

# The Impact of Different Intermittent Irrigation Management and Planting Distances on Yield and Yield Components of Rice Plant in Northern Iran

Kamyar Sabokrow Foomani<sup>1</sup>, Saeed Sayfzadeh<sup>1\*</sup>, Faramarz Ali Nia<sup>2</sup>, Seyed Alireza Valad Abadi<sup>1</sup>,  
Mohammadreza Yazdani<sup>2</sup>

<sup>1</sup>Department of Agronomy, Faculty of Agriculture, Takestan Branch, Islamic Azad University, Takestan, Iran

<sup>2</sup>Department of Seed Improvement, Rice Research Institute of Iran, Agricultural Research, Education and Extension Organization, Rasht, Iran

\*Corresponding author: Saeed Sayfzadeh, Email: ssayfzadeh2000@gmail.com

Submission: February 12, 2020; Revision: April 23, 2020; Acceptance: April 27, 2020

## ABSTRACT

In this study, a split plot experiment was conducted in a randomized complete blocks design with three iterations, for two years, in Gilan province (Iran), to investigate the impact of periodic irrigation and different planting distances on yield and yield components of rice plant. The irrigation was performed at five levels,  $I_1$ , daily flooding irrigation (control treatment) and  $I_2$ ,  $I_3$ ,  $I_4$  and  $I_5$ , every 5, 8, 10, and 15-days, respectively, as the main factor. Meanwhile, the planting distances were at four levels ( $S_1$ :  $20 \times 20$ ,  $S_2$ :  $25 \times 25$ ,  $S_3$ :  $15 \times 30$ , and  $S_4$ :  $20 \times 30$  cm) as the sub factor. The simple effects of irrigation, as well as planting distance on all traits except harvest index, were significant at the level of 1%. In addition, the interaction of irrigation and planting distance on seed yield, plant height, number of seeds per panicle, biological yield, and water use were also significant at the level of 1%. The  $20 \times 20$  planting distance resulted in the best conditions for the rice plant at different stress severities, thus, a  $20 \times 20$  planting distance is appropriate in order to achieve good yield. Meanwhile, of the irrigation levels, 5-day irrigation led to the highest yield. The 5-day irrigation produced higher yield compared to flooding irrigation, and is therefore suitable for achieving higher yields as well as for water conservation, a major agricultural problem.

**Keywords:** Intermittent irrigation management; planting distance; rice; water stress; and Northern Iran

## INTRODUCTION

The increasing urban population and demand for water in industries necessitates the rational reduction of water use for agriculture. Under these conditions, the key challenges in rice production include water storage, increasing water productivity, and producing more rice with less water (Bouman and Tuong, 2001). Therefore, several rice production systems, including intermittent rice irrigation, where less water is able to produce more rice, have been considered recently (Bouman and Tuong, 2001; Tao *et al.*, 2006; Hafeez *et al.*, 2007). Almost 75% of the rice produced in Asia

comes from low paddy areas (Dawe, 2005) generally irrigated by permanent flooding method, and this type of production increases the real need for water. Numerous surveys have estimated the water consumption by rice to be four times higher, compared to other cereals (Tao *et al.*, 2006) and almost 50% of the irrigation water allocated to agriculture worldwide (Guerra *et al.*, 1998). As a waterlogged plant, rice is one of the most susceptible crops to drought stress and has the highest water requirement of all cereals (Yang *et al.*, 2008). Conversely, as one of the most important crops in the world, rice is largely cultivated around the world (Park *et al.*, 2014).

