Agronomic Practices to Enhance Nutrient Acquisition, Grain Quality, Resource-Use Efficiency in Direct-Seeded Aerobic Rice in Eastern India

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Authors’ contributions

This work was carried out in collaboration among all authors. Author AD conceptualized and designed the research, guided collection of data and statistical analyses and edited manuscript. Authors SD, AKC and RS contributed in planning of research and editing of manuscript. Author AS collected crop data, did all required computations and prepared first draft. Author CVS laid-out experiment and managed experimental crop. Authors GAR, SC and AP contributed in chemical analysis of soil and plant samples. All authors read and approved the final manuscript.

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ABSTRACT

Aim: Rice (Oryza sativa L.) is mainly grown in the rainy season in eastern India on rainfed uplands with a low average productivity of 1.0-1.4 t ha⁻¹. Erratic rainfall leading to moisture stress and poor cultivation practices are the key reasons for low yields and rice grain quality in the area. Hence, the current study was designed to investigate the effects of irrigation scheduling, soil adjuvant and sowing methods on yield, grain quality and resource-use efficiency in aerobic rice.

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Methodology: The experiment was conducted in a three-time replicated split-plot design during rainy-season of 2016 on a sandy loam soil in Eastern India. Treatments included 8 combinations of 4-irrigation schedules, viz., irrigation at IW/CPE 0.9, 1.2, 1.5 and no-irrigation (rainfed) and 2-soil adjuvants (soil adjuvant applied and no-soil adjuvant) assigned to main-plots, and 2-planting methods (conventional dry seeding at 20 cm row spacing and spot-sowing (dibbling of 4-seeds hill⁻¹ at 20×15 cm interval) assigned to sub-plots.

Results: Irrigation at IW/CPE 1.5 increased grain yield by 37.3% over rainfed crop, 23% over crop irrigated at IW/CPE 0.9 and 13.5% over IW/CPE 1.2. Grain quality parameters were also best, in crop watered at IW/CPE 1.5. Net return, B: C ratio, net energy output, production efficiency (PE) and monetary efficiency (ME) were significantly greater with irrigation at IW/CPE 1.5 compared to other irrigation schedules. Spot-sowing proved superior to conventional drilling of seeds exhibiting about 7% improvement in grain yield and water-use efficiency (WUE). Effect of soil adjuvant application was not significant.

Interpretation: This study emphatically demonstrated that aerobic rice should be spot-sown and irrigated at IW/CPE 1.5, for obtaining higher yield with better grain quality. The findings are useful for aerobic rice production in eastern India and adjoining sub-humid regions.

Keywords: Aerobic rice; grain quality; nutrient harvest index; soil adjuvant; spot-sowing; water-use efficiency.

