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Review Article

Yield and water use efficiency of rice (*Oryza sativa* L.) relative to scheduling of irrigations

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Abstract: Irrigation scheduled at seven days' interval during vegetative stage and four days' interval during reproductive stage resulted in significantly higher panicle number and panicle weight, filled grains panicle^{-1} and grain yield. Permanent irrigation and interval irrigation methods had higher yield in comparison with saturated irrigation method in rice. Dry seeded rice significantly increased the water productivity with respect to irrigation water over wet seeded and transplanted rice. Intermittent irrigation in rice cultivation may reduce irrigation water use considerably (27-37%) compared with flooded rice cultivation. aerobic rice significantly required less water (67.91 ha^{-1} cm) to produce higher or on par yield as compared to transplanted puddled rice (122.59 ha^{-1} cm). Similarly, WUE was significantly higher in aerobic rice (81.31 kg ha^{-1} cm) as compared to transplanted rice (36.12 kg ha^{-1} cm). The irrigation schedule having three days' drainage period after disappearance of ponded water yielded rice higher with maximum water use efficiency compared to continuous submergence or submergence at critical stages such as tillering, panicle initiation, flowering and milk, followed by saturation or field capacity between intermittent periods.

Key words: Irrigation schedules; Rice; water requirement; water use efficiency; yield

Introduction

Irrigation scheduling is the process used by irrigation system managers to determine the correct frequency and duration of watering.

The following factors may be taken into consideration:

- Precipitation rate of the irrigation equipment - how quickly the water is applied, often expressed in inches or mm per hour.
- Distribution uniformity of the irrigation system - how uniformly the water is applied, expressed as a percentage, the higher the number, the more uniform.
- Soil infiltration rate - how quickly the water is absorbed by the soil, the rate of which also decreases as the soil becomes wetter, also often expressed in inches or mm per hour.
- Soil available water capacity, expressed in units of water per unit of soil, i.e. inches of water per foot of soil.
- Effective rooting depth of the plants to be watered, which affects how much water can be stored in the soil and made available to the plants.
- Current watering requirements of the plant (which may be estimated by calculating evapotranspiration, or ET), often expressed in inches per day.
- Amount of time in which water or labor may be available for irrigation.
- Amount of allowable moisture stress which may be placed on the plant. For high value vegetable crops, this may mean no allowable stress, while for a lawn some stress would be allowable, since the goal would not be to maximize production, but merely to keep the lawn green and healthy.
- Timing to take advantage of projected rainfall
- Timing to avoid interfering with other activities such as sporting events, holidays, lawn maintenance, or crop harvesting.

The goal in irrigation scheduling is to apply enough water to fully wet the plant's root zone while minimizing overwatering and then allow the soil to dry out in between waterings, to allow air to enter the soil and encourage root development, but not so much that the plant is stressed beyond what is allowable. In recent years, more sophisticated irrigation controllers have been developed that receive ET input from either a single on-site weather station or from a network of stations and automatically adjust the irrigation schedule accordingly. Other devices helpful in irrigation scheduling are rain sensors, which automatically shut off an irrigation system when it rains, and soil moisture sensing devices such as capacitance sensors, tensiometers and gypsum blocks. Rapid degradation of rice ecologies due to imbalanced use of fertilizers and unscientific water management has put tremendous pressure on the rice growers to make rice farming economically viable and ecologically sustainable. Scientific irrigation scheduling should go with an understanding of soil-water-plant-atmospheric continuum. Irrigation water economy can be aimed through appropriate irrigation schedules. There are several approaches for scheduling irrigation of field crops of which moisture regimes and climatological approach are found to be reliable and dependable.

Critical stages of water requirement

Critical stage refers to a stage when water scarcity or deficit of water causes comparatively greater reduction in yields which cannot be made by favourable water supply at earlier or later stages. Hence, water deficit during these stages should be avoided. Following are the important critical crop growth stages for water stress.