Therefore, the use of periodic or wet and dry irrigation in paddy fields is one way to overcome the problem of increasing productivity using low irrigation water and excessive water use in flooding irrigation. In this method of irrigation management, water is provided to the plant only when necessary and to the extent required by the plants, rather than continuously flooding the plants (Rezaie and Nahvi, 2007). The results of this study show there is no need for the rice plant to be in continuous flooding at all stages of growth, and instead, rice cultivation is possible by reducing the height of static water in the plot through changing the irrigation method from flooding to non-flooding (Bouman and Tuong, 2001; Belder *et al.*, 2007). Furthermore, worldwide studies have proven the effect of non-flooding irrigation management on seed yield and increase in water productivity for rice crop (Bouman *et al.*, 2002; Tuong *et al.*, 2005). Makara *et al.*, (2006) also reported drought stress is able to reduce seed yield by 12 to 46%, in rice reproductive stage. Meanwhile, a report by Loeve *et al.*, (2004) indicated the application of periodic irrigation, is able to significantly reduce water use without any decrease or percentage decrease in yield. Rezaii and Nahvi (2007) also examined the effect of periodic irrigation on water use and rice yield, for Hashemi cultivar, by applying four continuous flooding treatments and periodic irrigations of five, eight, and eleven days, over two years, and discovered 5-day periodic irrigation and permanent flooding treatments were associated with the highest and lowest water use efficiency, respectively.

In addition, the distance between plants has a considerable effect on the rice plant's growth and yield, because well-spaced plants obtain more sunlight due and are consequently, able to perform photosynthetic activity better and grow better, compared to the poorly-spaced plants. According to Baloch *et al.*, (2002), high plant density leads to increased number of panicles per unit area and decreased seed weight per panicle. Thus, increase in plant density affects other components of yield. A report by Amiri *et al.*, (2011) suggested a 25 × 25 cm planting distance produces an average two-year seed yield of 2611 kg/ha, with a 10% reduction in seed yield and a 25% irrigation saving, compared

to continuous flooding conditions and is therefore the best option for irrigation management and planting distance, in the conditions of Gilan province. Meanwhile, Surajit and Datta (1981) discovered increasing planting distance from 15 × 15 to 20 × 20 and 25 × 25 cm, decreased rice seed yield by 30 and 50%, respectively.

The water crises in the past few years resulted mainly from decreased raining due to climate change as well as increased demand for water, thus, the available water resources need to be effectively used and water productivity in the agricultural sector ought to be increased to the highest possible extent, by applying proper irrigation management. This study was therefore aimed at evaluating the impact of several managements of periodic irrigation and planting distance, on the yield and yield components of rice plant, as well as recommending a suitable irrigation method and planting distance for optimal yield.

## MATERIALS AND METHODS

To investigate the impact of periodic irrigation and different planting distances on yield and yield components of rice plant, a split plot experiment was conducted in a fully randomized block design with three replications in the Research Field of The Rice Research Institute of Gilan province (Iran), between the cultivation years of 2015-2016. The research site was positioned at a latitude of 36° and 49' east, longitude of 16° 37' northern and an altitude of 8 m above sea level. In this study, irrigation was performed at five levels, I<sub>1</sub> or daily flooding irrigation (control treatment) as well as I<sub>2</sub>, I<sub>3</sub>, I<sub>4</sub> and I<sub>5</sub>, with irrigation at every 5, 8, 10, and 15-day periods, respectively, as the main factor. Meanwhile, the planting distances were at four levels (S<sub>1</sub>: 20 × 20, S<sub>2</sub>: 25 × 25, S<sub>3</sub>: 15 × 30, and S<sub>4</sub>: 20 × 30 cm) in test units with dimensions of 3 × 3.5 m as the sub factor. The distance of each test unit in the main plot was 0.5 m and the borders of each test unit were covered with nylon, to prevent lateral penetration of water.

Soil sampling was carried out to specify the soil texture and water holding capacity at crop capacity, as well as wilting point limit and some chemical properties, including EC, pH, Ca, Na, Mg. Meanwhile,

Table 1. Physicochemical properties of soil collected from study site.

