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Influence of Irrigation Management Practices and Different Establishment Methods on Nutrient Use Efficiency of Rice

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A B S T R A C T

A field experiment was conducted at Zonal Agricultural Research Station, V. C. Farm, Mandya, to study the effect of irrigation management practices and rice establishment methods on growth and yield of rice (*Oryza sativa* L.) during *Kharif* 2018. The experiment was laid out in split plot design with three main plot irrigation methods and five sub plot rice establishment methods. The combination of 15 treatments was replicated thrice. The results revealed significantly higher leaf area (920.61 cm^2 $hill^{-1}$), dry matter production (70.82 g $hill^{-1}$) at harvest, net returns (42,495 Rs. ha^{-1}) and B:C ratio (2.00) in alternate wetting and drying up to PI followed by flooding 3 ± 2 cm after PI method of irrigation. While among establishment methods, manual transplanting recorded significantly higher grain yield (5253 kg ha^{-1}). Interaction between alternate wetting and drying up to PI followed by flooding 3 ± 2 cm after PI and mechanical transplanting recorded higher gross returns (99,377 Rs. ha^{-1}), net returns (55,112 Rs. ha^{-1}) and B:C ratio (2.25).

Introduction

Rice which belongs to Poaceae family is the second important crop after wheat in the world. It is the staple food in Asia, Latin America, parts of Africa and the Middle East. Half of the world's population subsists wholly or partially on rice (Yadav *et al.,* 2009). In India, rice cultivation area extends from 8º S to 34º S latitude *i.e*. extending almost throughout the country such as areas lying below sea level (Kerala) and up to an altitude of 2000 m mean sea level (Kashmir) (Somasundaram *et al.,* 2000). The area occupied by rice crop is around 43.99 million ha in India with a production and productivity of 109.69 million tonnes and 2494 kg ha^{-1}, respectively (Anon., 2017). Rice is the staple food for more than 2/3rd of population in India. As the crop plays a fundamental role in our national food security and is a means of livelihood for millions of rural families, the slogan "Rice for life" is most appropriate.

In terms of area cultivated, rice ranks second. Forty percent of world population uses rice as a prime source of calories. In terms of calorific value, rice crop occupies first place than any other cereal crops. 74.8 g carbohydrates, 2.6 g fat and 8.4 g protein in the form of oryzenin is present in 100 g of rice grain. The remaining are other minerals, amino acids and fibre content. Thus 100 g of rice can supply 477 kcal of energy.

It is estimated that, by 2025 the rice demand will be 140 million tonnes in India (Hugar *et al.,* 2009). In order to attain this target, the productivity of rice has to be ushered to the level of 3.3 tonnes ha^{-1} from present level of 2.2 tonnes ha^{-1} (Anjani *et al.,* 2014). Increase in production has undoubtedly to come from increased productivity under shrinking resources.

The increasing global demand for water in many sectors, including agriculture and intensifying water dearth has become a universal concern. In the next two decades, the share of water devoted to irrigation is expected to decline by 10 to 15% (Dhawan, 2017). Increasing water paucity is becoming real threat to rice cultivation. Around 13 million ha of Asia's wet-season rice and 2 million ha of its dry-season rice will encounter "physical water scarcity" by 2025 (Bouman and Tuong, 2001). Hence efficient water use technology which also conserves soil health, sustainability as well as economical stability is the only approach to save water for escalating irrigated agriculture (Subramaniam *et al.,* 2013). To accomplish this, diverse approaches have to be adopted and among them, enhancing water productivity or water use efficiency (WUE) is of foremost importance. Survey of literature shows that average WUE of major crops in India varies from 0.28 to 1.60 kg m^{-3} with ample differences among crop species.

Water has been taken for granted in irrigated rice production for centuries, but the looming water crisis may change the method of rice production in the future. Water saving technologies that were examined in the early 1970's such as maintaining soil under saturated condition and alternate wetting and drying are receiving renovated attention by researchers. One operation that has been revealed to trim down water use in rice systems is an irrigation management practice referred to as Alternate Wetting and Drying (AWD) (Lampayan *et al.,* 2015). AWD has been reported to lessen water inputs by 23% (Bouman and Tuong, 2001) compared to continuously flooded rice systems. As compared with conventional methods, rice grown on saturated soil culture with raised beds reduced the quantity of water use by approximately 32 per cent (Borell *et al.,* 1997).

One of the cultural practices which affect the rice crop through its effect on growth and development is method of establishment (Gopi *et al.,* 2006). Due to non availability of irrigation water, loss of applied nutrients and dearth of labour during peak periods, amplified labour wages make transplanting and manual weeding costly. Thus the area under transplanted rice in world is waning in recent years. Hence, there is call for exploring alternate crop establishment methods to augment the productivity of rice (Farooq *et al.,* 2011). This can be accomplished by adopting diverse establishment techniques in rice such as direct seeded rice, broadcasting, mechanical transplanting, drum seeded rice etc. Mechanical transplanting or direct seeded rice enables timely planting/seeding and better crop stand (Malik *et al.,* 2019). Direct seeded rice can lessen the labour requirement by as much as 50 per cent (Singh *et al.,* 2006).

Challenge is to develop advanced technologies and production systems that allow rice production to be sustained or improved in the face of waning water availability. With the intention to find out the efficient water and nutrient saving technology and method of establishment, a field experiment was undertaken.

Materials and Methods

The experiment was conducted at Zonal Agricultural Research Station, V. C. Farm, Mandya, University of Agricultural Sciences, Bengaluru under Cauvery Command Area of Karnataka to study the effect of irrigation management practices and rice establishment methods on growth and yield of rice during *Kharif* 2018. The experiment was laid out in a split plot design comprised of three main plot irrigation treatments, *viz*. Continuous flooding, Maintenance of saturation up to panicle initiation (PI) and flooding after PI and Alternate wetting and drying (AWD) up to panicle initiation (PI) and flooding after PI and five sub plot rice establishment treatments, *viz*. Drum seeded rice, Broadcasting of sprouted rice, Semi-dry rice, Mechanical transplanting and Manual transplanting. The combination of 15 treatments replicated thrice and medium duration paddy variety *'MTU 1001'* was used for the field experiment.