(a) Tillering
(b) Panicle initiation
(c) Boot leaf stage
(d) Heading/ panicle emergence
(f) Flowering/anthesis (Reproductive phase)

During these stages, soil moisture level should be maintained at saturation level

- Moisture stress at active tillering phase - 30% yield reduction
- Moisture stress at reproductive phase - 50 - 60% yield reduction

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Precautions for irrigation

- Withhold water for few days till the seedlings have established.
- Field to field irrigation should be avoided.
- Drain-off water for about 2 days prior to the application of fertilizers.
- Small bund may be formed parallel to the main bund of the field at a distance of 30 to 45cm within the field to avoid leakages of water through main bund crevices.
- To minimize percolation loss, the depth of stagnated water should be 5cm or less.
- In water logged conditions provide open drains about 60cm in depth and 45cm width across the field. Care should be taken not to allow development of cracks.
- In canal command area, conjunctive use of surface and ground water may be resorted to for judicious use of water.
- Where irrigation facilities are not available, store all the rain water in paddy fields by making 25 to 30 cm raised bunds.
- Maintain about 8-10 cm of water level in the fields at puddling time and subsequently depth of ponded water may be maintained throughout the growing period
- Drain-off water completely for 5 to 7 days following tillering and flowering stages. This helps to remove the toxic substances like sulphides and regulates oxygen supply to roots

The effect of scheduling of irrigations on rice yield and water use efficiency are reviewed as below

Effect of irrigation schedules on yield

In 31 field experiments analyzed by Bouman and Tuong (2001), 92 per cent of the alternate wetting and drying (AWD) treatments resulted in yield reductions varying from just more than zero per cent to seventy per cent compared with those of the flooded checks. At Coimbatore, irrigation of semi-dry rice with a water depth of 5 cm at weekly intervals upto 45 and 60 Days After Emergence (DAE) resulted in significantly superior yield compared to fortnightly irrigations (Thyagarajan and Selvaraju, 2001). Balasubramanian and Krishnarajan (2001) observed maximum grain yield with irrigating 5 cm depth of water one day after disappearance of ponded water in direct seeded rice as compared to transplanted rice. The grain yield of rice was reduced by 5-38 per cent under mild water stress while severe water stress reduced grain yield by 25-67 per cent (Yang *et al.,* 2002). In a field experiment conducted by Jadhav *et al.,* (2003) with upland rice cv. Sugandha revealed that irrigations scheduled at 1.8 and 1.2 IW/CPE ratios recorded significantly higher grain yield than the other irrigation at IW/CPE of 0.6. Rice crop irrigated at 1.2 IW/CPE ratio resulted in highest yield and maximum water use efficiency compared to other treatments (Singh *et al.,* 2003). Aerobic rice yields were lower by an average of 28 per cent in the dry season and 20 per cent lower in wet season (Ambrocio *et al.,* 2004). Magat and Apo (2004) reported higher yield potential between 5 and 6 t ha^{-1} in a tropical low land hybrid and a traditional upland inbred under aerobic condition at IRRI, Philippines. Belder *et al.,* (2005) observed higher grain yield in flooded condition (5.5 and 5.4 t ha^{-1} in 2002 and 2003 respectively) than the aerobic condition (4.8 and 3.9 t ha^{-1} in 2002 and 2003 respectively) at Los Banos, the Philippines. Experiments conducted at Rajendranagar and Jagityal with aerobic rice indicated that the highest grain yield of 4.0-5.3 t ha^{-1} was recorded with water savings of around 50 per cent compared with lowland transplanted rice (Devender, 2005). Shaobing *et al.,* (2006) reported that aerobic rice produced significantly lower grain yield than flooded rice at Los Banos, the Philippines. Kumar *et al.,* (2006) reported that grain yield obtained by irrigating the crop once in four days or irrigation for 5 days and no irrigation for subsequent 5 days was comparable and significantly higher than that of irrigation once in 5 or 6 days and irrigation for 7 days and no irrigation for 7 days in red soils during summer season. Flooded rice had higher harvest index than aerobic rice (Shaobing *et al.,* 2006). Xianqing *et al.,* (2006) opined that the grain yields were higher for irrigation to shallow water depth with wetting and drying (SWD) than traditional irrigation with 5-9 cm standing water in original soils of china during *kharif.* In an experiment conducted by Choudhury and Singh (2007) at New Delhi during rainy season of 2001 and 2002 on aerobic rice cultivated on raised-beds under different soil-moisture regimes (field capacity, 20 and 40 k Pa tensions), the yield was considerably less on raised-beds, varying from 12–24 per cent at field capacity to 40 -46 per cent in beds irrigated at 40 k Pa soil-water tension compared with the direct-seeded flat land at 20 cm row spacing. In 2003-2004, irrigation x nitrogen experiments were carried out near Beijing using variety HD297, the higher yield was 4460 kg ha^{-1} with 688 mm of total (rain plus irrigation) water input in 2003 and 6026 kg ha^{-1} with 705 mm of water input in 2004 (Chang *et al.,* 2008).