Texture	EC (ds/m)	pH	Organic Carbon (%)	N (%)	P (ppm)	K (ppm)	Sand (%)	Clay (%)	Silt (%)
Clay loam	1.48	7.4	2.05	0.16	6.7	142	12	46	42

meteorological data were obtained from the nearby station of Rice Research Institute. Table 1 shows the data specifications. The boundaries of each test unit were covered with nylon to avoid water infiltration, while irrigation treatments were applied to the depth of 5 cm and the water volume was measured by counter. In addition, the distance of each test unit in the main plot was 0.5 m, and no periodic irrigation was applied in the first 15 days after transplanting, to allow the plant establish well. At the time of rainfall, the water level was stabilized as the pre-rainfall amount and prevented from the increased depth due to rainfall. Rice nursery was conducted by the area's conventional method, and the rice field was plowed twice. The first plowing was performed in late autumn and early winter, while the second was perpendicular to the first plowing and conducted in spring. Transplanting was carried out on May 15. By this time, the transplants had reached a normal size of 20 to 25 cm with 4 to 5 leaves, and were therefore transferred from the nursery to the main field. The nursery was fully irrigated before transplanting to ease the operation of taking the transplants without harming the roots, and the transplant were then planted in the main field.

A few days after complete pollination and one week before harvest, the plant height was accurately measured with the precision of a millimeter from ground level to the end of the main panicle, in cm. Also, 1000 random seeds were first counted and then weighed in grams using a scale with the precision of one hundredth of a gram, to measure 1000 seed weight. Furthermore, a 250-gram sample of straw and seed was selected and weighed after oven-drying at 70 °C for 72 hours, to determine the shoot and seed dry weight. The dry weight of stem and seed was determined after determining the moisture content, while the harvest index was calculated by dividing the dry weight with the biomass counterpart (total dry weight of seeds and straw).

Subsequently, SAS and SPSS software were employed for ANOVA and Excel software was used to plot the diagrams, while comparison of means was conducted by the least significant difference (LSD) test.

## RESULTS AND DISCUSSION

According to the results of ANOVA, the simple effect of irrigation was significant at 1% level on all tested traits and the simple effect of planting distance was also significant on all traits except the harvest index. Furthermore, the interaction of irrigation and planting distance were significant at 1% level on seed yield, plant height, number of seeds per panicle, biological yield, and water use.

## Plant Height

The comparison of mean interaction of irrigation and planting distance effect on plant height indicated daily irrigation treatment and 30 × 15 planting distance had the highest effect on plant height, with a mean of 134 cm, while the 15-day irrigation treatment and 25 × 25 planting distance had the lowest, with a mean of 113 cm (Figure 1). Reducing planting distance led to the increase of growth-limiting factors and practically increased plant competition for light absorption by tillers of each plant. In fact, increased intra-plant competition, compared to inter-plant competition for light tends to result in taller rice plants. Mohaddesi *et al.*, (2010) examined the effect of planting distance on rice plant and reported 20 × 20 planting distance creates the tallest plant. Also, reducing the amount of water leads to reduced cell growth and consequently, decreased vegetative growth of rice plant. Amiri *et al.*, (2011) addressed the effect of different irrigation levels on rice plant and discovered flooding irrigation resulted in the tallest plants, while Kumar and Kumar (2002) claimed drought stress significantly reduced plant height and leaf area.

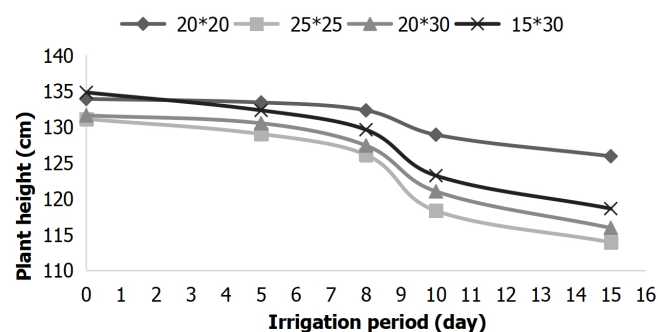


Figure 1. The interaction effects of irrigation and planting distance on plant height.