Soil of the experimental site was sandy loam containing organic carbon (0.67 %), available nitrogen (270.04 kg/ha), phosphorus (87.03 kg/ha) and potassium (287.14 kg/ha). The experiment comprised of three different irrigation methods. Irrigation was applied and quantified through PVC pipes connected to water meter. Fifteen days prior to sowing, 10 t ha^{-1} FYM was applied to the experimental plots and it was incorporated into the soil. Recommended dose of 100 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1}, 50 kg K_2O ha^{-1}, 20 kg $ZnSO_4$ ha^{-1} fertilizers were applied through urea, single super phosphate (SSP), muriate of potash (MOP) and zinc sulphate ($ZnSO_4$), respectively. 50% of N, full amount of P, K and $ZnSO_4$ were applied as basal dose and the remaining quantity of N was applied in two splits and was top dressed at 35 and 60 DAS. However, 0.4% $FeSO_4$ and humic acid was sprayed at 45 and 65 DAS to overcome the deficiency of iron. Irrigation was provided at daily basis for Continuous flooding method, once in 2-3 days for Maintenance of saturation up to panicle initiation (PI) and flooding after PI and once in 5-6 days for AWD depending on the soil condition. Necessary aftercare operations were followed as per the recommendations. No major pest and disease incidences were noticed during crop growth. Observations on growth parameters were recorded at regular intervals – 30, 60, 90 days after sowing and at harvest. Observations recorded during different phenological phases of rice crop were analyzed statistically to find out the result and to draw a conclusion of the experiment conducted. Fisher's method of analysis of variance (ANOVA) was used in the analysis as given by Gomez and Gomez (1984). Significance between the treatments was tested by "F" test. Whereas, difference between the treatments mean were tested by critical difference (CD) at 5% level of significance.

Results and Discussion

Leaf area

The data on leaf area as influenced by irrigation and rice establishment methods recorded at 30, 60, 90 DAS and at harvest are presented below in table 1.

At 30 and 60 DAS, effect of irrigation methods was non significant. While at 90 DAS and at harvest, alternate wetting and drying up to PI followed by flooding after PI recorded higher leaf area (1228.46 and 920.61

cm^2 hill^{-1}, respectively) than other methods. Similar observations were also made by Nguyen *et al.,* (2009). It might be due to more plant dry matter which resulted in greater leaf area at tillering and heading stages as recorded in this study. Bouman *et al.,* (2005) have also observed that the reduction in leaf area might be due to reduced turgor pressure under moisture stress conditions which affected the leaf cell expansion. Among establishment methods, at 30 DAS, semi dry rice recorded significantly higher leaf area (165.62 cm^2 hill^{-1}) over rest of the methods (13.91 to 102.83 cm^2 hill^{-1}). At 60, 90DAS and at harvest, mechanical transplanting recorded significantly higher leaf area (721.85, 1528.53 and1020.46 cm^2 hill^{-1}, respectively) was superior over rest of the establishment methods. Among interactions, continuous flooding with semi dry rice (191.71 cm^2 hill^{-1}) at 30 DAS, continuous flooding with mechanical transplanting (854.08 cm^2 hill^{-1}) at 60 DAS, alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting (1640.11 and 1145.52 cm^2 hill^{-1}, respectively) at 90 DAS and at harvest, respectively recorded significantly higher leaf area than rest of the interactions.

Dry matter production (g hill^{-1})

The data on dry matter production as influenced by irrigation and establishment methods of rice are presented in table 2.

At 30 and 60 DAS, continuous flooding recorded higher dry matter production (1.82 and 12.62 g hill^{-1}, respectively) and was on par with other methods (1.58 to 1.60 g and 11.35 to 12.43 g hill^{-1}, respectively). However, at 90 DAS and at harvest, alternate wetting and drying up to PI followed by flooding after PI method of irrigation recorded significantly higher dry matter (38.39 and 70.82 g hill^{-1}, respectively) as compared to rest of the methods (33.10 to 35.42 g hill^{-1} and 63.94 to 64.36 g hill^{-1}, respectively).The increased dry matter production in alternate wetting and drying up to PI followed by flooding after PI might be due to effective utilization of available resources which was favored by aeration of soil in intermittent wetting and drying. These findings were in accordance with Christine *et al.,* (2007). Semi dry rice recorded significantly higher dry matter (3.19 g hill^{-1}) over rest of the methods (0.27 to 1.98 g hill^{-1}) at 30 DAS. However, at 60, 90 DAS and at harvest, mechanical transplanting among establishment methods recorded significantly higher dry matter (15.04, 47.77 and 78.50 g hill^{-1}, respectively) over rest of the methods (10.11 to 13.06 g hill^{-1}, 28.12 to 35.85 g hill^{-1} and 57.35 to 67.77 g hill^{-1}, respectively). Similar trend of total dry matter production was observed at 60, 90 DAS and at harvest due to optimum nutrient supply and production of more number of leaves and leaf area which helped in absorption of more solar radiation hence more photosynthesis and more above ground biomass. These results are also in line with findings of Yadav *et al.,* (2010). Interaction between alternate wetting and drying up to PI followed by flooding after PI and mechanical transplanting recorded higher dry matter at 30, 60, 90 DAS and at harvest (3.69, 17.79, 51.25 and 88.12 g hill^{-1}, respectively) and was significantly superior over rest of the methods (0.24 to 2.73, 8.44 to 14.79, 22.23 to 46.17 and 46.62 to 76.05 g hill^{-1}respectively).

Grain yield (kg ha^{-1})

Data presented in Table 2 on grain yield varied significantly due to establishment methods and interaction between irrigation and establishment methods. No significant difference in grain yield was observed among irrigation methods. However, continuous flooding recorded higher grain yield (4916 kg ha^{-1}) than alternate wetting and drying up to PI followed by flooding after PI (4849 kg ha^{-1}) and maintenance of saturation up to PI followed by flooding after PI (4828 kg ha^{-1}). Higher grain yield recorded by manual transplanting (5253 kg ha^{-1}) was statistically on par with mechanical transplanting and semi dry rice (5171 and 4953 kg ha^{-1}, respectively) and was significantly superior over rest of the establishment methods (4197 to 4749 kg ha^{-1}). Interaction between alternate wetting and drying up to PI followed by flooding after PI and manual transplanting recorded higher grain yield (5745 kg ha^{-1}) and was statistically similar with interaction of alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting (5613 kg ha^{-1}), maintenance of saturation up to PI followed by flooding after PI with manual transplanting (5202 kg ha^{-1}), continuous flooding with semi dry rice (5189 kg ha^{-1}) and maintenance of saturation up to PI followed by flooding after PI with drum seeded rice (5137 kg ha^{-1}). However, former treatment was significantly superior over rest of the interactions (4093 to 5104 kg ha^{-1}). It might be due to planting of seedlings before third phyllochron, leading to quick crop establishment and longer tillering period which resulted in higher yield attributes and hence yield in case of transplanted rice. However, increase in grain yield in semi dry and drum seeded rice may be attributed to the early establishment, growth and development of crop along with irrigation methods. These results are in confirmation with the findings of Shantappa (2014).