Irrigation scheduled at 20 mm CPE (irrigation once in 5-6 days) recorded on par yield (45.47 q ha^{-1}) to that of 30 mm CPE (43.67 q ha^{-1}) (irrigation once in 8-9 days) and 40 mm CPE (40.68 q ha^{-1}) (irrigation once in 11-12 days) because of well distributed rainfall but recorded significantly higher yield over irrigation scheduled at 50 mm CPE (once in 13-14 days) and 60 mm CPE (once in 16-17 days) (35.36 q ha^{-1}) during *kharif* in aerobic rice (Murali *et al.,* 2009). Naoki and Toshihiro (2009) at Fukuoka, Japan recorded higher grain weight in continuous flooding and alternate wetting and drying than aerobic conditions. The grain yield was higher in alternate wetting and drying than the continuous flooding and aerobic condition. At Brisbane, Nguyen *et al.,* (2009) recorded 30 per cent higher mean grain yield in the flooded (FL) system than saturated soil conditions (SSC) systems. In a study conducted on silty clay soil in Iran. Irrigation schedule at IW/CPE ratio of 2.5 recorded significantly higher plant height (89.29 cm), total dry matter accumulation (104.55 g hill^{-1}), more number of productive tillers (25.74), filled spikelets panicle^{-1} (129.17), panicle weight (3.30 g), grain yield (6.40 t ha^{-1}) and net returns (`23491 ha^{-1}) (Shekhara *et al.,* 2010). Behrouz *et al.,* (2010) reported that significantly higher grain yield was recorded with irrigation to fill up the cracks and up to 5 cm ponding on the soil surface. Permanent irrigation and interval irrigation methods had higher yield in comparison with saturated irrigation method in rice. The higher yield was obtained in the permanent and interval irrigation with using of 300 kg urea fertilizer with three times (Allahyar, 2011). Ebrahim *et al.,* (2011) reported that the highest grain yield, biological yield and number of productive tillers hill^{-1} and harvest index was recorded from submerge irrigation and also 90 kg N ha^{-1} fertilizer consumption in loamy soils. Latheef *et al.,* (2011) revealed that irrigation scheduled at seven days' interval during vegetative stage and four days interval during reproductive stage resulted in significantly higher panicle number and panicle weight, filled grains panicle^{-1} and grain yield than that of irrigation scheduled once in two days in an experiment conducted at Hyderabad in red loamy soils during *kharif* 2008. Venkatesh *et al.,* (2012) observed that the performance of MAS 946-1 was superior in grain yield (41.00 q acre^{-1}) over Rasi (18.60 q acre^{-1}) with a yield advantage of 29.87 per cent at all the 27 locations. Results were elicited in district wise and grain yield obtained by growing MAS 946-1, under aerobic situation was on par with submerged rice. In a study on sandy clay loam soils at WTC, Hyderbad, Balamani *et al.,* (2012) reported in aerobic rice, higher grain yield and water use efficiency which was possible through bed-furrow method of irrigation scheduled at 1.5 IW/CPE up to panicle initiation and 2.0 IW/CPE for the remaining period during *kharif* season. Noor *et al.,* (2013) that MAS 868 with delayed irrigations at 0.6 IW/CPE ratio from 15-45 DAS and 0.8 IW/CPE ratio from 46 DAS to harvest can be followed for higher yield. Ramanamurthy and Reddy (2013) reported that, rice can be successfully grown under aerobic culture in north coastal zone of Andhra Pradesh by scheduling of irrigation at IW/CPE ratio of 1.2 in the best performance of rice in terms of productivity and profitability. Based on studies on red clay loam soils during *kharif* 2001 and 2002 at Davanegere, Denesh *et al.,* (2013) reported that maintaining saturation from 25 DAS to Physiological maturity (PM) found to be better in giving higher drum seeded rice pooled grain and straw yield with minimum quantity of water as compared to irrigation 2.5 cm from 25 DAS to 40 DAS and 5 cm from 41 DAS to PM in rice-rice cropping sequence under Bhadra command of Karnataka. The better performance of aerobic rice was possible when the soil is maintained at saturation throughout the growth period in sandy loam soils of Telangana region. Further, application of 150 kg N ha^{-1} is sufficient for realizing good yields in aerobic rice (MallaReddy *et al.,* 2013). Grain yield of direct-seeded rice was comparable to that of transplanted under flooded conditions. However, the yield of direct-seeded rice under aerobic conditions was up to 21 per cent lower than that under flooded conditions. The yield stability of direct-seeded rice could be lowered by the water-saving irrigation, compared with the conventional flooded culture (Midori *et al.,* 2013).

