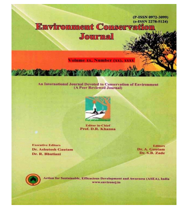
Environment Conservation Journal 23 (3):54-61, 2022

Journal homepage: https://www.environcj.in/

Environment Conservation Journal

ISSN 0972-3099 (Print) 2278-5124 (Online)



Impact of various irrigation and establishment methods on yield and water use efficiency in rice

T. Theerthana ✉

University of Agricultural Sciences, GKVK, Bangalore.

P. S. Fathima

Department of Agronomy, COA, V. C. Farm, Mandya, UAS, Bangalore.

G. R. Denesh

AICRP on Rice, ZARS, V. C. Farm, Mandya,

ARTICLE INFO

Received : 10 December 2021
Revised : 27 March 2022
Accepted : 04 April 2022

Available online: 26 July 2022

Key Words:
Establishment methods
Harvest index
Irrigation methods
Water use efficiency

ABSTRACT

The field experiment was executed to evaluate the impact of various irrigation and establishment methods on yield and water use efficiency in rice during *Kharif* 2018. Split plot design was used in the experiment which consists of three irrigation treatments in the main plot and five rice establishment treatments in the sub plot. The results revealed that, higher yield parameters like number of panicles/m^2 (364.83), number of grains per panicle (73.98), number of filled grains per panicle (60.29) were recorded with maintenance of saturation up to panicle initiation (PI) and flooding after PI. Manual transplanting among rice establishment methods recorded significantly higher test weight (25.04 g), grain yield (5253 kg/ha) and harvest index (0.45). Whereas, mechanical transplanting recorded significantly higher number of grains per panicle (74.61) straw yield (7939 kg/ha). Among different irrigation methods, alternate wetting and drying up to PI followed by flooding after PI recorded significantly lower total water usage (94.94 cm) and higher water use efficiency (52.39 kg/ha-cm). Among rice establishment methods, mechanical transplanting recorded significantly lower total water usage (117.81 cm) and higher water use efficiency (48.80 kg/ha-cm). Interaction between alternate wetting and drying up to PI followed by flooding after PI and mechanical transplanting recorded lower total water usage (81.88 cm) and also recorded higher water use efficiency (68.75 ha-cm).

Introduction

Rice (*Oryza sativa* L.) is grown on 164.19 million ha worldwide. China produced 211.86 million metric tonnes of paddy rice in 2020, whereas India produced 178 million metric tonnes (FAOSTAT, 2021). India produces 178 million tonnes of rice in an area of 44 Million ha which constitutes about 35% of area and 40% of production of the food grain in the country. It is a staple food of about 65% of the country's population, which itself indicates its importance in the food security of the country (Kumar *et al.,* 2018). Rice is ranked second in terms of cultivated area. Rice is the primary source of calories for 40% of the world's population (Sain, 2020). Rice crops outnumber all other cereal crops in terms of calorific value. Rice is a rich source of carbohydrate; consisting of protein, fat as well as vitamin B complexes like niacin, riboflavin, and thiamine. The grain of rice constitutes water 12%, starch 75–80%, and protein only 7% with a full complement of amino acids. Its protein, due to its higher lysine concentration (~4%), is highly digestible (93%) with a high biological value (74 percent) and a protein efficiency ratio (2.02%–2.04%). Minerals such as calcium (Ca), magnesium (Mg) and phosphorus (P) together with some traces amount of copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) are present (Verma *et al.,* 2018).