Nutrient status of soil after harvest of crop

Nutrients uptake by rice (kg ha^{-1})

Nitrogen uptake by rice grain (kg ha^{-1})

Nitrogen uptake by rice grain varied significantly with establishment methods and interaction are presented in Table 3. Among irrigation methods, alternate wetting and drying up to PI followed by flooding after PI recorded higher nitrogen uptake by grain (61.52 kg ha^{-1}) which was on par with continuous flooding (61.51 kg ha^{-1}) and maintenance of saturation up to PI followed by flooding after PI (60.88 kg ha^{-1}). Higher available nitrogen content in alternate wetting and drying up to PI followed by flooding after PI might be due to effective mineral uptake by roots with larger surface area (Taiz and Zeiger, 2006). Among establishment methods, manual transplanting recorded significantly higher nitrogen uptake by grain (66.49 kg ha^{-1}) as compared to rest of the methods (54.08 to 63.74 kg ha^{-1}). Lower nitrogen uptake by grain (54.08 kg ha^{-1}) was recorded by broadcasting of sprouted rice. This may be due to the water stress conditions created by the competition from more plants per unit area which might have made the roots unable to take up nutrients from the soil due to slow ion diffusion and water movement rates as well as lack of root activity (Dubey and Pessarakli, 2001). Alternate wetting and drying up to PI followed by flooding after PI with manual transplanting recorded significantly higher nitrogen uptake by grain (73.25 kg ha^{-1}) over rest of the interactions (52.01 to 68.13 kg ha^{-1}). The root growth and activity was found better in case of seedlings transplanted with alternate wetting and drying method of irrigation due to the prolific growth of root which helped plants to absorb more nitrogen and accumulate in grains from comparatively deeper layers. Similar results were recorded by Dass and Chandra, (2012).

Nitrogen uptake by rice straw (kg ha^{-1})

Alternate wetting and drying up to PI followed by flooding after PI recorded higher nitrogen uptake by straw (58.64 kg ha^{-1}) and was on par with rest of the irrigation methods (56.85 to 57.14 kg ha^{-1}). Mechanical transplanting recorded significantly higher nitrogen uptake by straw (61.86 kg ha^{-1}) as compared to rest of the methods (54.91 to 57.53 kg ha^{-1}). Lower nitrogen uptake by straw (54.91 kg ha^{-1}) was recorded by broadcasting of sprouted rice. Nutrient uptake is a function of soil physical, chemical and biological properties, plant population, quantity of dry matter accumulated by crop and amount of fertilizer applied. Nitrogen uptake is a product of above ground biomass and nitrogen content (Taiz and Zeiger, 2006), which has enhanced the nitrogen uptake significantly in rice by mechanical transplanting method. Among interactions, alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting recorded significantly higher nitrogen uptake by straw (64.20 kg ha^{-1}) as compared to rest of the interactions (52.99 to 61.92 kg ha^{-1}).

Total nitrogen uptake (Kg ha^{-1})

The total nitrogen uptake in different irrigation methods was non significant. However, alternate wetting and drying up to PI followed by flooding after PI recorded higher total nitrogen uptake at harvest (120.06 kg ha^{-1}) compared with rest of the methods (118.02 to 118.36 kg ha^{-1}). Among establishment methods, mechanical transplanting recorded significantly higher total nitrogen uptake (125.60 kg ha^{-1}) followed by manual transplanting (123.79 kg ha^{-1}). Lower total nitrogen uptake (108.99 kg ha^{-1}) was recorded in broadcasting of sprouted rice. This may be due to transplanting of younger seedlings in which the root injury is minimum and presence of more active roots, which resulted in rapid and stable establishment by utilizing more nutrients and moisture for longer period. The results are in conformity with Satyanarayana and Babu (2004). Interaction between alternate wetting and drying up to PI followed by flooding after PI and manual transplanting recorded significantly higher total nitrogen uptake (134.04 kg ha^{-1}) which was closely followed by alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting (132.33 kg ha^{-1}) compared to rest of the interactions (109.08 to 125.43 kg ha^{-1}).

Phosphorus uptake by rice grain (kg ha^{-1})

Data on phosphorus uptake by rice grain at harvest as influenced by irrigation and establishment methods are presented in Table 4. Phosphorus uptake by rice grain was non significant among irrigation methods. However, continuous flooding recorded higher phosphorus uptake by grain at harvest (11.33 kg ha^{-1}) than rest of the irrigation methods (10.87 to 11.05 kg ha^{-1}). Among establishment methods, manual transplanting recorded significantly higher phosphorus uptake by grain (13.80 kg ha^{-1}) followed by mechanical transplanting (12.45 kg ha^{-1}) as compared to rest of the methods (7.04 to 11.50 kg ha^{-1}). Among interactions, alternate wetting and drying up to PI followed by flooding after PI with manual transplanting recorded significantly higher phosphorus uptake by grain (16.85 kg ha^{-1}) followed by alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting (15.13 kg ha^{-1}) over rest of the interactions (6.17 to 14.02 kg ha^{-1}). Effective absorption of nutrients was seen under early established seedlings. This might be due to the well developed root system. The results are in close agreement with the findings of Dass and Chandra, (2012).

Phosphorus uptake by rice straw (Kg ha^{-1})

No significant difference was observed in different irrigation methods. However, higher phosphorus uptake by straw (9.37 kg ha^{-1}) was recorded by alternate wetting and drying up to PI followed by flooding after PI followed by maintenance of saturation up to PI followed by flooding after PI (8.83 kg ha^{-1}) and continuous flooding (8.46 kg ha^{-1}). Mechanical transplanting recorded significantly higher phosphorus uptake by straw (11.02 kg ha^{-1}) as compared to rest of the methods (7.44 to 9.00 kg ha^{-1}). Interaction between alternate wetting and drying up to PI followed by flooding after PI and mechanical transplanting recorded significantly higher phosphorus uptake by straw (11.98 kg ha^{-1}) which was closely followed by continuous flooding with mechanical transplanting (10.86 kg ha^{-1}) over rest of the interactions (6.75 to 10.64 kg ha^{-1}).