1. INTRODUCTION

For millions of people worldwide, rice (Oryza sativa L.) is the staple food that forms a key energy source for over 50% of the world’s population [1,2]. In Eastern India, rice is predominantly grown on rainfed uplands in rainy season (June-October) with low average productivity of about 1–1.4 t ha⁻¹. The most important reason for low yields and quality of rice grain in rainfed tracts of eastern India is the erratic rainfall. Long dry-spells of 15–20 days, as have been seen in the last decade and a low water holding capacity (WHC) of soil exposes the rainfed rice crop to the extreme water-stress, and a very high rainfall occasionally damages lowland rainfed rice by causing lodging and upland rice by removing nutrient-rich top-soil, rendering soil deficient in both nutrients and water [3]. In irrigated areas, the declining availability and increasing costs of water, shortage of labour during transplanting time and escalating labour cost constraint the traditional method of producing irrigated rice production. Thus, new agronomic practices need to be developed and standardized to cope up the water scarcity for rice cultivation. Among water-saving rice technologies, aerobic rice provides the highest yield per unit of water used. With reduced percolation, infiltration and evaporative losses, aerobic rice systems can save 44% irrigation water over traditional transplantation (CT), while maintaining yield at a reasonable level of 6 t ha⁻¹ [4]. Maheswari et al. [5] observed higher growth and yield of aerobic rice under irrigations scheduled at IW/CPE 1.2. Whereas, Malamasuri et al. [6] and Dari et al. [7], reported higher yield of direct-seeded rice (DSR) under irrigations applied at IW/CPE ratio 1.5–2.0. However, irrigating DSR at such a higher IW/CPE ratio (>1.5) envisaging irrigations at relatively shorter intervals compared to lower IW/CPE ratio, may not be feasible under ever-growing shortage of irrigation water across the world. In-fact under any method of cultivation, optimum water supply is the main factor governing availability and uptake of essential nutrients, growth, yield and quality of the rice [8]. The adverse effects of water stress on crop yield, nutrient absorption and quality may be minimized by altering the properties of irrigation water itself, which helps boost soil WHC, which in turn, makes it easier for the soil to absorb and maintain greater amounts of water for extended period of time [9]; this can be achieved by the use of adjuvants that accelerate the speed of water penetration into the soil micro-pores, and interstices and, thereby, reduce water loss through evaporation and deep percolation. An adjuvant would function by reducing the surface tension of a fluid at the interface between compounds. Their mode of action enables water to penetrate and thoroughly wet the soils to substantially improve the WUE and the quality of the crop produced. A critical level of plant population is pre-requisite to obtaining high yields with better grain quality. Since the number of panicles per unit area is the major yield determinant [10], ensuring adequate plant stand and thereby adequate number of healthy
panicles per unit area, is of enormous significance. Zhou et al. [11] reported that rice grain quality was superior in lower or medium population density than highly populated plots. Similarly, Xu et al. [12] reported that reductions in planting density resulted in significantly higher protein content in milled rice. Several workers have suggested a row spacing of 20–35 cm to be ideal for the planting of aerobic rice. No reports are available on the effects of planting patterns (spot-planting or point planting-dibbling 4–5 seeds per hill at 10–20 cm intra-row interval with rows ideally spaced at 20–25 cm distance). Thus, the current experiment designed to investigate the effects of irrigation scheduling, soil adjuvant and sowing methods on: (i) yield, grain quality and nutrient harvest index, and (ii) economics and resource-use efficiency in aerobic rice.

2. MATERIALS AND METHODS

The field experiments on aerobic rice were laid-out at Central Rainfed Upland Rice Research Station, Hazaribagh (23°56’34″ N and 85°21’46″ E with an altitude of 614 m above mean sea level), Jharkhand, India. The clay loam soil of the experimental field was neutral in reaction and medium fertility. Field capacity of the surface soil (0-15 cm) was 28.72% and permanent wilting point in 14.87%. The initial chemical and physical properties of the soil determined by using method described by Dass et al. [13] and Rana et al. [14] are shown in Table 1. The experimental site has warm and humid climate with a mean maximum temperature 31.4°C and mean minimum temperature of 13.7°C. The rainfall of the district is 1083.9 mm [15]. During the current experiment period, July (329 mm) and August (406 mm) months received sufficient and well distributed rainfall. Total rainfall during crop period was (1237 mm) with September month receiving the highest rainfall (431 mm), but not well distributed (Fig. 1).

The three-time replicated field experiment was conducted in a split-plot design keeping 8-combinations of 4-irrigation schedules and 2-soil adjuvants (Adjuvant applied-APSA80™ and without-adjuvant) in the main-plots and 2-planting methods in the sub-plots; thus, making a total of 16 treatment combinations.

Among the several approaches of scheduling irrigation, IW/CPE ratio is one of the easiest, dependable cost-effective and quickest methods, hence was used in the current experiment. In this present experiment, a common irrigation was given 1 week after seeding. Five centimetre depth of water was applied as soon as the cumulative pan-evaporation (CPE) reached 56, 42, and 33 mm desired to get irrigation water (IW)/CPE ratio of 0.9, 1.2 and 1.5, respectively. The quantity of water applied to each plot was the product of the depth of irrigation (50 mm) and area of the plot. Soil adjuvant (APSA 80™) was applied on soil surface twice @ 450 ml ha⁻¹ dissolved in 500 litres of water, at tillering and panicle emergence stages.