Effect of irrigation schedules on water requirement

Bouman (2001) reported that for crop growth duration of 100 days, water required is about 1,500-2,000 mm as a typical value in many lowland areas depending on the season and soil characteristics. Cabangon *et al.,* (2001) reported that dry seeded rice significantly increased the water productivity with respect to irrigation water over wet seeded and transplanted rice. Further, early establishment of the direct seeded rice reduced the water uptake, thereby saving in irrigation water up to 40 per cent. Castaneda *et al.,* (2002) reported that direct seeded aerobic management eliminate water loss due to puddling and percolation, thereby reducing losses due to evaporation and percolation, reducing total irrigation requirement by 30-50 per cent. According to Bouman *et al.,* (2002) compared with lowland rice, water inputs in aerobic rice were more than 50 per cent lower (only 470-650 mm), water productivities 64-88 per cent higher, gross returns 28-44 per cent lower (345-633 $ ha^{-1}) and labour use 55 per cent lower, but require improved varieties bred specifically for aerobic condition. Intermittent irrigation in rice cultivation may reduce irrigation water use considerably (27-37%) compared with flooded rice cultivation, while at the same time yields increase slightly (4-6%). Intermittent irrigation was associated with a similar yield increase of varieties Sanyou 10 and 923 (Qinghua *et al.,* 2002). According to Wang *et al.,* (2002) total water productivity of aerobic rice was 1.6 to 1.9 times higher and water use about 60 per cent less than lowland rice. Romeo *et al.,* (2004) opined that the productivity of irrigation water in AWD (alternate wetting and drying) was about 5-35 per cent higher than in continuous flooding but differences were significant only when the rainfall was low and evaporation was high. The results suggest that in typical irrigated low lands in silty clay loam soils of china, AWD can reduce water input without affecting rice yields and does not require N-fertilizer management differently from continuous flooding. Bandi *et al.,* (2005) reported that crop consumed 950 mm of water, out of which 467 mm was effective rainfall and 483 mm was irrigation water requirement. There is 40-50 per cent water saving with very high water use efficiency of 63.15 kg ha^{-1} cm. Basavaraju *et al.,* (2005) reported that aerobic rice significantly required less water (67.91 ha^{-1} cm) to produce higher or on par yield as compared to transplanted puddled rice (122.59 ha^{-1} cm). Similarly, WUE was significantly higher in aerobic rice (81.31 kg ha^{-1} cm) as compared to transplanted rice (36.12 kg ha^{-1} cm). A Four-year experiment conducted in Beijing (China) from 2001 to 2004 by Cui *et al.,* (2008) observed that the highest daily ET occurred at the stage from booting to heading stage with the average value of 9.8 mm day^{-1}. Therefore, booting to heading is the key stage of water requirement for aerobic rice. Tran *et al.,* (2008) reported that the conventional flooding regime in clay soils required keeping field water depth at 5 ± 3cm. So, irrigation input was more in alternate wetting and drying than continuous flooding. The water productivity of AWD (alternate wetting and drying) was higher than continuous flooding during summer and rainy seasons. Bas Bouman and Mia Aureus (2009) reported that under water scarce condition, the system of aerobic rice is very useful. In this system, aerobic rice varieties we grown in well drained, non-puddled and non-flooded soils and aerobic rice produced up to 4-6 tons' hectare^{-1} while using less than half the water required in flooded rice.

Saharawat *et al.,* (2009) observed that the direct seeding of rice had a 9 to 11 per cent less water application without a yield penalty compared to conventional puddled transplanting and water use efficiency was higher in dry direct seeded rice (0.33 g L^{-1}) than with transplanted rice (0.29-0.32 g L^{-1}). Ghosh *et al.,* (2009) revealed that in aerobic rice 40-50 per cent water could be saved at the expense of 30-60 per cent yield decline while providing irrigation at -20 and -40 k Pa soil moisture tension. Bueno *et al.,* (2010) reported that the amount of water input for the whole crop growth in dry season was significantly higher under continuous flooding (45.51 to 50.34 m^3) compared with that under AWD (37.59 to 42.39 m^3). This corresponded to a significant reduction of 13-20 per cent under AWD in heavy clay soils of Los Banos, Phillippines. Shekara *et al.,* (2010) reported that irrigating crops once in 4 to 6 days (IW/CPE 2.5 or 2) was found optimum and economical for aerobic rice under Cauvery command area. Based on their studies on sandy loam soils in Ludhiana, Mahajan *et al.,* (2011) predicted that for more economic water use in the north-western part of Indo- Gangetic Plains (IGP), growing rice in aerobic direct seeded rice (ADSR) recorded lower water requirement, yield maintenance and relatively higher stress tolerance index (STI) when compared to conventional puddled transplanted rice (CPTR). The total amount of water applied (including rainfall) in the aerobic plots was 967 and 645 mm compared to 1546 and 1181 mm in flooded rice system, during 2009 and 2010, respectively. This resulted in 37 to 45 per cent water savings with the aerobic method. The soil moisture in aerobic treatment was maintained in the –30 to –40 kPa range throughout the crop growth (Kadiyala *et al.,* 2012).