Continuous flooding brought the phosphorus to available form and hence the uptake was more. Whereas, in case of alternate wetting and drying, plant roots were successful in excavating the soil and hence increase in uptake of phosphorus present around the plant roots. Similar results were reported in the findings of Chandrapala *et al.,* (2010).

Total phosphorus uptake (Kg ha^{-1})

Total phosphorus uptake was higher in alternate wetting and drying up to PI followed by flooding after PI (20.24 kg ha^{-1}) and the effect was non significant when compared to rest of the methods (19.79 to 19.88 kg ha^{-1}). Among establishment methods, mechanical transplanting recorded significantly higher total phosphorus uptake (23.46 kg ha^{-1}) followed by manual transplanting (22.76 kg ha^{-1}) as compared to rest of the methods (14.48 to 20.50 kg ha^{-1}). This may be due to the synchrony between supply and uptake of nutrients through proliferated root system (Chandrapala *et al.,* 2010). Among interactions, alternate wetting and drying up to PI followed by flooding after PI with manual transplanting recorded significantly higher total phosphorus uptake (27.49 kg ha^{-1}) followed by alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting (27.11 kg ha^{-1}) as compared to rest of the interactions (13.15 to 23.88 kg ha^{-1}).

Potassium uptake by rice grain (kg ha^{-1})

Data on potassium uptake as influenced by irrigation methods and establishment methods are presented in Table 5. Irrigation had no significant effect on potassium uptake by grain. However, alternate wetting and drying up to PI followed by flooding after PI recorded higher potassium uptake by grain (47.43 kg ha^{-1}) among irrigation methods. Manual transplanting recorded significantly higher potassium uptake by grain (48.68 kg ha^{-1}) followed by mechanical transplanting (48.06 kg ha^{-1}) and semi dry rice (47.64 kg ha^{-1}) over rest of the establishment methods (45.59 to 47.08 kg ha^{-1}). Potassium uptake by the crop is influenced by potassium content and dry matter production, so significant difference was found as confirmed by the findings of Rani and Sukumari (2013).

Among interactions, alternate wetting and drying up to PI followed by flooding after PI with manual transplanting recorded significantly higher potassium uptake by grain (50.01 kg ha^{-1}) followed by alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting (49.56 kg ha^{-1}) and maintenance of saturation up to PI followed by flooding after PI with manual transplanting (49.21 kg ha^{-1}) as compared to rest of the interactions (45.16 to 48.84 kg ha^{-1}).

Potassium uptake by rice straw (kg ha^{-1})

Different irrigation methods have no significant effect on potassium uptake by straw. However, alternate wetting and drying up to PI followed by flooding after PI recorded higher potassium uptake by straw (73.16 kg ha^{-1}). Mechanical transplanting recorded significantly higher potassium uptake by straw (76.52 kg ha^{-1}) over rest of the establishment methods (69.03 to 72.28 kg ha^{-1}).

Mechanical transplanting produced higher dry matter which may be due to the effective absorption of the potassium by plants. Similar results were reported by Hugar *et al.,* (2009). Interaction between alternate wetting and drying up to PI followed by flooding after PI and mechanical transplanting recorded significantly higher potassium uptake by straw (78.82 kg ha^{-1}) as compared to rest of the interactions (68.42 to 75.98 kg ha^{-1}).

Total potassium uptake (kg ha^{-1})

No significant variations were found among irrigation methods with respect to total potassium uptake. Among establishment methods, mechanical transplanting recorded significantly higher total potassium uptake (124.58 kg ha^{-1}) as compared to rest of the methods (114.62 to 120.96 kg ha^{-1}). The results obtained are in conformity with the earlier findings of Jayadeva and Prabhakara Shetty (2008) and Satyanarayana and Babu, (2004).

Among interactions, AWD with mechanical transplanting recorded significantly higher total potassium uptake (128.38 kg ha^{-1}) followed by alternate wetting and drying up to PI followed by flooding after PI with manual transplanting (125.99 kg ha^{-1}) over rest of the interactions (113.27 to 124.59 kg ha^{-1}).

Chemical properties of soil after harvest

The data on pH, EC (dSm^{-1}), organic carbon (per cent OC) and available nutrient status of the soil (kg ha^{-1}) is presented in table 6.

pH, EC and per cent OC of soil after harvest of crop

Among irrigation methods, continuous flooding recorded higher pH and EC (7.92 and 0.21 dS m^{-1}, respectively) which were on par with alternate wetting and drying up to PI followed by flooding after PI (7.86 and 0.20 dS m^{-1}, respectively) and maintenance of saturation up to PI followed by flooding after PI (7.84 and 0.20 dS m^{-1}, respectively). However, AWD recorded higher OC (0.62%) and was at par with rest of the methods (0.56 to 0.61%). Among establishment methods, drum seeded rice recorded higher pH and EC (8.05 and 0.21 dS m^{-1}, respectively) while semi dry rice recorded higher OC (0.68%) and were statistically on par with rest of the methods. Interaction effect between irrigation methods and establishment methods was not significant with respect to pH, EC and per cent OC.

Available nitrogen status of the soil (kg ha^{-1})

Alternate wetting and drying up to PI followed by flooding after PI recorded higher available nitrogen content in soil (274.19 kg ha^{-1}) whereas, continuous flooding recorded lower available nitrogen content in soil (248.27 kg ha^{-1}). This may be due to the various forms of nitrogen losses under submerged condition (Taiz and Zeiger, 2006). Among establishment methods, both drum seeded rice and broadcasting of sprouted rice recorded higher available nitrogen content in soil (264.15 kg ha^{-1}) and was on par with rest of the methods of establishment (253 to 259.97 kg ha^{-1}). The results are in line with Chandrapala *et al.,* (2010). Among interactions, alternate wetting and drying up to PI followed by flooding after PI with broadcasting of sprouted rice recorded higher available nitrogen content in soil (293.42 kg ha^{-1}) and effect was non significant.