## Number of Tillers

Space and time are known as an energy source in agro ecosystems, thus, this production advantage is somewhat attributed to sufficient number of plants on one hand and conversely, to the much higher number of plants in the 20 × 20 cm planting distance, as well as higher share of the main stem and number of tillers. The planting distance 20 × 20 with 13 tillers, and the planting distance 25 × 25 with 11 tillers, respectively, had the most and least number of tillers. Mohaddesi *et al.*, (2010) therefore concluded the highest number of tillers was obtained at 20 × 20 planting distance. In addition, irrigation enhances the number of tillers of rice plants. The highest number of tillers was obtained

in 5-day irrigation (13 tillers) and the lowest, in 15-day irrigation (10 tillers). These findings are in line with the studies of Wang *et al.*, (2018), as well as Ockerby and Fukai (2001). Miller *et al.*, (1991) also disclosed the key component of seed yield in flooding and direct irrigation of rice is the number of fertile tillers. This factor is more important than density, and accounts for 89% of the seed yield changes.

### 1000 Seeds Weight

This trait is one of the key components of yield, and indicates the allocation of photosynthetic materials to the seeds. The 20 × 20 planting distance produced the highest seed weight of 20.2g, while the 25 × 25 planting distance with a seed weight of 19.3 g, had the least. A study by Chamara *et al.*, (2016) reported high densities of rice crop led to a decline in yield and yield components, including 1000-seed weight. The highest 1000-seed weight was obtained from daily irrigation (21.3 g), while the lowest was produced by 15-day irrigation (17.3 g). Meanwhile, Rezaei and Nahvi (2007) argued drought stress caused by non-flooding irrigation led to a decline in the number of tillers, leaf area, dry matter accumulation, and 1000-seed weight and consequently, reduced yield by preventing the transfer of minerals and nutrients to the plant and reducing photosynthesis.

### Emptiness Percentage

Drought stress increases the number of empty seeds, and under low humidity conditions, the pollen seeds cannot penetrate the ovary, thus, poor insemination occurs and the seeds become empty. The highest emptiness percentage was obtained in 15-day irrigation (24.6%) while the lowest was observed in 5-day irrigation (18.2%). Ashouri (2014) claimed 11-day drought stress significantly increased the amount of empty seeds and emptiness percentage, while Amiri *et al.*, (2011) also stated drought stress increases emptiness percentage. The 20 × 20 planting distance had the highest emptiness percentage of 21.6%, while the 25 × 25 planting distance had the lowest of 20.4%. Therefore, increase in plant density increases competition also consequently, leads to a larger emptiness percentage.

### The Number of Filled Seeds per Panicle

A comparison of the mean interaction effects of irrigation and planting distance on the number of filled seeds per panicle showed the 5-day irrigation treatment and 25 × 25 planting distance had the most number of seeds per panicle, with a mean of 55.4, while the 15-day irrigation treatment and 20 × 20 planting distance

had the lowest number of seeds per panicle, with a mean of 47.9 (Figure 2). Irrigation is one of the factors influencing the number of filled seeds per panicle, and the results of this study confirms the report by Lafitte (2003), stating the percentage of filled seeds is one of the main components of seed yield affected by drought stress. Boojang and Fukai (2002) assessed the effect of drought stress on the seed yield and components of seed yield of rice cultivars in different growth stages and discovered application of low irrigation (less irrigation) at the vegetative stage had low impact on seed growth and yield, and the decreased number of panicles and seeds resulted in a 30% decrease in yield. However, the application of low irrigation during the flowering stage, affected yield greatly, as flowering was delayed and number of seeds per panicle declined up to 60%, compared to non-stress conditions, thus, leading to reduction in seed filling percentage.