Effect of irrigation schedules on water use efficiency

Bouman and Tuong (2001) revealed that the shift from anaerobic to aerobic systems of rice cultivation will have major positive consequences with respect to weed, disease, and insect pest management, nutrient and soil organic matter dynamics and greenhouse gasses emission sequestration at experimental station, at Beijing. The potential water saving was large when rice was grown under upland condition, with high seepage rates. Nieuwenhuis *et al.,* (2002) in a pot experiment to study the physiological water use, growth and yield of high yielding upland rice under irrigated aerobic condition revealed highest water use efficiency and better yield under continuously flooded condition and aerobic condition reduced the yield by 35 per cent. Qinghao *et al.,* (2002) concluded that intermittent irrigation treatment with variety Youch 647 received 48 mm (27%) irrigation water less than flooded treatment, while its yield was 6 per cent higher and WUE of intermittent irrigation treatment 61 per cent higher than that of flooded treatment. Savings in irrigation water and increase in water productivity is possible if rice is grown under aerobic conditions like an irrigated upland crop. For rice to succeed as an aerobic crop, it should tolerate intermittent water deficits and high soil impedance created due to aerobic conditions (Lafitte and Bennett, 2002). Singh *et al.,* (2003) reported that in upland paddy irrigation should be applied at IW /CPE ratio of 1.2 or after 50 mm CPE (4-5 irrigations) or 8-10 days' interval for getting at par grain yield with irrigations at field capacity (10-11 irrigations). The IW/CPE ratio not only yielded at par grain yield but gave maximum water use efficiency also (7.48 kg ha^{-1} mm of water). Ambrocio *et al.,* (2004) reported that aerobic rice saved 73 per cent of irrigation water for land preparation and 56 per cent during the crop growth stage, more over it could effectively use rainfall during the dry season. Aerobic rice yields were lower by an average of 28 per cent in the dry season and 20 per cent in the wet season at IRRI, Philippines. At Los Banos, the Philippines, higher water productivity was obtained in aerobic condition (0.57 and 0.42 kg m^{-3} in 2002 and 2003 respectively) than flooded condition (0.45 and 0.37 kg m^{-3} in 2002 and 2003 respectively). The water productivity was significantly increased by N application and under limited water stress ranged from 0.70 to 1.17 kg m^{-3} in zero N plots and from 1.27 to 1.66 kg m^3 at 180 kg N ha^{-1}. Water saving regimes also increased water productivity under non-water stressed conditions compared with continuous submergence. Water requirement was less in aerobic rice (842 and 940 mm in 2002 and 2003 respectively) as compared to flooded rice (1233 and 1473 mm in 2002 and 2003 respectively) (Belder *et al.,* 2005). Irrigating the crop once in four days recorded better field water use efficiency (4.58 kg grain ha mm^{-1}) than that of irrigating the crop daily (2.99 kg grain ha mm^{-1}) or once in two days (3.22 kg grain ha mm^{-1}). Under limited water supply irrigating the crop once in two days or once in four days saves water use by 12.7 per cent and 42.9 per cent respectively with marginal yield loss as compared to daily irrigation (AvilKumar *et al.,* 2006*)*.The irrigation schedule having three days drainage period after disappearance of ponded water yielded rice higher with maximum water use efficiency compared to continuous submergence or submergence at critical stages such as tillering, panicle initiation, flowering and milk, followed by saturation or field capacity between intermittent periods (Husain *et al.,* 2008). Chang *et al.,* (2008) conducted an experiment during summer in sandy soils of Beijing revealed that the irrigation water they can be supplied in 2- 4 applications and should aim at keeping the soil water tension in root zone below 100-200 k Pa. Under those conditions, the amount of water use by evapotranspiration (ET) was 458-483 mm. The water productivity with respect to total water input was 0.89-1.05 g grain per kg water and with respect to ET was 1.28-1.42 g grain kg^{-1} water. In experiments at Japan by Kato *et al.,* (2009) in aerobic fields, the total amount of water supplied (irrigation plus rainfall) was 800-1300 mm. The average water productivity under aerobic conditions was 0.8-1.0 kg grain m^{-3} water. The average yield under aerobic conditions was similar to or even higher than that achieved with flooded conditions (7.9 t ha^{-1} in 2007 and 9.4 t ha^{-1} in 2008 for aerobic conditions versus 8.2 t ha^{-1} for flooded situation). The water productivity was higher under aerobic conditions (0.43 kg m^{-3}) as compared to transplanted conditions (0.33 kg m^{-3}) and alternate wetting and drying and continuous flooding (Naoki and Toshihiro, 2009). At Brisbane, Nguyen *et al.,* (2009) found similar WUE values in aerated (AR) and flooded (FL) treatments which are significantly lower than those observed for saturated soil conditions (SSC). Shekara *et al.,* (2010) reported that the irrigation schedule at IW/CPE ratio of 1.0 *i.e.*, once in 10-12 days recorded higher water use efficiency (52.09 kg grain ha cm^{-1}) and lower with irrigation schedule at IW/CPE ratio of 2.5 (41.31 kg grain ha cm^{-1}) in aerobic rice during *kharif.* Mahajan *et al.,* (2011) reported that the WUE values for Fang-ai-zan, RH-257 (hybrid), PAV-201 and PR-120 were significantly higher than other cultivars like Panjab Mehak, RH-664.