Table.1 Leaf area at different growth stages and at harvest as influenced by irrigation management practices and establishment methods in rice

Treatment	Leaf area (cm^2 $hill^{-1}$)			
	DAS			At harvest
	30	60	90	
Irrigation methods (I)				
I_1: Continuous flooding	94.51	605.80	1059.29	836.62
I_2: Maintenance of saturation up to panicle initiation (PI)followed by flooding after PI	82.32	596.49	1133.55	831.22
I_3: Alternate wetting and drying up to PI followed by flooding 5±2cm	82.94	544.58	1228.46	920.61
S.Em.±	3.33	13.62	21.65	11.03
CD (p= 0.05)	NS	NS	84.81	43.21
Rice establishment methods (E)				
E_1: Drum seeded rice	67.53	502.56	985.53	822.65
E_2: Broadcasting of sprouted rice	102.83	626.78	899.88	745.55
E_3: Semi dry rice	165.62	485.08	1147.31	880.98
E_4: Mechanical transplanting	13.91	721.85	1528.53	1020.46
E_5: Manual transplanting	83.06	575.16	1140.91	844.44
S.Em.±	3.70	15.56	18.98	17.68
CD (p= 0.05)	10.81	45.42	55.40	51.60
Interaction				
I_1E_1	75.57	439.33	1051.31	895.31
I_1E_2	110.20	684.64	1000.11	889.81
I_1E_3	191.71	405.34	977.71	810.38
I_1E_4	12.26	854.08	1555.95	981.59
I_1E_5	82.80	645.59	711.36	606.02
I_2E_1	75.05	641.11	910.08	701.61
I_2E_2	92.99	618.68	807.68	644.63
I_2E_3	141.88	512.20	1326.51	937.00
I_2E_4	13.51	601.55	1389.55	934.27
I_2E_5	88.15	608.91	1233.92	938.60
I_3E_1	51.97	427.25	995.20	871.04
I_3E_2	105.29	577.01	891.84	702.22
I_3E_3	163.28	537.72	1137.71	895.57
I_3E_4	15.95	709.92	1640.11	1145.52
I_3E_5	78.24	470.98	1477.44	988.69
S.Em.±	6.63	27.69	36.51	29.52
CD (p= 0.05)	18.72	78.67	95.95	89.37

Note: NS – Non significant

Table.2 Dry matter production at different growth stages and at harvest as influenced by irrigation management practices and establishment methods in rice

Treatment	Dry matter production(g hill^{-1})				Grain yield (kg ha^{-1})
	DAS			At harvest	
	30	60	90		
Irrigation methods (I)					
I_1: Continuous flooding	1.82	12.62	33.10	64.36	4916
I_2: Maintenance of saturation up to panicle initiation (PI)followed by flooding after PI	1.58	12.43	35.42	63.94	4828
I_3: Alternate wetting and drying up to PI followed by flooding 3±2cm	1.60	11.35	38.39	70.82	4849
S.Em±	0.06	0.28	0.68	0.85	190
CD (p= 0.05)	NS	NS	2.65	3.32	NS
Rice establishment methods (E)					
E_1: Drum seeded rice	1.30	10.47	30.80	63.28	4749
E_2: Broadcasting of sprouted rice	1.98	13.06	28.12	57.35	4197
E_3: Semi dry rice	3.19	10.11	35.85	67.77	4953
E_4: Mechanical transplanting	0.27	15.04	47.77	78.50	5171
E_5: Manual transplanting	1.60	11.98	35.65	64.96	5253
S.Em±	0.07	0.32	0.59	1.36	121
CD (p= 0.05)	0.21	0.95	1.73	3.97	354
Interaction					
I_1E_1	1.59	12.69	32.85	68.87	4932
I_1E_2	1.44	12.53	31.25	68.45	4544
I_1E_3	1.50	10.67	30.55	62.34	5189
I_1E_4	3.14	14.26	48.62	75.51	5104
I_1E_5	0.24	8.44	22.23	46.62	4811
I_2E_1	0.31	9.81	28.44	53.97	5137
I_2E_2	0.26	9.15	25.24	49.59	3953
I_2E_3	1.79	13.36	41.45	72.08	5050
I_2E_4	2.12	13.45	43.42	71.87	4797
I_2E_5	2.02	12.89	38.56	72.20	5202
I_3E_1	1.45	11.20	31.10	67.00	4177
I_3E_2	1.00	8.90	27.87	54.02	4093
I_3E_3	1.70	12.02	35.55	68.89	4619
I_3E_4	3.69	17.79	51.25	88.12	5613
I_3E_5	2.73	14.79	46.17	76.05	5745
S.Em±	0.13	0.58	1.14	2.27	267
CD (p= 0.05)	0.36	1.64	3.00	6.87	614

Note: NS - Non significant

Table.3 Nitrogen uptake at harvest as influenced by irrigation management practices and establishment methods in rice

Treatments	N uptake (kg ha^{-1})		
	Grain	Straw	Total
Irrigation methods (I)			
I_1: Continuous flooding	61.51	56.85	118.36
I_2: Maintenance of saturation up to panicle initiation (PI)followed by flooding after PI	60.88	57.14	118.02
I_3: Alternate wetting and drying up to PI followed by flooding 3±2cm	61.52	58.64	120.16
S.Em±	0.78	0.58	1.30
CD (p= 0.05)	NS	NS	NS
Rice establishment methods (E)			
E_1: Drum seeded rice	60.27	56.13	116.40
E_2: Broadcasting of sprouted rice	54.08	54.91	108.99
E_3: Semi dry rice	61.93	57.53	119.46
E_4: Mechanical transplanting	63.74	61.86	125.60
E_5: Manual transplanting	66.49	57.30	123.79
S.Em±	0.49	0.32	0.56
CD (p= 0.05)	1.43	0.93	1.65
Interaction			
I_1E_1	61.83	57.52	119.35
I_1E_2	57.11	56.09	115.43
I_1E_3	64.89	55.74	120.63
I_1E_4	63.51	61.92	125.43
I_1E_5	60.21	52.99	113.20
I_2E_1	64.12	54.95	119.07
I_2E_2	52.01	54.07	109.08
I_2E_3	62.69	59.11	121.80
I_2E_4	59.57	59.46	119.36
I_2E_5	66.02	58.12	124.14
I_3E_1	54.86	55.91	111.44
I_3E_2	53.13	54.56	111.02
I_3E_3	58.22	57.74	115.96
I_3E_4	68.13	64.20	132.33
I_3E_5	73.25	60.79	134.04
S.Em±	1.09	0.76	1.56
CD (p= 0.05)	2.48	1.62	2.85