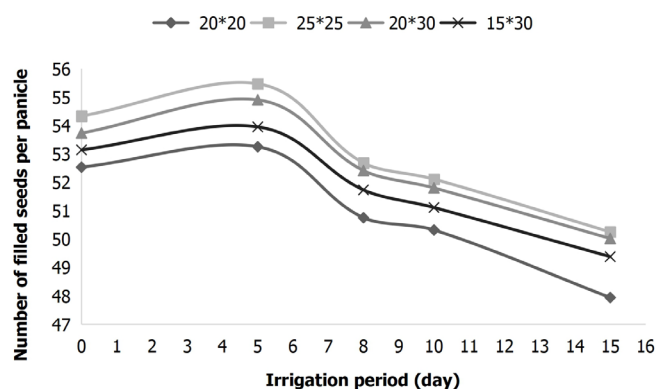


Figure 2. Interaction effects of irrigation and planting distance on number of filled seeds per panicle.

### Biological Yield

A comparison of the mean interaction effect of irrigation and planting distance on biological yield showed daily irrigation treatment and 30 × 15 planting distance had the most value, while the 15-day irrigation and 25 × 25 planting distance produced the lowest biological yield (Figure 3). In addition, the flooding irrigation led to the highest biological yield. A study by Shahsavari *et al.*, (2014) stated drought stress decreases the biological yield. Despite increasing the number of plants per unit area, the decreased planting distance between rice plants decreased biological yield due to the reduced number of panicles per plant. Conversely, the space closure and increased shading led to increased competition for light and influenced the biological yield of crop because of changes in light intensity and quality. Thus increase in density increases biological yield as well, because the positive effect of

density on the number of plants per unit area is higher, compared to the negative effect on the dry weight of aerial organs. Also, the biological yield increases with increase in density (Asghar *et al.*, 2001).

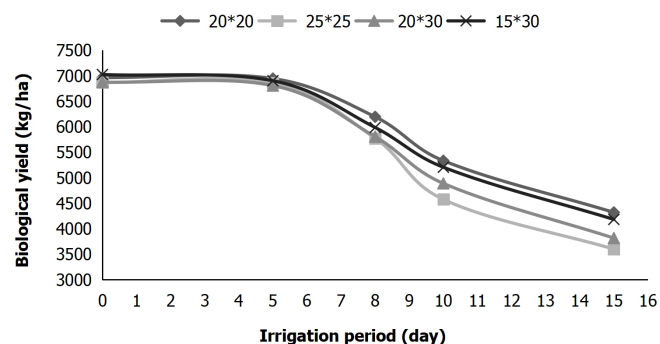


Figure 3. Interaction effects of irrigation and planting distance on Biological yield.

### Seed Yield

A comparison of mean interaction effect of irrigation and planting distance on seed yield showed 5-day irrigation and 20 × 20 planting distance had the highest seed yield, with a mean of 4023 kg/ha, while 15-day irrigation and 25 × 25 planting distance had the lowest, with a mean of 1928 kg/ha (Figure 4). In addition, an optimum density is required to achieve maximum seed yield, and any further increase leads to decreased yield. Space and time are known as an energy source in agro ecosystems, this production advantage is somewhat attributed to the number of plants and the higher relative share of main stem as well as primary tillers in seed yield. Furthermore, in lower densities, the over-exposure of radiation in the test site is also possibly attributed to these factors, allowing the light to penetrate into the canopy and to be used more effectively. Increasing plant dry matter and finally increasing seed yield in rice cultivars are obtained regarding the appropriate plant density. In large densities, the number of plants per unit area is increased and the plant's required resources (light, food, and space) for each plant decrease, leading to declined yield (Baloch *et al.*, 2002).

Meanwhile, Mohaddesi *et al.*, (2010) stated highest seed yield was obtained at 20 × 20 planting distance. Drought stress leads to decreased plant yield, as water plays a key role in achieving maximum yield in rice plant. Ashouri (2014) argued flooding irrigation had the highest seed yield, while an 11-day drought stress was associated with the lowest yield. In addition, Roost *et al.* (2004) indicated the application

of intermittent irrigation, is able to significantly reduce water use, without causing a decrease in yield or a small percentage of decrease in yield.