![Fig. 1. Weekly weather parameters of experimental site](image-url)
Sahabhagi Dhan, a high-yielding rice variety, was used in the experiment. Sowing was done using pre-determined methods, namely conventional planting and spot-sowing. In conventional planting, rice seeds were manually drilled in rows spaced 20 cm apart using seed rate of 60 kg ha⁻¹. In spot-sowing method, four seeds were dibbled per hill at 20x15 cm spacing manually, which required 30 kg seed ha⁻¹. All plots were evenly fertilized with 120 kg N, 60 kg P₂O₅ and 30 kg K₂O, as nutrient supplementation. N was supplied through urea and diammonium phosphate (DAP). P and K were supplied through DAP and muriate of potash, respectively. Half of N and entire amounts of P, K were incorporated basally just before planting. The remaining amount of N was top-dressed in two equal instalments, the first at active tillering and the second at panicle initiation stage. For management of weeds pendimethalin @ 1.0 kg ha⁻¹ and bispopyrubic-Na @ 0.025 kg ha⁻¹ applied as pre-emergence and post-emergence, respectively.

For computing grain and biological yields, all rice plants from the net-plot area of 16.38 m² were harvested plot-wise, dried, thrashed and weighed. From each plot, 200 g sun-dried paddy (whole grains) samples drawn and hulled in a mini rice mill and weight of brown rice taken. Hulling percentage was computed by dividing the weights of brown rice by rough rice multiplied with 100. The hulled brown rice was passed through rice whitening machine for 2 minutes to get the milled rice. Milling percentage was calculated by dividing the milled rice by brown rice multiplied with 100. For estimating head rice recovery, the milled rice was sieved using proper appropriate sieves to distinguish whole kernels from the broken ones. Small proportion of whole kernels which passed through the sieve along with broken ones was hand-separated. Percentage of head rice recovery was calculated by dividing the weight of whole milled rice by weight of rough rice multiplied with 100. Crude protein content in rice grain was determined by multiplying N--conc. with Jone’s factor 5.95 [16], and expressed in percentage. WUE calculated by dividing the grain yield with total water used (irrigation + effective rainfall), and expressed as kg ha-mm⁻¹. The economics of treatments was worked on the basis of prevailing market prices of inputs and outputs. PE (kg ha⁻¹ day⁻¹) was computed as total seed yield (kg ha⁻¹) divided by crop duration (days) and ME (¥ ha⁻¹ day⁻¹) was computed as total net returns (¥ ha⁻¹) divided by crop duration (days). In order to assess the energy dynamics and energy-use efficiency (EUE), each and every input used in rice production and the respective output was converted into the form of energy using energy equivalents. The energy efficiencies were also calculated using the following formulae as suggested by Mittal and Dhawan [17]; Babu et al. [18]; Singh et al. [19].

\[
\text{EUE} = \frac{\text{Energy output (MJ ha}^{-1})}{\text{Energy input (MJ ha}^{-1})}.
\]

Energy productivity (kg MJ⁻¹) = Product output (kg ha⁻¹)/energy input (MJ ha⁻¹).

Specific energy (MJ kg⁻¹) = Energy input (MJ ha⁻¹)/product output (kg ha⁻¹).