To meet the rising demand for rice the global rice production needs to increase by 116 million tons by 2035 (Yamano *et al.,* 2016). India's rice demand is

Corresponding author E-mail: *theerthumuthu@gmail.com*
Doi: https://doi.org/10.36953/ECJ.10142227

expected to reach 140 million tonnes by 2025 (Hugar *et al.,* 2009). To meet this goal, rice productivity must increase to 3.3 tonnes ha^{-1} from the current level of 2.2 tonnes ha^{-1} (Anjani *et al.,* 2014).
The proportion of water used for irrigation is predicted to decrease by 10 to 15% during the next two decades (Dhawan, 2017). As a result, the only way to save water for expanding irrigated agriculture is to adopt efficient water usage technology that also conserves soil health, sustainability, and economic stability (Subramaniam *et al.,* 2013). An irrigation management approach known as Alternate Wetting and Drying (AWD) has been discovered to cut down on water use in rice systems (Lampayan *et al.,* 2015). Transplanting and manual weeding become prohibitively expensive due to a lack of irrigation water and a labor shortage during peak seasons. As a result, the global area under transplanted rice has decreased in recent years. As a result, there is a need to investigate alternative crop establishment methods in order to boost rice output (Farooq *et al.,* 2011). This can be achieved by using several rice establishment techniques such as direct seeded rice, broadcasting, mechanical transplanting, and drum seeded rice, among others. Timely planting/seeding is made possible by mechanical transplanting or direct seeded rice (Malik *et al.,* 2019).

Material and Methods

The experiment was conducted at C-Block, Zonal Agricultural Research Station, V. C. Farm, Mandya, University of Agricultural Sciences, Bangalore to study the impact of various irrigation and establishment methods on yield and water use efficiency in rice during *Kharif* 2018. The experimental area was geographically positioned at 76º 82′ East Longitude and 12º 57′ North Latitude with an altitude of 756.80 metre above mean sea level. Considering the nature of factors under study and the convenience of agricultural operation, the experiment was laid out in split plot design, assigning three irrigation management practices *viz*., continuous flooding, maintenance of saturation up to panicle initiation (PI) followed by flooding after PI and Alternate wetting and drying (AWD) with five sub plot rice establishment treatments, *viz*., Drum seeded rice, Broadcasting of sprouted rice, Semi dry rice, Mechanical transplanting and Manual transplanting. The whole field was divided into three blocks each representing a replication.

Irrigation water management

I_1: 5 ± 2 cm of standing water was maintained throughout the crop growth stage.

I_2: The plots were kept under saturated condition (2 cm of water at each irrigation) up to panicle initiation stage. Later, after panicle initiation, the same plots were completely flooded with 5 ± 2 cm standing water.

I_3: The main principle behind this method is to irrigate the plots when hair-line crack appears on the soil surface. The plots were irrigated at 5 to 6 days interval with 5 cm water.

Irrespective of treatments, water was applied to the main plots with the help of PVC pipes and the quantity of water applied was measured at each time by using water meter. Application of water was stopped seven days before harvesting of the crop to facilitate easy harvesting.

Irrigation water

Total water used (cm): The total quantity of irrigation water applied to each treatment was measured using water meters. The effective rainfall received during the crop growth period and the soil moisture contribution was added to the irrigation water and expressed in cm.

Total water = Irrigation water + Effective rainfall + Soil moisture

Table-1: Irrigation water given and total water requirement as influenced by different irrigation methods

Treatments	Effective Rainfall (cm)	Irrigation water given (cm)				Total WR (cm) (WR=ER+IW)
		R_1	R_2	R_3	Mean	
I_1	29.57	153.7	164.9	134.6	151.0	180.66
I_2	29.57	86.89	87.23	78.29	84.13	113.70
I_3	32.07	75.49	62.05	46.60	61.38	93.45

Water Use Efficiency (kg ha-cm^{-1}): Water use efficiency (WUE) is the yield of marketable crop produced per unit of water used (cm). It was worked out by using the following formula and was expressed as kg ha-cm^{-1}.

WUE = Marketable yield (kg ha^{-1}) / total water used (cm)

Water requirement (cm): Total water requirement of the crop is calculated by adding the effective rainfall in the crop growth period and the irrigation water given to each treatment (Table 1).