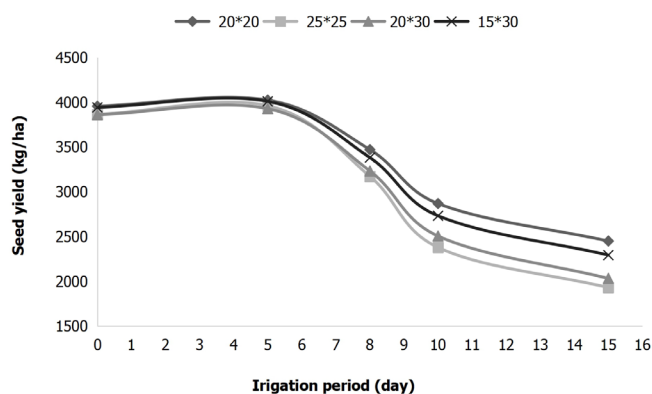


Figure 4. Interaction effects of irrigation and planting distance on seed yield.

### Harvest Index

The harvest index indicates how the assimilation of sunlight is shared among plants and seed vegetative structures. Increased competition at higher densities tends to relatively affect seed yield and biological yield, and consequently, enhance harvest index. Also, increased harvest index tends to increase the rice plant's yield potential. Meanwhile, the highest and lowest harvest index were obtained in 5-day and 15-day irrigation, respectively. Under drought stress conditions, any factor reducing the yield components tends to decrease the seed yield and consequently, harvest index, because the effect of drought stress on seed yield is applied through yield components. Therefore, by reducing harvest index under drought stress conditions, the seed yield becomes more sensitive (Quinones *et al.*, 2017).

### The Amount of Water Use

Water use is one of the key indicators of rice planting. A comparison of the mean interaction effect of irrigation and planting distance on water use indicated daily irrigation and 25 × 25 planting distance with 6345 m<sup>3</sup>/ha, had the highest water use, while 15-day irrigation and 20 × 20 planting distance with 4128 m<sup>3</sup>/ha, had the lowest water use (Figure 5). Pascual and Wang (2017) reported intermittent irrigation of three and seven-day intervals led to a 55% and 74% conservation of water, respectively, compared to continuous flooding, while Rezaei and Nahvi (2007) showed intermittent irrigation reduces water use and improves water use efficiency in rice plant.

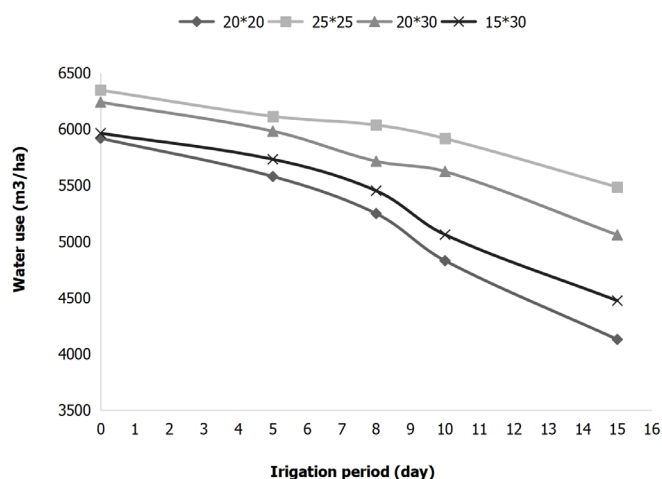


Figure 5. Interaction effects of irrigation and planting distance on water use.

## CONCLUSIONS

The results of this study showed 5-day irrigation produced the highest yield of all irrigation levels. Due to the higher yield in 5-day irrigation, compared to flooding irrigation, this management is suitable to achieve both higher yields and save water, thus solving one of the agricultural problems. An investigation of different planting distances showed 20 × 20 planting distance provided the best conditions for rice crop at different stress intensities, while the 25 × 25 planting distance provided the poorest conditions for the plant. Furthermore, at low densities, inter-plant (between rows) and even intra-plant competitions are less until the flowering and seed formation stage. Subsequently, there is a high competition for photosynthetic materials in the panicle seeds, leading to seed emptiness. Therefore, a 20 × 20 planting distance is appropriate to achieve optimum yield.