Note: NS - Non significant

Table.4 Phosphorus uptake at harvest as influenced by irrigation management practices and establishment methods in rice

Treatments	P uptake (kg ha^{-1})		
	Grain	Straw	Total
Irrigation methods (I)			
I_1: Continuous flooding	11.33	8.46	19.79
I_2: Maintenance of saturation up to panicle initiation (PI)followed by flooding after PI	11.05	8.83	19.88
I_3: Alternate wetting and drying up to PI followed by flooding 3±2cm	10.87	9.37	20.24
S.Em±	0.59	0.31	0.88
CD (p= 0.05)	NS	NS	NS
Rice establishment methods (E)			
E_1: Drum seeded rice	10.62	8.02	18.64
E_2: Broadcasting of sprouted rice	7.04	7.44	14.48
E_3: Semi dry rice	11.50	9.00	20.50
E_4: Mechanical transplanting	12.45	11.02	23.46
E_5: Manual transplanting	13.80	8.96	22.76
S.Em±	0.51	0.30	0.55
CD (p= 0.05)	1.48	0.88	1.61
Interaction			
I_1E_1	11.52	8.58	20.10
I_1E_2	7.99	8.21	16.20
I_1E_3	13.58	7.89	21.47
I_1E_4	13.02	10.86	23.88
I_1E_5	10.53	6.75	17.28
I_2E_1	13.21	7.44	20.65
I_2E_2	6.17	6.98	13.15
I_2E_3	12.65	10.05	22.70
I_2E_4	9.19	10.21	19.40
I_2E_5	14.02	9.49	23.51
I_3E_1	7.14	8.03	15.17
I_3E_2	6.96	7.12	14.08
I_3E_3	8.26	9.07	17.33
I_3E_4	15.13	11.98	27.11
I_3E_5	16.85	10.64	27.49
S.Em±	0.98	0.56	1.23
CD (p= 0.05)	2.57	1.52	2.78

Note: NS - Non significant

Table.5 Potassium uptake at harvest as influenced by irrigation management practices and establishment methods in rice

Treatments	**K uptake (kg ha^{-1})**		
	Grain	Straw	Total
Irrigation methods (I)			
I_1: Continuous flooding	47.39	71.14	118.53
I_2: Maintenance of saturation up to panicle initiation (PI)followed by flooding after PI	47.40	71.79	119.19
I_3: Alternate wetting and drying up to PI followed by flooding 3±2cm	47.43	73.16	120.60
S.Em±	0.31	0.97	1.07
CD (p= 0.05)	NS	NS	NS
Rice establishment methods (E)			
E_1: Drum seeded rice	47.08	70.33	117.41
E_2: Broadcasting of sprouted rice	45.59	69.03	114.62
E_3: Semi dry rice	47.64	72.00	119.64
E_4: Mechanical transplanting	48.06	76.52	124.58
E_5: Manual transplanting	48.68	72.28	120.96
S.Em±	0.41	0.33	0.54
CD (p= 0.05)	1.21	0.97	1.58
Interaction			
I_1E_1	47.13	71.79	118.92
I_1E_2	46.08	70.56	116.64
I_1E_3	48.84	69.48	118.32
I_1E_4	48.09	76.50	124.59
I_1E_5	46.82	67.36	114.18
I_2E_1	48.23	68.97	117.20
I_2E_2	45.16	68.11	113.27
I_2E_3	47.87	74.17	122.04
I_2E_4	46.53	74.23	120.76
I_2E_5	49.21	73.49	122.70
I_3E_1	45.87	70.23	116.10
I_3E_2	45.52	68.42	113.94
I_3E_3	46.21	72.36	118.57
I_3E_4	49.56	78.82	128.38
I_3E_5	50.01	75.98	125.99
S.Em±	0.71	1.09	1.36
CD (p= 0.05)	2.10	1.68	2.74

Note: NS - Non significant

Table.6 Available nutrients status in soil after harvest as influenced by irrigation management practices and establishment methods in rice

Treatments	pH	Ec (dS m^{-1})	OC (%)	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
Irrigation methods (I)						
I_1: Continuous flooding	7.92	0.21	0.61	248.27	97.44	213.23
I_2: Maintenance of saturation up to panicle initiation (PI)followed by flooding after PI	7.84	0.20	0.56	257.46	99.73	211.50
I_3: Alternate wetting and drying up to PI followed by flooding 3±2cm	7.86	0.20	0.62	274.19	99.65	212.29
S.Em±	0.13	0.01	0.01	8.87	1.02	2.72
CD (p= 0.05)	NS	NS	NS	NS	NS	NS
Rice establishment methods (E)						
E_1: Drum seeded rice	8.05	0.21	0.59	264.15	98.30	213.75
E_2: Broadcasting of sprouted rice	8.04	0.21	0.58	264.15	99.61	212.26
E_3: Semi dry rice	7.99	0.20	0.68	258.58	100.70	212.40
E_4: Mechanical transplanting	7.43	0.20	0.49	259.97	97.15	213.42
E_5: Manual transplanting	7.88	0.21	0.64	253.00	98.93	209.87
S.Em±	0.29	0.01	0.01	9.04	1.71	0.92
CD (p= 0.05)	NS	NS	NS	NS	NS	NS
Interaction						
I_1E_1	7.99	0.22	0.53	259.97	100.17	213.55
I_1E_2	8.04	0.21	0.56	255.79	96.84	211.78
I_1E_3	7.95	0.22	0.57	243.25	94.58	215.36
I_1E_4	7.88	0.20	0.51	251.61	99.98	214.58
I_1E_5	7.76	0.21	0.55	230.70	95.63	210.87
I_2E_1	8.04	0.18	0.57	255.79	96.02	213.20
I_2E_2	8.01	0.21	0.55	243.25	100.56	215.28
I_2E_3	8.61	0.19	0.55	268.34	104.70	211.17
I_2E_4	6.61	0.19	0.54	255.79	99.47	210.04
I_2E_5	7.94	0.23	0.54	264.15	97.91	207.82
I_3E_1	8.11	0.22	0.55	276.70	98.71	214.51
I_3E_2	8.06	0.20	0.53	293.42	101.44	209.72
I_3E_3	7.40	0.19	0.54	264.15	102.82	210.66
I_3E_4	7.79	0.20	0.50	272.52	92.01	215.65
I_3E_5	7.94	0.20	0.54	264.15	103.26	210.92
S.Em±	0.46	0.01	0.02	16.57	2.83	3.07
CD (p= 0.05)	NS	NS	NS	NS	NS	NS