Table 1. Initial physical and chemical properties of experimental soil

| Particular                              | Content |
|-----------------------------------------|---------|
| A. Physical characteristics             |         |
| Mechanical composition                  |         |
| Sand                                    | 26      |
| Silt                                    | 43      |
| Clay                                    | 31      |
| Textural class                          | Clay loam |
| Moisture at 1/3 atm tension (%)         | 28.72   |
| Moisture at 15 atm tension (%)          | 14.87   |
| Bulk density (0–15 cm layer) (g cm⁻³)   | 1.35    |
| B. Chemical characteristics             |         |
| Organic carbon (%)                      | 0.62    |
| Alkaline-permanganate oxidizable N (kg ha⁻¹) | 153 |
| Available phosphorus (P kg ha⁻¹)        | 11.3    |
| Available potassium (K kg ha⁻¹)         | 380     |
| Available iron (Fe mg kg⁻¹)             | 13.42   |
| Available zinc (Zn mg kg⁻¹)             | 2.79    |
| pH (1:2.5 soil: water)                  | 6.8     |
Net energy (MJ ha\(^{-1}\)) = Energy output (MJ ha\(^{-1}\)) − energy input (MJ ha\(^{-1}\)).

NHI computed as ‘uptake of a nutrient by grain/total uptake of that nutrient in biomass × 100’ [20]. The statistical analysis of the experimental data was done using analysis of variance (ANOVA) technique. The significance of treatment means was tested using F-test [14]. The critical difference (P=0.05) was worked out to evaluate differences between treatment means.

3. RESULTS AND DISCUSSION

3.1 Grain and Biological Yields

Rice, being a water-loving plant has a high water requirement, and when cultivated under aerobic conditions frequency of irrigation is immensely important in maintaining ideal soil-moisture regimes throughout crop period, as occurrence of water stress has been shown to be one of the reasons for low yield and poor quality of aerobic rice by hampering photosynthesis and other vital physiological processes [21,10]. Since rainfall was not adequate and also not well distributed, particularly during reproductive stages of the experimental crop, irrigation schedules did influence the grain and biomass yields significantly. Frequent irrigation at IW/CPE ratio 1.5, resulted in the highest grain yield that was significantly than all other treatments, the increase being 37.3% over rainfed crop, 23% over crop irrigated at IW/CPE 0.9 and 13.5% over IW/CPE 1.2: Irrigation at IW/CPE 1.2 and 0.9 significantly enhanced grain yield over water-stressed rainfed crop (Table 2). The similar effects of irrigation regimes were also reported on biological yield. Frequent irrigations (at IW/CPE 1.5 and 1.2) created desirable soil water conditions enabling the rice plants grow copiously and yield higher grain and biomass by providing conducive micro-climate and enhanced solubility of nutrients in the soil and higher absorption, translocation and assimilation of nutrients, especially P, iron (Fe) and manganese (Mn) by the plants for various physiological processes [22,7]. Effect of soil adjuvant on grain and biological yields was non-significant. This was due to higher rainfall after the application of the adjuvant, which nullified its positive impact on soil moisture-retention longevity. Spot-sowing improved grain yield by about 7% over conventional method of planting. A significant improvement of grain and biological yield in wide-spaced spot-sowing method might be due to the tillering elasticity properties of rice which leads to higher vigorous growth of plant in less competition condition. Wider spacing, as was maintained in the current experiment, enhances dry matter accumulation in stems and grains by improving root growth, water and nutrients acquisition, and exposure of plants to sunlight and CO\(_2\) leading to higher production and movement of carbohydrates from leaves to stems and grains [10]. Higher dry matter accumulation and yield of crop under wider spacing stem from higher net photosynthetic rate [10] and root activity, number of functional leaves and leaf area.

3.2 Economics

The cost of cultivation was highest with the irrigations applied at IW/CPE 1.5 largely due to higher number of irrigations (34.55 × 10\(^3\) ₹ ha\(^{-1}\)). The highest net return (46.78 × 10\(^3\) ₹ ha\(^{-1}\)) was found in treatment involving irrigations at IW/CPE 1.5 due enhancement grain (37.3%) and straw (12.1%) yields over the rainfed treatment. The net return from crop irrigated at IW/CPE 1.5 was 46.1% higher over the rainfed crop. Spot-sowing in spite of of higher cost of production, fetched 7.2% higher net return with higher B: C ratio over conventional method (Table 2), mainly due to greater grain and straw yields. A little increase in yield did not compensate the additional cost incurred by use of soil adjuvant, and hence net returns were statistically alike for the adjuvant applied and not applied plots.