## CONFLICT OF INTEREST

The authors declare no conflict of interests.

## REFERENCES

- Amiri, E., Razavipour, T., Farid, A. & Bannayan, M. (2011). Effects of Crop Density and Irrigation Management on Water Productivity of Rice Production in Northern Iran: Field and Modeling Approach. *Communications in Soil Science and Plant Analysis*, 42(17), 2085-2099.
- Asghar, A. A., Tanveer, M., Choudhry, A., Sohail, R. & Akram, M. M. (2001). Growth and yield response of rice bean (*Vigna unbellata*) to different seeding rates and planting patterns. *Pakistan Journal of biological science*, 4(4), 460-461.
- Ashouri, M. (2014). Water use efficiency, irrigation management and nitrogen utilization in rice production in the North of Iran. *APCBEE Procedia*, 8(2013), 70-74. <http://doi.org/10.1016/j.apcb.2014.03.003>.
- Baloch, A. W., Soomro, A. M., Javed, M. A., Ahmed, M., Bughio, H. R., Bughio, M. S. & Mastoi, N. N. (2002). Optimum plant density for high yield in rice. (*Oryza Sativa L.*) *Asian Journal of plant sciences*, 1(1), 25-27.
- Boojuang, H. & Fukai, S. (2002). Effects of soil deficit at different growth stages on rice growth and yield under upland conditions. 1: Growth during drought. *Field Crops Research*, 1, 37-45.
- Bouman, B. A. M., & Tuong. T. P. (2001). Field water management to save water and increase its productivity in irrigated lowland rice. *Agricultural Water Management*, 49(1,2), 11-30. ↑
- Bouman, B. A. M., Hengsdijk, H., Hardy, B., Bindaban, P. S., Tuong, T. P. & Ladha, J. K. (2002). Water-wise rice production. *Proceedings of the International Workshop on Water-wise Rice Production*, 8-11 April 2002, Los Banos, Philippines. IRRI. 356 pp.
- Belder, P., Bouman, B. A. M. & Spiertz, J. H. J. (2007). Exploring option for water savings in lowland rice using a modeling approach. *Agricultural Systems*, 92, 91-114.
- Chamara, B. S., Marambe, B. & Bhagirath, S. (2017). Management of *Cleome ruidosperma* DC using high crop density in dry-seeded rice. *Crop Protection*, 95, 120-128.
- Dawe, D. (2005). Increasing water productivity in rice-based systems in Asia-past trends, current problems, and future prospects. *Plant Production Science*, 8, 221-230.
- Guerra, L. C., Bhuiyan, S. I., Tuong, T. P. & Barker, R. (1998). Producing more rice with less water from irrigated systems. SWIM Paper 5. IWMI/IRRI, Colombo, Sri Lanka, p. 24.
- Hafeez, M. M., Bouman B. A. M., Van de Giesen, N. & Vlek, P. (2007). Scale effects on water use and water productivity in a rice-based irrigation system (UPRIIS) in the Philippines. *Agricultural Water Management*, 92, 81-89.
- Kumar, R. & Kumar, R. (2002). Effect of drought on growth, leaf rolling, plant water status and yield of rice (*Oryza sativa L.*). *Indian Journal of Agronomy*, 47, 61-66.
- Lafitte, R. (2003). Managing water for controlled drought in breeding plots. In: Fischer, K. S., R. Lafitte, S. Fakai, G. Altin and B. Hardy, (eds.). *Breeding rice for drought prone environment*. International Rice Research Institute. Los Banos, Philippines.