Note: NS - Non significant

Table.7 Nutrient use efficiency as influenced by irrigation management practices and establishment methods in rice

Treatments	Nitrogen use efficiency (kg grain kg^{-1} N)	Phosphorus use efficiency (kg grain kg^{-1} P_2O_5)	Potassium use efficiency (kg grain kg^{-1} K_2O)
Irrigation methods (I)			
I_1: Continuous flooding	49.16	98.32	98.32
I_2: Maintenance of saturation up to panicle initiation (PI)followed by flooding after PI	48.28	96.56	96.56
I_3: Alternate wetting and drying up to PI followed by flooding 3±2cm	48.49	96.99	96.99
S.Em±	1.90	3.80	3.80
CD (p= 0.05)	NS	NS	NS
Rice establishment methods (E)			
E_1: Drum seeded rice	47.49	94.97	94.97
E_2: Broadcasting of sprouted rice	41.97	83.93	83.93
E_3: Semi dry rice	49.53	99.06	99.06
E_4: Mechanical transplanting	51.71	103.43	103.43
E_5: Manual transplanting	52.53	105.05	105.05
S.Em±	1.21	2.43	2.43
CD (p= 0.05)	3.54	7.09	7.09
Interaction			
I_1E_1	49.32	98.64	98.64
I_1E_2	45.44	90.88	90.88
I_1E_3	51.89	103.78	103.78
I_1E_4	51.04	102.08	102.08
I_1E_5	48.11	96.21	96.21
I_2E_1	51.37	102.73	102.73
I_2E_2	39.53	79.06	79.06
I_2E_3	50.50	101.01	101.01
I_2E_4	47.97	95.94	95.94
I_2E_5	52.02	104.05	104.05
I_3E_1	41.77	83.54	83.54
I_3E_2	40.93	81.86	81.86
I_3E_3	46.19	92.38	92.38
I_3E_4	56.13	112.26	112.26
I_3E_5	57.45	114.89	114.89
S.Em±	2.67	5.35	5.35
CD (p= 0.05)	6.14	12.27	12.27

Note: NS - Non significant

Table.8 Economics as influenced by irrigation management practices and establishment methods in rice

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B: C ratio
Irrigation methods (I)				
I_1: Continuous flooding	45850	84777	38927	1.86
I_2: Maintenance of saturation up to panicle initiation (PI) followed by flooding after PI	43650	83634	39984	1.92
I_3: Alternate wetting and drying up to PI followed by flooding 3±2cm	42050	84545	42495	2.00
Rice establishment methods (E)				
E_1: Drum seeded rice	42840	81955	39115	1.91
E_2: Broadcasting of sprouted rice	42590	72832	30242	1.71
E_3: Semi dry rice	40390	85574	45184	2.12
E_4: Mechanical transplanting	46065	90680	44615	1.97
E_5: Manual transplanting	47365	90552	43187	1.92
Interaction				
I_1E_1	44840	85191	40351	1.90
I_1E_2	44590	78863	34273	1.77
I_1E_3	42390	88572	46182	2.09
I_1E_4	48065	88855	40790	1.85
I_1E_5	49365	82406	33041	1.67
I_2E_1	42640	87694	45054	2.06
I_2E_2	42390	68681	26291	1.62
I_2E_3	40190	87804	47614	2.18
I_2E_4	45865	83809	37944	1.83
I_2E_5	47165	90181	43016	1.91
I_3E_1	41040	72980	31940	1.78
I_3E_2	40790	70952	30162	1.74
I_3E_3	38590	80346	41756	2.08
I_3E_4	44265	99377	55112	2.25
I_3E_5	45565	99068	53503	2.17

Note: NS - Non significant

Available phosphorus status of the soil (kg ha^{-1})

Among irrigation methods, maintenance of saturation up to PI followed by flooding after PI recorded higher available phosphorus content in soil (99.73 kg ha^{-1}) an was at par with alternate wetting and drying up to PI followed by flooding after PI (99.65 kg ha^{-1}) and continuous flooding (97.44 kg ha^{-1}). This can be attributed to lower uptake of phosphorus by grain and straw which was due to higher available phosphorus in soil after harvest of rice crop as confirmed in this study. These results are also in accordance with the findings of Jat *et al.,* (2015). Semi dry rice recorded higher available phosphorus content in soil (100.70 kg ha^{-1}) followed by broadcasting of sprouted rice (99.61 kg ha^{-1}) while mechanical transplanting recorded lower available phosphorus content in soil (97.15 kg ha^{-1}). Similar results were recorded by Jat *et al.,* (2015). Interaction between irrigation and establishment methods had no significant effect on available phosphorus content in soil.

Available potassium status of the soil (kg ha^{-1})

Higher available potassium content in soil (213.23 kg ha^{-1}) was recorded in continuous flooding. Whereas, lower available potassium content in soil (211.50 kg ha^{-1}) was recorded under maintenance of saturation up to PI followed by flooding after PI. The results are in conformity with the findings of Jayadeva and Prabhakara Shetty (2008). Drum seeded rice recorded higher available potassium content in soil (213.75 kg ha^{-1}) and the effect was non significant when compared to rest of the methods. This may be due to poor uptake of nutrient from the soil (Chandrapala *et al.,* 2010). Among interactions, alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting recorded higher available potassium content in soil (215.65 kg ha^{-1}). However, the data showed non significant difference among different interactions.

Nutrient use efficiency (kg kg^{-1} nutrient)

The data on nutrient use efficiency of rice as influenced by irrigation and establishment methods are presented in the Table 7.