Results and Discussion

Number of panicles/m^2

Higher number of panicles/m^2 was recorded with maintenance of saturation up to panicle initiation (PI) followed by flooding after PI (364.83) which was on par with continuous flooding (357.50) and alternate wetting and drying up to PI followed by flooding after PI (354.83) as mentioned in Table.2. However, the results were non-significant, there as on behind lesser number of panicles/m^2 in alternate wetting and drying may be due to the unfavorable condition created with drying of rhizosphere during panicle tillering period and panicle initiation stage. These results are in conformity with reports of Hemlata (2015).

Among establishment methods, broadcasting of sprouted rice recorded more number of panicles/m^2 (428.33) and was significantly superior over rest of the methods (313.33 to 367.22). This might be due to the synchronization in maximum tillering period and optimum nutrient supply as confirmed by Sowmyalatha (2015).

Number of grains per panicle

Maintenance of saturation up to panicle initiation (PI) followed by flooding after PI recorded significantly higher number of grains per panicle (73.98) than alternate wetting and drying up to PI followed by flooding after PI (69.11) and continuous flooding (65.94) (Table.2). Lower number of total grains per panicle recorded in continuous flooding indicates that the depth of water can be reduced to greater extent without disturbing crop performance with respect to total number of grains per panicle. The results were in conformity with Kishor (2016).

Among establishment methods, higher number of grains per panicle (74.61) was with mechanical transplanting method followed by manual transplanting (71.89) and was significantly higher as compared to rest of the methods (62.61 to 70.51). Alternate wetting and drying up to PI followed by flooding after PI in mechanical transplanting recorded higher number of grains per panicle (86.35) which was closely followed by continuous flooding in broadcasting of sprouted rice (85.87) and were significantly superior over rest of the interactions (56.43 to 77.12). Higher number of total grains per panicle recorded by mechanical transplanting might be due to the availability of more space within the panicle to accommodate the individual seeds resulting in well-developed seeds (Sowmyalatha, 2015).

Number of filled grains per panicle

Number of filled grains per panicle is tabulated in Table.2. Among establishment methods drum seeded rice recorded significantly higher number of filled grains per panicle (66.08) over rest of the methods (51.02 to 59.86). Lower number of filled grains per panicle was recorded by semi dry method (51.02) might be due to excessive growth during vegetative phase which led to nitrogen dilution in reproductive phase, which in turn reduced spikelet differentiation and hence reduced number of filled grains per panicle. This was in accordance with the findings of Saharawat *et al.* (2010).

Among interactions, maintenance of saturation up to panicle initiation (PI) followed by flooding after PI in drum seeded rice recorded significantly higher number of filled grains per panicle (76.48) as compared to rest of the interactions (44.37 to 69.28). This may be due to the early establishment of crop and early grain filling period which coincided with the nutrient supply and hence higher uptake of available resources like nutrients, moisture etc. The results are also in conformity with findings of Sanjay *et al.* (2018).

Test weight (g)

Continuous flooding recorded significantly higher test weight (24.51 g) as compared to other methods (24.10 to 24.11) as mentioned in Table.2. Different irrigation methods had significant effect on test weight. The possible reason may be due to the effect of irrigation methods on number of grains per panicle and per cent chaffyness and this result is in confirmation with the study of Shantappa (2014). Manual transplanting among establishment methods recorded significantly higher test weight (25.04 g) over rest of the methods (23.05 to 24.55 g). Among interactions higher test weight (25.19 g) was recorded in alternate wetting and drying up to

Table 2: Yield parameters as influenced by irrigation management practices and establishment methods in rice