Conclusion

If irrigation water is not a limiting factor for rice cultivation, continuous shallow land submergence with 5 cm water could be ideal to achieve the benefits of land submergence in *kharif, rabi* and summer. If the irrigation water is not adequate intermittent land submergence could be followed. Irrigation 2-5 days after disappearance of ponded water depending upon the stage of the crop appears to be reasonable for most locations. Great economy in irrigation water could be achieved if suitable measures are adopted to minimise the deep percolation losses.

References

1. Allahyar. "Interactive effects of nitrogen and irrigation methods on the growth and yield of rice in Amol area." *Intl. J. Agri. Crop Sci.,* 3.4 (2011):111-113.
2. Ambrocio, Bouman, Shaobing and Romeo. "Mitigating water scarcity through an aerobic system of rice production". In: Proc. of the 4th Intl. Crop Science Congress, 26 Sep – 1 Oct, (2004) Brisbane, Australia (available online at www. cropscience. org. au/icsc 2004).
3. AvilKumar, Reddy, Reddy and Sadasiva Rao. "Effect of irrigation scheduling on performance of summer rice." *Oryza*, 43.2 (2006): 97-100.
4. Balasubramanian and Krishnarajan. "Economics of direct seeded wetland rice under different water management practices." *Oryza*, 38.1 & 2 (2001):69-71.
5. Bandi, Prarhakar and Krlshnamurthy. "Performance of rice varieties at various spacing under aerobic method of cultivation". Proc.of Nation. Sem. on Rice and Rice based System for Sustainable Productivity. (2005):164-165.
6. Bas Bouman and Mia Aureus. "Every drop counts." *Rice Today*, 8.3 (2009):16-18.
7. Basavaraju, Somasekhar, Rukmini, Satisha, Naryanappa, Kavitha, Ashok and Nagaraju. "Performance of aerobic rice under tank command situation in central dry zone of Karnataka." Proc.of Nation. Sem. on Rice and Rice based System for Sustainable Productivity. (2005):112-113.
8. Behrouz, Fatemah, Sayad and Mohammad. "Effect of irrigation water management on yield and water use efficiency of rice in cracked paddy soils." *Australian J. Crop Sci.,* 4.3 (2010): 136-141
9. Belder, Bouman, Spiertz, Peng, Castaneda and Visperas "Crop performance, nitrogen and water use in flooded and aerobic rice." *Plant and Soil*, 273 (2005): 167–182.
10. Bouman. "Water efficient management strategies in rice production." *Intl. Rice Res. Note.,* 16.2 (2001): 17-22.
11. Bouman and Tuong. "Field water management to save water and increase its productivity in irrigated rice." *Agric. Water Mngt.,* 49.1 (2001) : 11-30.
12. Bouman, Yang, Wang, Wang, Zhao, Wang and Cheng. "Aerobic rice (Han Dao) : a new way of growing rice in water-short areas." In: Proc. of the 12th Intl. Soil Conser. Organization Conf., 26-31 May, 2002, Beijing, China Tsinghua University Press. (2002):175-181.
13. Bueno, Bucourt, Kobayashi, Inubushi and Lafarge. "Water productivity of contrasting rice genotypes grown under water-saving conditions in the tropics and investigation of morphological traits for adaptation." *Agric. Water Mngt.,*98 (2010): 241–250.