3.3 Production Efficiency, Monetary Efficiency and Water-Use Efficiency

Higher grain and biological yields of the crop irrigated at IW/PE of 1.5 and 1.2 got reflected in the higher PE of 36.94 and 33.12 kg ha\(^{-1}\) day\(^{-1}\), respectively; which was 1.2 and 1.3 times higher than rainfed crop (28.45 kg ha\(^{-1}\) day\(^{-1}\)). Soil adjuvant effect on PE was non-significant as was on yields. By virtue of higher grain yield, spot-planting returned 6% higher PE over conventional planting (33.36 kg ha\(^{-1}\) day\(^{-1}\)). Like PE, the highest ME was recorded with irrigation at IW/CPE 1.5 followed by IW/CPE 1.2 and 0.9; rainfed crop bore the lowest ME (Table 2). These variations in the ME are directly related to the influence of these irrigation regimes on grain yield and net returns. Spot-planting improved ME by 7% over conventional method, consequent to 7.2% rise in grain yield. Soil adjuvant did not improve ME because of lower net return due to additional cost incurred on the use of soil adjuvant and a small yield increment.
Table 2. Effect of irrigation regimes, soil adjuvant and planting methods on yield, economics, monetary efficiency, production efficiency and water-use efficiency of aerobic rice

| Treatment                          | Grain yield (t ha\(^{-1}\)) | Biological yield (t ha\(^{-1}\)) | Cost of cultivation (×10\(^{3}\) ₹ ha\(^{-1}\)) | Net return (₹ ha\(^{-1}\)) | B:C ratio | Monetary efficiency (₹ ha\(^{-1}\) day\(^{-1}\)) | Production efficiency (kg ha\(^{-1}\) day\(^{-1}\)) | Water-use efficiency (kg ha-mm\(^{-1}\)) |
|-----------------------------------|-----------------------------|---------------------------------|-----------------------------------------------|----------------------------|-----------|-----------------------------------------------|-----------------------------------------------|----------------------------------|
| Irrigation (IW/CPE ratio)         |                             |                                 |                                               |                           |           |                                               |                                               |                                  |
| 0.9                               | 3.35                        | 9.35                            | 30.57                                         | 36.73                     | 1.16      | 309.5                                         | 31.20                                         | 3.23                             |
| 1.2                               | 3.63                        | 9.88                            | 31.37                                         | 40.68                     | 1.20      | 339.9                                         | 33.12                                         | 3.37                             |
| 1.5                               | 4.12                        | 10.53                           | 34.55                                         | 46.24                     | 1.30      | 383.6                                         | 36.94                                         | 3.29                             |
| Rainfed                           | 3.00                        | 8.72                            | 28.19                                         | 32.78                     | 1.34      | 277.9                                         | 28.45                                         | 3.35                             |
| SEM±                              | 0.10                        | 0.20                            | 1.65                                          | 0.05                      | 15.13     | 0.892                                         | 0.09                                           |                                  |
| CD (P=0.05)                       | 0.30                        | 0.60                            | 5.031                                         | 0.155                     | 45.91     | 2.71                                          | NS                                              |                                  |
| Soil adjuvant (SA)                |                             |                                 |                                               |                           |           |                                               |                                               |                                  |
| SA-applied                        | 3.55                        | 9.63                            | 31.70                                         | 38.99                     | 1.23      | 328.8                                         | 32.63                                         | 3.33                             |
| SA-not applied                    | 3.50                        | 9.54                            | 30.65                                         | 39.23                     | 1.27      | 326.6                                         | 32.22                                         | 3.29                             |
| SEM±                              | 0.07                        | 0.10                            | 1.173                                         | 0.036                     | 10.70     | 0.631                                         | 0.06                                           |                                  |
| CD (P=0.05)                       | NS                          | NS                              | NS                                            | NS                        | NS        | NS                                            | NS                                              |                                  |
| Planting method                   |                             |                                 |                                               |                           |           |                                               |                                               |                                  |
| Conventional                      | 3.41                        | 9.40                            | 30.46                                         | 37.75                     | 1.23      | 316.6                                         | 31.49                                         | 3.20                             |
| Spot-planting                     | 3.64                        | 9.77                            | 31.88                                         | 40.47                     | 1.27      | 338.8                                         | 33.36                                         | 3.42                             |
| SEM±                              | 0.05                        | 0.07                            | 0.74                                          | 0.026                     | 6.99      | 0.461                                         | 0.05                                           |                                  |
| CD (P=0.05)                       | 0.15                        | 0.21                            | 2.227                                         | NS                        | 20.95     | 1.38                                          | 0.16                                           |                                  |
WUE can be raised either by raising yield with same level of WU or by reducing WU maintaining same or little lower level of yield. Often, WUE rises with fall in WU as yield improvement is not always proportionate to the increments in the WU [23]. In the current study, the highest WUE was found in rainfed crop, which was, however, at par with IW/CPE 1.5, 1.2 and 0.9 (Table 2). The total saving of irrigation water by not applying any irrigation to aerobic rice (rainfed treatment) was 142 mm, 178 mm and 355 mm compared to irrigations at IW/CPE 0.9, 1.2 and 1.5 ratio, respectively. Yet, the WUE in rainfed crop that received much less quantity of water (rainfall only), did not differ significantly from WUE achieved with any of the irrigation schedule, because the grain yield from the rainfed crop was much lower than the irrigated crop. The grain yield was 37.3% higher from the crop irrigated at IW/CPE 1.5 over rainfed crop but the WU was also higher, thus WUE of both crops stood close to each other. Since grain yield and WU were alike between soil adjuvant applied and not applied plots, WUE also did not differ between them. Spot-sowing at a wider spacing resulted in about 7% increase in WUE over conventional dry seeding method; a significant increase in grain yield led to higher WUE recorded with wider over closer spacing [23,24].