Treatments	Number of panicles/m^2	No. of grains per panicle	No. of filled grains per panicle	Test weight (g)
Irrigation methods (I)				
I_1: Continuous flooding	357.50	65.94	56.60	24.51
I_2: Maintenance of saturation up to panicle initiation (PI)followed by flooding after PI	364.83	73.98	60.29	24.11
I_3: Alternate wetting and drying up to PI followed by flooding 3±2cm	354.83	69.11	56.90	24.10
S.Em±	3.83	0.87	0.96	0.08
CD (p= 0.05)	NS	3.42	NS	0.32
Rice establishment methods (E)				
E_1: Drum seeded rice	320.28	70.51	66.08	24.55
E_2: Broadcasting of sprouted rice	428.33	66.93	53.81	24.34
E_3: Semi dryrice	366.11	62.61	51.02	24.22
E_4: Mechanical transplanting	367.22	74.61	58.86	23.05
E_5: Manual transplanting	313.33	71.89	59.86	25.04
S.Em±	3.88	1.30	1.02	0.05
CD (p= 0.05)	11.32	3.80	2.98	0.14
Interaction				
I_1E_1	376.67	74.88	67.52	24.64
I_1E_2	407.50	85.87	60.85	24.73
I_1E_3	343.33	60.96	52.11	24.70
I_1E_4	370.00	62.99	48.75	23.42
I_1E_5	290.00	63.41	53.76	25.08
I_2E_1	274.17	74.45	76.48	24.37
I_2E_2	440.83	58.51	56.21	24.12
I_2E_3	402.50	61.44	50.35	24.60
I_2E_4	366.67	74.51	58.56	22.61
I_2E_5	340.00	77.12	59.84	24.84
I_3E_1	310.00	62.19	54.24	24.63
I_3E_2	436.67	56.43	44.37	24.17
I_3E_3	352.50	65.44	50.61	23.36
I_3E_4	365.00	86.35	69.28	23.13
I_3E_5	310.00	75.15	65.97	25.19
S.Em±	7.12	2.20	1.85	0.11
CD (p= 0.05)	19.61	6.57	5.16	0.24

PI followed by flooding after PI with manual transplanting and was on par with continuous flooding with manual transplanting method (25.08 g) which were significantly superior over other interactions (22.61 to 24.73 g). In alternate wetting and drying, aeration was found to reduce the above and below ground competition for water, solar radiation and nutrients. In continuous flooding, plants did not experience any kind of stress during grain filling period. In case of manual transplanting, the transplanted seedlings absorbed moisture, nutrients and solar radiation more effectively hence more photosynthate was accumulated in grains. Similar result was reported by Rajesh and Thanunathan (2003).

Grain yield (kg/ha)

Data tabulated in Table.3 shows that the interaction of alternate wetting and drying up to PI followed by flooding after PI and manual transplanting produced a higher grain yield (5745 kg/ha) and was statistically similar to interactions of alternate wetting and drying up to PI followed by flooding after PI with mechanical transplanting (5613 kg/ha), maintenance of saturation up to PI followed by flooding after PI with manual transplanting (5202 kg/ha), and continuous flooding with semi-dry rice (5189 kg/ha). The former therapy, on the other hand, was significantly superior to the remainder of the interactions (4093 to 5104 kg/ha). It could be because seedlings were planted before the third phyllochron, resulting in faster crop establishment and a longer tillering period, resulting in greater yield characteristics and thus yield in transplanted rice. The early establishment, growth, and development of the crop, as well as irrigation methods, may be responsible for the increase in grain production in semi-dry and drum seeded rice. Shantappa's conclusions are supported by these results (2014).

Straw yield (Kg/ha)

Mechanical transplanting produced a much greater straw production (7939 kg/ha) than the other establishment methods (5685 to 6509 kg/ha)(Table.3). In comparison to the rest of the interactions, the interaction between alternate soaking and drying up to PI followed by flooding after PI and mechanical transplanting produced significantly greater straw production (9569 kg/ha) (5430 to 7191 kg/ha). The increased absorption of solar radiation in the plant tissues, which increased the rate of photosynthesis and hence the accumulation of more photosynthates in the above ground biomass and creation of more dry matter, could be the reason. These findings are consistent with Satyanarayana and Babu's (2004) and Shantappa's findings (2014).