14. Cabangon, Tuong, Bouman, Feng and Zhang. "Irrigation management effects on yield and water productivity of inbred and aerobic rice varieties in Kaiting, IRRI, Phillipines. (2001): pp. 27.
15. Castaneda, Bouman and Vispcras. The potential of aerobic rice to reduce water use in water scarce irrigated lowlands in the tropics. Water wise Rice Production, 8-11 IRRI, Philippines, (2002):165-176.
16. Chang, Yang, Bouman, Deng, Zhang, Yan, Zhang, Rouzi and Wang. "Optimizing yield, water requirements and water productivity of aerobic rice for the North China Plain." *Irrig. Sci.,* 26.6 (2008): 459-474.
17. Cui, Xue, Yang, Yang, Zhang, Wang and Bouman. "Field evapotranspiration characteristics and water use efficiency of aerobic rice under different water treatments." *Trans. of the Chinese Soc. of Agric. Engg.,* 24.4 (2008): 9-54.
18. Denesh, Jayadeva and Bhairappanavar. "Water requirement and yield of drum seeded rice-rice cropping system." *Mysore J. Agric. Sci.,* 47.2 (2013): 337-341.
19. Devender. "Water management and Aerobic rice." Paper presented at XXXIV Research and Extension Advisory Council Meeting, March 28-29, 2005 of Acharya NG Ranga Agricultural University, Rajendranagar, Hyderabad. (2005): pp. 20-23.
20. Ebrahim, Fereshteh, Marl and Harmid. "Evaluation effect of different nitrogen fertilizer rates under irrigation management in rice farming." *World Appl. Sci. J.,* 13.5 (2011):1248-1252.
21. Ghosh, Rao, Singh, Dash, Samal, Pandey, Kumar and Zhao. "Conserving water in rice cultivation- its potential and prospect under looming crisis of water resources." 4th World Congress on Conser. Agric., (2009): 161-162.
22. Jadhav, Dhoble and Dahiphale. "Irrigation and nitrogen management for upland irrigated rice on vertisols." *J. Maharashtra Agric. Univ.,* 28.1 (2003): 103-104.
23. Kadiyala, Mylavarapu, Li, Reddy and Reddy. "Impact of aerobic rice cultivation on growth, yield, and water productivity of rice–maize rotation in semiarid tropics." *Agron. J.,* 104.6 (2012): 1757-1765.
24. Kato, Okami and Katsura. "Yield potential and water use efficiency of aerobic rice (Oryza sativa L.) in Japan." *Field Crops Res.,* 113.3 (2009):328-334.
25. Kumar, Reddy, Reddy and Sadasiva Rao. "Effect of irrigation scheduling on performance of summer rice." *Oryza,* 2006, 43.2 (2006): 97-100.
26. Lafitte and Bennett. "Requirements for aerobic rice: physiological and molecular considerations" In: Water-wise Rice Production, IRRI, Phillippines and PRI, Netherlands. (2002): 259-274.
27. Mahajan, Timsina and Kuldeep. "Performance and water-use Efficiency of rice relative to establishment methods in north-western indo-gangetic plains." *J. Crop Improv.,* 25.5 (2011): 597-617.
28. MallaReddy, Padmaja, Veeranna and Vishnu Vardhan Reddy. "Response of aerobic rice to irrigation scheduling and nitrogen doses under drip irrigation." *J. Res. ANGRAU,* 41.2 (2013): 144-148.
29. Latheef, Reddy, Reddy and UmaDevi. "Effect of irrigation schedule, weed management and nitrogen levels on weed growth in rice (Oryza sativa) under aerobic conditions." *Indian J. Weed Sci.,* 43 (2011): 1-2.
30. Midori, Yoichiro and Junko. "Grain Yield and Leaf Area Growth of Direct-Seeded Rice on Flooded and Aerobic Soils in Japan." *Plant Prod. Sci.,* 2013, 16.3 (2013): 276-279.
31. Murali, Shankar, Ramanagowda and Krishnamurthy. Irrigation scheduling in aerobic rice compared with farmers practice of lowland rice. Fifth Asian Regional Conf. during 6-11, December, New Delhi, India. (2009).
32. Naoki and Toshihiro. Growth and yield of six rice cultivars under three water saving cultivations. *Plant Prod. Sci.,* 12.4 (2009): 514-525.
