies like drip and fertigation are going to be answers for the challenges of water and the overall need for high efficiency input management and higher production efficiency [4].

According to researcher [13], water requirements under drip irrigation were lower compared to conventional (flooding) irrigation. It was also observed that water use efficiency was highest with drip irrigation, at 8.126 t~~/~~ha^{-1}cm. This study indicated that both the average yield and water use efficiency were higher with the drip system compared to conventional

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methods. Similar results were reported by other researchers. [14,15,16,17].

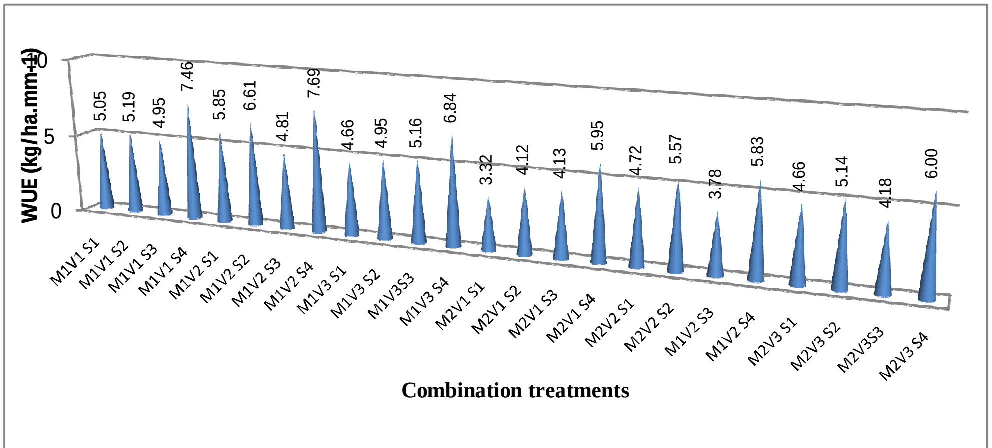

Fig 3: Effect of ~~treatments~~ Treatments on Water ~~use~~ Use Efficiency (kg/ha.mm^{-1})

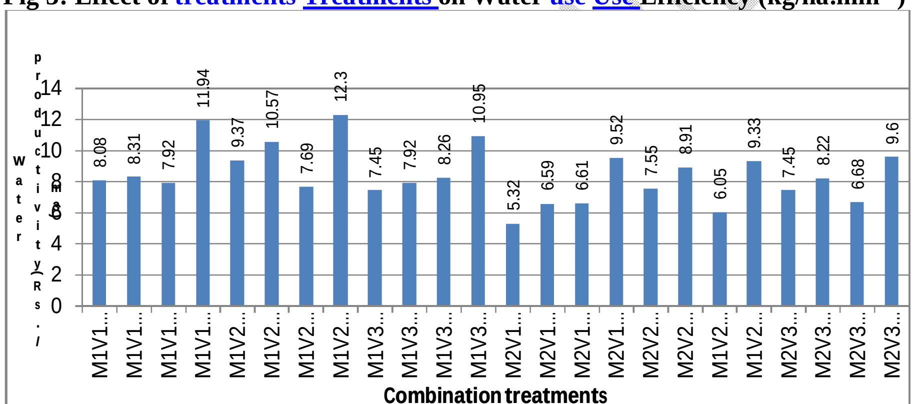

Fig 4: Effect of ~~treatments~~ Treatments on Water ~~productivity~~ Productivity (Rs.~~/~~m-^{3})

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4. CONCLUSION

The optimal drip irrigation system for rice cultivation uses a 90 cm lateral spacing and 60 cm dripper spacing with a 4 lph discharge rate. Among the establishment methods, direct seeding is the most effective for drip-irrigated rice. The 'TKM-13' variety performed best across all yield parameters. The paired row method with a spacing of 20 x 40 x 10 cm is ideal for drip irrigation in rice cultivation. Combining direct seeding with the medium-duration variety 'TKM 13' at 20x40x10 cm spacing yields the highest results, including 7075 kg~~/~~ha- in yield, Rs. 82,526/ha in net return, a BCR of 2.76, and ~~a water~~water use efficiency of 7.69 kg/ha-mm during the Samba (Rabi) season. Direct seeding with 'TKM 13' at ~~a 20x40x10~~20x40x10 cm spacing in raised beds is the best method for maximizing water use efficiency and productivity in drip-irrigated rice during the Samba (Rabi) season.

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