- Loeve, R., Barker, R., Dawe, D., Lin, H. & Bin, D. (2004). *Growing more rice with less water: an overview of research in liuyuankou irrigation system*. Henan Province, China. Available on the Url: [www.iwmi.cgiar.org/Assessment/proceedings/IWMI-Paper-RLoeve.doc](http://www.iwmi.cgiar.org/Assessment/proceedings/IWMI-Paper-RLoeve.doc).
- Makara, O., Basnayake, J., Tsubo, M., Fukai, S., Fisher, K. S., Cooper, M. & Nesbitt, H. (2006). Use of drought response index for identification of drought tolerant genotypes in rainfed lowland rice. *Field Crops Reserch*, 1, 48-58.
- Miller, B. C., Hill, J. E. & Roberts, S. R. (1991). Plant population effects on growth and in water-seeded rice. *Agronomy Journal*, 83, 291-297.
- Mohaddesi, A., Abbasian, A., Bakhshipour, S. & Salehi, M. (2010). Effects of nitrogenous fertilizer and planting density on yield and yield components of 843 rice line. *Journal of Crop Ecophysiology*, 2(3), 198-208.
- Ockerby, S. E. & Fukai, S. (2001). The management of rice grown on raised beds with continuous furrow irrigation. *Field Crops Research*, 69, 215-226.
- Park, G. H., Kim, J. H. & Kim, K. M. (2014). QTL analysis of yield components in rice using a cheongcheong/nagdong doubled haploid genetic map. *American Journal of Plant Sciences*, 5, 1174-1180.
- Pascual, V. J. & Wang, Y. M. (2017). Impact of water management on rice varieties, yield, and water productivity under the system of rice intensification in Southern Taiwan. *Water*, 9(3), 1-15.
- Quinones, C., Mattes, N., Faronilo, J., Yadav, S., Jagadish, K. S. V. 2017. Drought stress reduces grain yield by altering floral meristem development and sink size under dry-seeded rice cultivation. *Crop Science*, 57, 2098-2108.
- Rezaei, M. & Nahvi, M. (2007). Effect of different irrigation management methods on water use efficiency and rice yield. *Agricultural Science*, 1, 15-25.
- Roost, N., Molden, D., Zhu, Z. & Loeve, R. (2004). Identifying water saving opportunities examples from three irrigation districts in China's yellow river and yangtze basins. International Water Management Institute, Colombo, Sri Lanka.
- Shahsavari, N., Jais, H. M. & Shirani Rad, A. H. (2014). Responses of canola morphological and agronomic characteristics to zeolite and zinc fertilization under drought stress. *Communications in Soil Science and Plant Analysis* 45(13), 1813-1822.
- Singh, A. K., Choudhury, B. U. and, Bouman, B. A. M. 2002. Effects of rice establishments methods on crop performance, water use, and mineral nitrogen. In B. A. M. Bouman et al. (ed.) *Water-wise rice production*, part 3. Rice- wheat. Proceedings of the International Workshop on Water-Wise Rice Production, Los Baños, Philippines: International Rice Research Institute: 237-246.
- Surajit, K. & Datta, D. (1981). *Principles and practices of rice production*. John Wiley and Sons Inc. Singapore, 618. pp.
- Tao, H., Brueck, H., Dittert, K., Kreye, C., Lin, S. H. & Sattelmacher, B. (2006). Growth and yield formation of rice (*Oryza sativa* L.) in the water-saving ground cover rice production system (GCRPS). *Field Crops Research*, 95, 1-12.
- Tuong, T. P., Bouman, B. A. M. & Mortimer, M. (2005). More rice, less water—integrated approaches for increasing water productivity in irrigated rice-based systems in Asia. *Plant Production Science*, 8(3), 229-239.
- Wang, Z., Gu, D., Beebout, S., Zhang, H., Liu, L., Yang, J. & Zhang, J. (2018). Effect of irrigation regime on grain yield, water productivity, and methane emissions in dry direct-seeded rice grown in raised beds with wheat straw incorporation. *The Crop Journal*, 6, 495-508.
- Yang, J. C., Liu, K., Zhang, S. F., Wang, X. M., Wang, Z. Q. & Liu, L. J. (2008). Hormones in rice spikelets in responses to water stress during meiosis. *Acta Agronomica Sinica*, 34, 111-118.