3.4 Crop Quality Parameters, Nutrient Harvest Index

The physical quality parameters, viz. hulling (81.7%), milling (68.6%), and head rice recovery (58.6%), were best with irrigation at IW/CPE 1.5, which were, however, comparable with IW/CPE 1.2 and 0.9 (Table 3). As expected, the lowest values of all these grain quality parameters, but higher broken rice content, were observed in rainfed crop. Maintenance of adequate water in root-zone as a result of irrigation, aids the soil and applied nutrient availability, their uptake, translocation and assimilation, which ultimately leads higher yield with improved grain quality [25]. The principal indicator of chemical grain quality is the amount of protein content; the higher the content of protein, the higher the quality of rice grain. Therefore, in hulling and milling operations, the breakage of rice depends on the amount of protein content in the rice grain. The higher protein content lessens rice breakage. The head rice (full-length rice) recovery is partly depends on the protein content in it. In the present investigation protein content of aerobic rice did not differ significantly, however higher protein content was observed in plots irrigated at IW/CPE 1.5 ratio. Soil adjuvant application and sowing method did not cause significant improvement in any of the above grain quality parameters.

Nutrient harvest index (NHI) shows the portioning of the total uptake of a nutrient between economic part and biomass. More frequent irrigation (IW / CPE 1.5) contributes to higher P and K availability, uptake and translocation, resulting in higher P-NHI and K-NHI; the lowest NHI of P and K, presumably due to water stress, was observed in the rainfed treatment (Table 3). Effect of irrigation scheduling on N-NHI was found non-significant. Likewise, soil adjuvant application had no impact on NHI of any nutrient. Compared to conventionally sown rice, spot-planting of aerobic rice depicted positive impact on the P- and K-NHI. This could likely be due to the less competition among rice plants for nutrients under widely spaced spot-planted rice.