Harvest index

Significantly higher harvest index (0.45) was recorded in manual transplanting followed by semi dry rice and drum seeded rice (0.44) as compared to other establishment methods (0.40 to 0.42) as mentioned in Table.3. This might be due to the higher grain yield obtained by the former treatments. Similar result was reported by Shantappa (2014).

Total water used (cm)

Total water consumed is tabulated in Table.3 and it depicts that the continuous flooding (186.79 cm) was substantially higher than maintenance of saturation up to PI followed by flooding after PI (118.63 cm) or alternate wetting and drying up to PI followed by flooding after PI (118.63 cm) (94.94 cm). Due to the restriction of seepage and deep percolation losses by irrigating once every 5 to 6 days when hair line cracks appear on the soil surface and maintaining water level up to saturation, the maximum irrigation water saving was observed under alternate wetting and drying up to PI followed by flooding after PI followed by saturation method. Shantappa's observations are supported by the findings (2014). Drum seeded rice used the most total water (145.31 cm), followed by sprouted rice broadcasting (144.20 cm), and was much better than the other establishing methods (117.81 to 131.76 cm).In comparison to the remainder of the interactions, the interaction between continuous flooding and establishment methods like drum seeded rice and broadcasting of sprouted rice used significantly more total water (196.09 and 196.09 cm, respectively) (81.88 to 184.09 cm). The interplay of alternate wetting and drying up to PI, followed by flooding after PI, and mechanical transplanting, however, resulted in lower overall water usage (81.88 cm).

Water use efficiency (kg/ha-cm)

Among methods of irrigation, higher water use efficiency (52.39 kg/ha-cm) was recorded in alternate wetting and drying up to PI followed by flooding after PI method as compared to maintenance of saturation up to PI followed by flooding after PI (41.43 kg/ha-cm) and continuous flooding (26.42 kg/ha-cm) and is represented in Table.3. Water use efficiency was significantly higher in mechanical transplanting (48.80 kg/ha-cm) closely followed by manual transplanting (44.38 kg/ha-cm) as compared to rest of the establishment methods (30.98 to 41.94 kg/ha-cm).
Among interactions, interaction between alternate wetting and drying up to PI followed by flooding after PI and mechanical transplanting recorded higher water use efficiency (68.55 kg/ha-cm) over rest of the interactions (23.12 to 61.10 kg/ha-cm).
The higher water use efficiency was mainly attributed to the increased grain yield besides water saving by reducing seepage and percolation losses in mechanical transplanting when alternate wetting and drying up to PI followed by flooding after PI was followed (Bouman and Tuong, 2001, Elamathi *et al*. 2012 and Pandian, 2012).

Table 3: Grain yield, straw yield, harvest index, total water used and water use efficiency (WUE) as influenced by irrigation management practices and establishment methods in rice.

Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest Index	Total water used (cm)	WUE (kg/ha-cm)
Irrigation methods (I)					
I_1: Continuous flooding	4916	6121	0.45	186.79	26.32
I_2: Maintenance of saturation up to panicle initiation (PI)followed by flooding after PI	4828	6389	0.43	118.63	41.43
I_3: Alternate wetting and drying up to PI followed by flooding 3±2cm	4849	6954	0.41	94.94	52.39
S.Em±	190	264	0.01	4.03	2.03
CD (p= 0.05)	NS	NS	NS	15.78	7.95
Rice establishment methods (E)					
E_1: Drum seeded rice	4749	5976	0.44	145.31	34.31
E_2: Broadcasting of sprouted rice	4197	5685	0.42	144.20	30.98
E_3: Semi dry rice	4953	6331	0.44	128.20	41.94
E_4: Mechanical transplanting	5171	7939	0.40	117.81	48.80
E_5: Manual transplanting	5253	6509	0.45	131.76	44.38
S.Em±	121	180	0.01	1.47	1.36
CD (p= 0.05)	354	525	0.03	4.29	3.96
Interaction					
I_1E_1	4932	6279	0.44	196.09	25.13
I_1E_2	4544	6159	0.42	196.09	23.12
I_1E_3	5189	5548	0.49	184.09	28.33
I_1E_4	5104	7191	0.42	171.59	29.68
I_1E_5	4811	5430	0.47	186.09	25.85
I_2E_1	5137	5502	0.48	134.80	38.10
I_2E_2	3953	5433	0.42	134.80	29.32
I_2E_3	5050	7004	0.42	110.80	45.57
I_2E_4	4797	7057	0.40	99.97	47.96
I_2E_5	5202	6949	0.43	112.80	46.19
I_3E_1	4177	6148	0.40	105.04	39.70
I_3E_2	4093	5464	0.43	101.71	40.49
I_3E_3	4619	6442	0.42	89.71	51.92
I_3E_4	5613	9569	0.37	81.88	68.75
I_3E_5	5745	7148	0.45	96.38	61.10
S.Em±	267	385	0.02	4.63	2.92
CD (p= 0.05)	614	910	NS	7.44	6.87

Conclusion

Alternate wetting and drying up to PI followed by flooding after PI method of irrigation up to panicle initiation followed by flooding 3 ± 2 cm among the irrigation methods, mechanical transplanting or semidry method among rice establishment methods and Alternate wetting and drying up to PI followed by flooding after PI method of irrigation in mechanical transplanting and manual transplanting among interactions can be recommended due to higher yield parameters, grain yield, straw yield and WUE.

Acknowledgement

The authors gratefully acknowledge the College of Agriculture, V. C. Farm, Mandya, University of Agricultural Sciences, GKVK, Bangalore, Karnataka, India for providing the research facilities and to the All India Coordinated Research Project on Rice, Zonal Agricultural Research Station, V. C. Farm, Mandya, Karnataka, India for providing the assistance to carry out the study.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Anjani, K., Dasgupta, Pragnakumar, & Rakesh. (2014). Emerging opportunities and challenges in rice production. *Popular Kheti*, *2*(2), 6–11.

Bouman, B. A. M., & Tuong, T. P. (2001). Field water management to save water and increase productivity in irrigated low land rice. *Agricultural Water Management*, *49*(1), 11–30.

Dhawan, V. (2017). Water and agriculture in India. Global Forum of Food and Agriculture (pp. 17–24).

Elamathi, S., Balasubramanian, P., Pandian, B. J., Chellamuthu, S., & Sundarapandian, T. (2012). Effect of improved production technology on rice yield in tank irrigated regions of Giridhamal sub basin, Tamil nadu. *Proceedings of the International Symposium on 100 Years of Rice Science and Looking Beyond* (pp. 492–493). Tamil Nadu Agricultural University.

FAOSTAT. (2019). FAO statistical databases. http://www.fao.org. Food and Agriculture Organization (Food and Agriculture Organization) of the United Nations.

Farooq, M., Siddique, K. H. M., Rehman, H., Aziz, T., Lee, D., & Wahid, A., J. L. and Wahid. (2011) Rice direct seeding: Experiences, challenges and opportunities. *Soil and Tillage Research*, *111*(2), 87–98.

Hemlata. (2015). *Effect of drip irrigation and establishment methods on productivity, water use and economics of summer rice* [PhD Thesis] submitted to Indira Gandhi Krishi Vishwavidyalaya. Raipur, India.

Hugar, A. Y., Chandrappa, H., & Jayadeva, H. M. (2009). Comparitive performance of different rice establishment methods in Bhadra command area. Salish, A and Mallikarjun, G. B. *Karnataka Journal of Agricultural Sciences*, *22*(5), 992–994.