Nitrogen use efficiency (NUE) (kg grain kg^{-1} N)

Among the different irrigation methods, the nitrogen use efficiency was non-significant. Among establishment methods, manual transplanting recorded higher NUE (52.53 kg grain kg^{-1} N) followed by mechanical transplanting (51.71 kg grain kg^{-1} N) and were significantly higher as compared to rest of the methods (41.97 to 49.53 kg grain kg^{-1} N). However, among interactions, alternate wetting and drying up to PI followed by flooding after PI with manual transplanting recorded significantly higher NUE (57.45 kg grain kg^{-1} N) which was closely followed by alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting (56.13 kg grain kg^{-1} N) as compared to rest of the interactions (39.53 to 52.02 kg grain kg^{-1} N). This may be due to the effective utilization of nitrogen through reduced losses in alternate wetting and drying method of irrigation and effective absorption of nutrients through well developed deep root systems in transplanted rice. Similar results were reported by Borkar *et al.,* (2008).

Phosphorus (PUE) (kg grain kg^{-1} P_2O_5) and Potassium use efficiency (KUE) (kg grain kg^{-1} K_2O)

Among irrigation methods, continuous flooding recorded higher PUE and KUE (98.32 kg grain kg^{-1} P_2O_5 and K_2O) followed by alternate wetting and drying up to PI followed by flooding after PI (96.99 kg grain kg^{-1} P_2O_5 and K_2O) and maintenance of saturation up to PI followed by flooding after PI (96.56 kg grain kg^{-1} P_2O_5 and K_2O). Manual transplanting among establishment methods recorded significantly higher PUE and KUE (105.05 kg grain kg^{-1} P_2O_5 and K_2O) followed by mechanical transplanting (103.43 kg grain kg^{-1} P_2O_5 and K_2O) as compared to rest of the methods (83.93 to 99.06 kg grain kg^{-1} P_2O_5 and K_2O). Interaction between alternate wetting and drying up to PI followed by flooding after PI and manual transplanting recorded significantly higher PUE and KUE (114.89 kg grain kg^{-1} P_2O_5 and K_2O) which was closely followed by alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting (112.26 kg grain kg^{-1} P_2O_5 and K_2O) over rest of the interactions (81.86 to 104.05 kg grain kg^{-1} P_2O_5 and K_2O). Among establishment methods, manual transplanting and mechanical transplanting recorded higher NUE, PUE and KUE. The possible reason may be due to transplanting of young age seedlings where root injury is minimal and that helped in quick establishment after transplantation and hence efficient utilization of applied nutrients for its growth and development. Results are in confirmation with Sowmyalatha (2015).

Economics

The data on cost of cultivation, gross returns, net returns and B: C ratio of rice as influenced by irrigation and establishment methods and their interactions are presented in Table 8.

Cost of cultivation (□ ha^{-1})

Among irrigation methods, alternate wetting and drying up to PI followed by flooding after PI recorded lower cost of cultivation (42,050 □ ha^{-1}) over rest of the methods (43,650 to 45,850 □ ha^{-1}). Among establishment methods, lower cost of cultivation (40,390 □ ha^{-1}) was recorded in semi dry rice than other methods (42,590 to 47,365 □ ha^{-1}). Among treatment combinations, alternate wetting and drying up to PI followed by flooding after PI with semi dry rice recorded lower total cost of cultivation (38,590 □ ha^{-1}) as compared to rest of the treatment combinations (40,190 to 49,365 □ ha^{-1}). Lower cost of cultivation under alternate wetting and drying up to PI followed by flooding after PI may be due to the reduced irrigation costs while lower cost of cultivation in semi dry rice may be due to the reduced puddling, nursery raising and transplanting costs (Shantappa, 2014).

Gross and net returns (□ ha^{-1})

Continuous flooding recorded higher gross returns (84,777 □ ha^{-1}) than other methods (83,634 to 84,545 □ ha^{-1}) whereas, alternate wetting and drying up to PI followed by flooding after PI recorded higher net returns (42,495 □ ha^{-1}) than other methods (38,927 to 39,984 □ ha^{-1}) among irrigation methods. Among establishment methods, mechanical transplanting recorded higher gross returns (90,680 □ ha^{-1}) as compared to rest of the methods (72,832 to 90,552 □ ha^{-1}) however, semi dry rice recorded higher net returns (45,184 □ ha^{-1}) as compared to rest of the methods (30,242 to 44,615 □ ha^{-1}). However, lower gross and net returns were recorded in broadcasting of sprouted rice (72832 and 30242 □ ha^{-1}). Higher gross returns may be due to higher grain and straw yield whereas, higher net returns may be mainly due to lower cost of cultivation. Similar results were reported by Manjunatha *et al.,* (2009b) and Jayadeva and Prabhakara Shetty (2008). Among treatment combinations, higher gross returns and net returns (99,377 and 55,112 □ ha^{-1}, respectively) were recorded in alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting over rest of the treatment combinations (68,681 to 99,068 and 26,291 to 53,503 □ ha^{-1},respectively).

B: C ratio

Among irrigation methods, alternate wetting and drying up to PI followed by flooding after PI recorded higher B: C ratio (2.00) than other methods (1.86 to 1.92). However, among establishment methods, semi dry rice recorded higher B: C ratio (2.12) over other methods (1.71 to 1.97). Alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting among treatment combinations recorded higher B: C ratio (2.25) than rest of the treatments (1.67 to 2.18). Higher B: C ratio may be due to higher net returns and lesser cost of cultivation. These results are in line with Jayadeva and Prabhakara Shetty (2008).

In conclusion the efficient water saving technology and method of establishment on nutrient uptake in rice has been evaluated. Among irrigation methods, alternate wetting and drying up to PI followed by flooding after PI recorded higher leaf area than other methods at 90 DAS and at harvest. In establishment methods, mechanical transplanting recorded significantly higher leaf area. However, at 90 DAS and at harvest, alternate wetting and drying up to PI followed by flooding after PI method of irrigation recorded significantly higher dry matter. However, at 60, 90 DAS and at harvest, mechanical transplanting among establishment methods recorded significantly higher dry matter over rest of the methods. Manual transplanting among rice establishment methods recorded significantly higher grain yield. Among rice establishment methods, mechanical transplanting recorded significantly higher total nitrogen uptake, total phosphorus uptake and total potassium uptake. However, manual transplanting recorded higher NUE, PUE and KUE. Among irrigation methods, alternate wetting and drying up to PI followed by flooding after PI recorded lower cost of cultivation, higher net returns and B: C ratio. Among treatment combinations, higher gross returns, net returns and B: C ratio was recorded in alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting.

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