3.5 Energy Dynamics

Although field operations like, tillage, weed management, fertilizer rates, diseases, and pest control were common for all treatments, the quantity of seed, planting methods, soil adjuvant, and number of irrigations, was different. Hence, the resultant total energy input also varied among different (Range 2420–16626 MJ ha\(^{-1}\)) (Table 4). Concerning irrigation schedules, the trend of energy input followed the order of IW/CPE 1.5 > 1.2 > 0.9 > rainfed crop. Between the two planting methods, conventionally sown rice involved higher amount of energy input mainly due to the use of 30 kg ha\(^{-1}\) additional quantity of seed.

Applying irrigation at IW/CPE 1.5 returned the highest grain energy output, total energy output and net energy output. All irrigation schedules were superior to rainfed crop for all energy outputs, due to significantly higher grain (11.67 to 37.33%) and biological (7.22 to 20.76%) yields in irrigated crop. Specific energy was also highest with irrigation at IW/CPE 1.5 and lowest in rainfed crop, because the former treatment involved greater amount of power in the form of irrigation water, but increase in the energy output, as usual, was not proportionate. Energy outputs and specific energy were alike in adjuvant applied and control treatments due to similar yields. Spot-planting improved the grain, total and net energy output by 6.88, 4.11 and 4.99%, respectively. Whereas, EUE and EP were
both highest in rainfed crop, however, IW/CPE 1.2 was at par with rainfed crop for EUE. These results indicate that although irrigation at frequent intervals (IW/CPE 1.5) increased grain and biomass yields but the increase was not in proportion to the increase in energy use, hence leading to lower EUE and EP. Use of soil adjuvant reduced EP by 3.03% because of higher energy input with minimal improvement in yield, due to its application. Spot-planting of aerobic rice exhibited higher EUE over the conventional planting because it required lower energy input and enhanced grain and straw yield significantly.

Table 3. Effect of irrigation regimes, soil adjuvant and planting methods on quality parameters and nutrient harvest index of aerobic rice

| Treatment                          | Hulling (%) | Milling (%) | Head rice recovery (%) | Broken rice (%) | Protein (%) | Nutrient harvest index (%) |
|------------------------------------|-------------|-------------|------------------------|----------------|-------------|---------------------------|
|                                    |             |             |                        |                |             | N | P | K |
| Irrigation (IW/CPE ratio)          |             |             |                        |                |             |   |   |   |
| 0.9                                | 77.9        | 66.0        | 54.8                   | 45.2           | 6.78        | 56.24  | 43.62 | 9.16 |
| 1.2                                | 78.3        | 66.0        | 56.4                   | 43.6           | 7.04        | 57.77  | 45.51 | 10.11 |
| 1.5                                | 81.7        | 68.6        | 58.6                   | 41.4           | 7.11        | 58.47  | 47.69 | 10.63 |
| Rainfed                            | 75.4        | 64.1        | 52.9                   | 47.0           | 6.71        | 56.36  | 43.90 | 8.66 |
| SEm± (P=0.05)                      | 1.71        | 1.23        | 1.31                   | 1.31           | 0.17        | 0.755  | 0.806 | 0.256 |
| Soil adjuvant                      |             |             |                        |                |             |   |   |   |
| SA-applied                         | 78.6        | 66.6        | 55.8                   | 44.2           | 6.93        | 57.07  | 45.49 | 9.66 |
| SA-not applied                     | 78.1        | 65.8        | 55.5                   | 44.5           | 6.89        | 57.35  | 44.87 | 9.61 |
| SEm±                               | 1.21        | 0.86        | 0.93                   | 0.93           | 0.11        | 0.534  | 0.570 | 0.181 |
| CD (P=0.05)                        | NS          | NS          | NS                     | NS             | NS          | NS | 2.44 | 0.78 |
| Planting method                    |             |             |                        |                |             |   |   |   |
| Conventional                       | 77.8        | 65.7        | 54.6                   | 45.4           | 6.87        | 56.91  | 44.41 | 9.49 |
| Spot-planting                      | 78.8        | 66.7        | 56.8                   | 43.24          | 6.96        | 57.51  | 45.95 | 9.78 |
| SEm±                               | 0.79        | 0.77        | 0.96                   | 0.961          | 0.11        | 0.600  | 0.456 | 0.120 |
| CD (P=0.05)                        | NS          | NS          | NS                     | NS             | NS          | NS | 1.37 | 0.36 |