33. Nguyen, Fischer and Fukai. Physiological responses to various water saving systems in rice. Field Crops Res., 112 (2009): 189-198.
34. Nieuwenhuis, Bouman and Castaneda. "Crop-water responses of aerobically grown rice: preliminary results of pot experiments." In: Water-wise Rice Production, IRRI and Pl. Res. Intl., (2002):177-185.
35. Noor, Ramachandrappa, Nanjappa, Mudalagiriappa, Shankaralingappa and Shailaja. "Effect of irrigation Schedules on growth and yield of Aerobic rice (Oryza sativa L.) genotypes." *Mysore J. Agric. Sci.,* 47.1 (2013): 94-99.
36. Qinghao, Visperas and Mcclang. "Contribution of rice tiller to dry matter accumulation and yield." *Agron. J.,* 90 (2002): 317-323.
37. Qinghua, Xiaochun, Muying, Xueming and Fengfeng. "Effect of different water management practices on rice growth." In: Water-wise Rice Production, IRRI, Phillippines and PRI, Netherlands, (2002) : 3-13.
38. Ramanamurthy and Reddy. "Effect of irrigation and weed management practices on Nutrient uptake and Economics of production of Aerobic rice." *J. Agric. Veter. Sci.,* 3.1 (2013): 15-21.
39. Romeo, Cabangon, Phuc, Ernesto, Castillo, Lang, Guoan, Guangho, Yuanlai, Bouman, Yuanhua, Chongde and Jianzhang. "Effect of irrigation method and N-fertilizer management on rice yield, water productivity and nutrient-use efficiencies in typical lowland rice conditions in China." *Paddy Water Environ.,* 2 (2004): 195–206.
40. Saharawat, Bhagat, Malik, Gathala, Jat, RajGupta and Ladha. "Productivity, water use and income of the rice-wheat systems with alternative tillage and crop establishment methods in a rice-wheat rotation in north western IGP. 4th World Congress on Conservation Agriculture, (2009):127.
41. Shaobing, Bouman, Romeo, Ambrocio, Lixiao and Hong. "Comparison between aerobic and flooded rice in the tropics: Agronomic performance in an eight-season experiment." *Field Crops Res.,* 96 (2006): 252-259.
42. Shekara, Sharnappa and Krishnamurthy. "Effect of irrigation schedules on growth and yield of aerobic rice (Oryza sativa L.) under varied levels of farmyard manure in Cauvery command area." *Indian J. Agron.,* 55.1 (2010): 35-39.
43. Singh, Khokhar, Yadav and Verma. "Water Economy in paddy." *Indian Farming,* 2003, 53.9 (2003): 27.
44. Thyagarajan and Selvaraju. "Water-saving rice cultivation in India." In: Proc. of Intl. Workshop, Water-Saving Rice Production Systems, Nanjing University, China, April 2-4, 2001. Plant Research International, Wageningen, Report 33, (2001): 15-45.
45. Tran, Trinh, Chu, Pham and Roland. "Effect of seeding rate and nitrogen management under two different water regimes on grain yield, water productivity and profitability of rice production." *Omonrice,* 16 (2008): 81-87.
46. Venkatesh, Rudresh, Shivamurthy and Shailaja. "Performance and adoption of new aerobic rice variety MAS 946-1 (Sharada) in southern Karnataka." *Karnataka J. Agric. Sci.,* 25.1 (2012): 5-8.
47. Wang, Bouman, Dule, Wang and Moya. "Aerobic rice in Northern China: Oppurtunities and Challenges." In: Water-wise Rice Production, IRRI, Phillippines and PRI, Netherlands, (2002):143-154.
48. Xianqing, Weijun, Defeng, Huizhe and Yuping. "Nitrogen accumulation, remobilization and partitioning in rice (Oryza sativa L.) under an improved irrigation practice." *Field Crops Res.,* 96 (2006): 448–454.
49. Yang, Wang, Wang, Chan and Bouman. "Yield of aerobic rice (Han Dao) under different water regimes III North China." In: Water-wise Rice Production (Eds.), IRRI. (2002):155-163.

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