Kishor, J. M. (2016). *Standardization of alternate wetting and drying (AWD) method of water management in low land rice (Oryza sativa (L.) for up scaling in command outlets* [PhD Thesis] submitted to *Professor Jayashankar Telangana State Agricultural University*. Hyderabad, India.

Kumar, A., Singh, R. K. P. K., Singh, M., & Mishra, J. S. (2018). Economics of paddy (*Oryza sativa*) production: A comparative study of Bihar and Punjab. *Indian Journal of Agricultural Sciences*, *88*(2), 314–319.

Lampayan, R. M., Rejesus, R. M., Singleton, G. R., & Bouman, B. A. M. (2015). Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Research*, *170*, 95–108. Malik, R. K., Kamboj, B. R., Jat, M. L., Sidhu, H. S., Bana,

A., Singh, V., Saharawat, Y. S., Pundir, A., Sahnawaz, R. D., Anuradha, T., & Kumaran, N. (2019). No-till and unpuddled mechanical transplanting of rice-operational manual. *Gates Open Research*, *3*.

Pandian, B. J. (2012). System of Rice Intensification (SRI) enhances water productivity in rice. International symposium on 100 years of rice science and looking beyond (pp. 499–450). Tamil Nadu Agricultural University.

Rajesh, V., & Thanunathan, K. (2003). Effect of seedling age, number and spacing on yield and nutrient uptake of traditional Kambanchamba rice. *Madras Agriculture Journal*, *90*, 47–49.

Saharawat, Y. S., Singh, B., Malik, R. K., Ladha, J. K., Gathala, M., Jat, M. L., & Kumar, V. (2010). Evaluation of alternative tillage and crop establishment methods in a rice-wheat rotation in North Western IGP. *Field Crops Research*, *116*(3), 260–267.

Sain, M. 2020. Production of bioplastics and sustainable packaging materials from rice straw to eradicate stubble burning: A mini-review. Environment Conservation Journal, 21(3), 1-5.

Sanjay, K., Ashok, K. S., Singh, G., Nareshmani, P., Ajit, K., & Dinesh, K. (2018). Effect of establishment methods and weed management practices on the growth and yield of direct seeded rice (*Oryza sativa* L.). *Journal of Pharmacognosy and Phytochemistry*, *7*(1), 164–168.

Satyanarayana, A., & Babu, K. S. (2004). A revolutionary method of rice cultivation. In *Manual on system of rice intensification (SRI)* p. 6. Acharya N G Ranga Agricultural University.

Shantappa, D. (2014). *Studies on establishment techniques, irrigation water levels and weed management practices on productivity and emission of green house gasses (Ghgs) in rice (Oryza sativa L.)* [PhD Thesis] submitted to University of Agricultural Sciences. Raichur, India.

Sowmyalatha, B. S. (2015). *Standardization of agro-techniques for mechanized system of rice (Oryza sativa L.) intensification* [PhD Thesis] submitted to University of Agricultural Sciences. Bangalore, India.

Subramaniam, G., Kumar, M. R., Humayaun, P., Srinivas, V., Kumari, R. B., Vijayabharathi, R., Singh, A., Surekha, K., Padmavathi, C. H., Somashekar, N., Rao, R. P., Latha, P. C., Rao, S. L. V., Babu, V. R., Viraktamath, B. C., Goud, V. V., Gujja, B., & Om, R. (2013). Assessment of different methods of rice cultivation affecting growth parameters, soil chemical, biological and microbiological properties, water saving and grain yield in rice-rice system. *Paddy and Water Environment*, 254–263.

Yadav, D. B., Yadav, A., & Punia, S. S. (2009). Evaluation of bispyribac-sodium for weed control in transplanted rice. *Indian Journal of Weed Science*, *41*(1–2), 23–27.

Yamano, T., Arouna, A., Labarta, R. A., Huelgas, Z. M., & Mohanty, S. (2016). Adoption and impacts of international rice research technologies. *Global Food Security*, *8*, 1–8.