Table 4. Effect of irrigation regimes, soil adjuvant and planting methods on energy input, output and their efficiencies

| Treatment                          | Energy input (MJ ha\(^{-1}\)) | Grain energy output (MJ ha\(^{-1}\)) | Total energy output (MJ ha\(^{-1}\)) | Net energy (MJ ha\(^{-1}\)) | Energy-use efficiency | Energy productivity (kg MJ\(^{-1}\)) | Specific energy (MJ kg\(^{-1}\)) |
|------------------------------------|-------------------------------|--------------------------------------|---------------------------------------|-----------------------------|------------------------|--------------------------------------|-----------------------------|
|                                    |                               |                                      |                                       |                             |                        |                                      |                             |
| Irrigation (IW/CPE ratio)          |                               |                                      |                                       |                             |                        |                                      |                             |
| 0.9                                | 13997                         | 48868                               | 123665                                | 109667                      | 8.84                   | 0.67                                | 1.49                         |
| 1.2                                | 14523                         | 52848                               | 129133                                | 114609                      | 8.90                   | 0.68                                | 1.47                         |
| 1.5                                | 16626                         | 60013                               | 140200                                | 123574                      | 8.44                   | 0.61                                | 1.67                         |
| Rainfed                            | 12420                         | 43745                               | 115240                                | 102819                      | 9.28                   | 0.72                                | 1.40                         |
| SEm±                               | -                             | 1425                                | 2275                                  | 2275                        | 0.164                  | 0.008                               | 0.017                        |
| CD (P=0.05)                        | -                             | 4324                                | 6903                                  | 6903                        | 0.50                   | 0.02                                | 0.05                         |
| Soil adjuvant                      |                               |                                      |                                       |                             |                        |                                      |                             |
| SA-applied                         | 14530                         | 51686                               | 127661                                | 114267                      | 8.82                   | 0.66                                | 1.52                         |
| SA-not applied                     | 14253                         | 51051                               | 126457                                | 105971                      | 8.91                   | 0.68                                | 1.49                         |
| SEm±                               | -                             | 1007                                | 1609                                  | 1609                        | 0.116                  | 0.005                               | 0.012                        |
| CD (P=0.05)                        | -                             | NS                                  | NS                                    | NS                          | NS                     | 0.02                                | NS                           |
| Planting method                    |                               |                                      |                                       |                             |                        |                                      |                             |
| Conventional                       | 14571                         | 49660                               | 124499                                | 109927                      | 8.57                   | 0.67                                | 1.49                         |
| Spot-planting                      | 14212                         | 53077                               | 129620                                | 115407                      | 9.16                   | 0.67                                | 1.52                         |
| SEm±                               | -                             | 714                                 | 640                                   | 640                         | 0.046                  | 0.007                               | 0.015                        |
| CD (P=0.05)                        | -                             | 2143                                | 1920                                  | 1920                        | 0.14                   | NS                                  | NS                           |
4. CONCLUSION

This study vividly demonstrated that aerobic rice should be spot-sown and irrigated at IW/CPE 1.5, for obtaining higher yield with better grain quality. Irrigation at IW/CPE 1.5 means shorter irrigation intervals compared to lower IW/CPE (1.2, 0.9). However, under the circumstances of limited irrigation water availability, as seen in a larger chunk rice-growing Asian countries, the demonstrated higher WUE with irrigation at IW/CPE 1.2 (longer irrigation interval) convincingly imply that it could be a beneficial option to irrigate aerobic rice following this irrigation schedule with a little loss in yield as the irrigation water so saved could be used for bringing additional area under irrigation. The findings are useful for aerobic rice production in eastern India and in adjoining sub-humid regions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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