# Water Saving by Shallow Intermittent Irrigation and Growth of Rice

Jong Gun Won<sup>1</sup>, Jang Soo Choi<sup>1</sup>, Seung Phil Lee<sup>1</sup>, Seung Ho Son<sup>2</sup> and Sang Ok Chung<sup>2</sup>

(<sup>1</sup>Gyeongbuk Agricultureal Technology Administration, Taegu 702-708, Korea; <sup>2</sup>Kyungpook National University, Taegu, Korea)

**Abstract** : To reduce water requirement and improve water productivity (the grain yield per unit volume of water irrigated) by water-saving irrigation techniques, we examined the effects of very shallow intermittent irrigation (VSII, 2cm), shallow intermittent irrigation (SII, 4cm) and traditional deep water irrigation (DWI, 10cm) on rice growth and yield in the field for two years. The amount of water irrigation during the rice-growing period (average of two years) was 318, 391 and 469 mm in VSII, SII and DWI, respectively. Rice growth and grain yield were not significantly influenced by the treatments. As the irrigation water input decreased, the water productivity increased by 46 % in VSII and 20 % in SII on the average as compared with DWI. The shallower the irrigation depth, the lower the breaking weight and the higher the lodging resistance, and the deeper the roots in the paddy soil. In DWI, the percentage of head rice was lower and the protein content was higher, suggesting deterioration in the palatability of cooked rice due to the increase of chalky rice. The water-saving rate was 32.9 % in VSII and 17.2 % in SII as compared with typical deep water irrigation in Korea.

Key words : Rice growth, Water management, Water productivity, Water saving ratio.

Traditionally, during the rice growth period, farmers try to irrigate to maintain the depth of water near 10 cm in order to control weeds and reduce the frequency of irrigation in Korea. Therefore, the amount of water irrigated is usually much more than the actual requirement. This leads to a large amount of surface runoff, seepage and percolation (Bouman, 2001).

Korea has a relatively high annual rainfall (1,283 mm), which is 1.3 times of the world average (973 mm). However, the average amount of rainfall per capita per annum (2,700 m<sup>3</sup>) is only 10 percent of the world average (26,800 m<sup>3</sup>) because of the high population density. Water demand has been steadily increasing for the last several decades due to the increase of population, irrigation area and industries, as well as the rapid expansion of urban areas. The water use in 1998 amounted to about 33.1 billion m<sup>3</sup>, which comprises 7.3 billion m<sup>3</sup> of municipal use, 2.9 billion m<sup>3</sup> of industrial use, 15.8 billion m<sup>3</sup> of agricultural use and 7.1 billion m<sup>3</sup> of in-stream flow. About a half of the total water was used for agriculture (Cheong, 2003). However, as the demand for water for domestic, municipal, industrial, and environmental purposes rises in the future, less water will be available for agriculture. Furthermore, the potential for new water resource development projects is limited.

Because of the population growth, increasing urban and industrial demand, and decreasing availability because of pollution (chemical, salts, and silt) and resource depletion, the availability of fresh water is decreasing. In many Asian countries, per capita availability of fresh water declined by 40-60 % between 1955 and 1990, and is expected to decline further by 15-54 % in the next 35 years (Gleick, 1993; Bouman and Tuong, 2001).

The realization of water scarcity promoted the study on improving water saving system and water productivity (rice yield/water irrigated). In the ricewheat system in India, Gupta et al. (2002) reported farmer's common observation that the raised bed systems reduced water input by 30-45 % compared with the conventional flooding system, without yield losses or sometimes with some increase in yield. From the compiled database on saturated soil culture (SSC) and alternate wetting and drying (AWD), Bouman and Tuong (2001) reported that SSC and AWD resulted in decreased water input by 5-50 %, but at the expense of 0-12 % decreased yield. In the experiment with raised beds in Australia to facilitate SSC practices, Borell et al. (1997) reported that water savings were 34 % and yield losses were 16-34 % compared with flooded rice, and Thompson (1999) found that SSC reduced both irrigation water input and yield by slightly more than 10 %.

Although saturated soil and alternate wetting and drying culture have received some attention as mentioned above, studies on lodging, root distribution and quality of rice plant under very shallow intermittent irrigation and other water-saving irrigation methods have been scarcely reported.

Received 16 April 2004. Accepted 26 January 2005. Corresponding author : J.G. Won (jgwon67@empal.com, fax +82-53-320-0294).



Fig. 1. Three irrigation treatments and water depth in rice field (Growth stage. a : Transplanting , b : Rooting, c : Tillering, d : Midseason drainage, e : Panicle formation, f : Milky, g : Yellow ripe).

Therefore, this study was conducted to determine the effect of water management systems on water efficiency and productivity and on plant responses in terms of lodging, root distribution and rice quality.

# **Materials and Methods**

This study was carried out in 2002 and 2003 at the field of Gyeongbuk Provincial Agricultureal Technology Administration (Taegu, Korea,  $35^{\circ}51^{\circ}$  N latitude,  $128^{\circ}35^{\circ}$  E longitude ; silty clay loam), using "Whayongbyeo", a medium maturing, high yield and high quality Japonica-type rice cultivar, developed in Korea. Thirty-day old seedlings were transplanted ( $5^{\circ}7$ seedlings per hill) mechanically on May 30, at a density of  $30 \times 14$  cm. Fertilizers were applied at a rate of 110 kg N ha<sup>-1</sup>, 45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, and 57 kg K<sub>2</sub>O ha<sup>-1</sup> in total. As the basal application, 50 % of N, all of P<sub>2</sub>O<sub>5</sub> and 70 % of K<sub>2</sub>O were broadcasted just prior to transplanting. Twenty percent of N was applied at tillering stage and 30 % of N and K<sub>2</sub>O shortly after the panicle initiation stage as top dressing.

In this study, the rice plants were cultivated by the following three water management treatments (Fig. 1). (1) Very shallow intermittent irrigation (VSII, 2cm); after transplanting, the water level was kept at a 4 to 5cm depth for 10 days to treat with a herbicide, then after the disappearance of flooding water, irrigation water was applied to a 2cm depth. After the disappearance of flooding water, the same treatment was repeated, although the field was dried at the maximum tillering stage for 10 days (midseason drainage). (2) Shallow intermittent irrigation (SII): The method of water management was the same as that of VSII, except that water depth was adjusted to 4 cm instead of 2 cm. (3) Deep water irrigation (DWI): The method was the same as that of (1) and (2), but the water depth was adjusted to 4 cm instead of 2 cm.

Every water management treatment was given in an  $80 \times 8$  m plot with one replication. The amount of rainfall and the irrigation depth were measured in the field every day. The irrigation depth was continuously measured with a water level logger during the rice growth period. The water volume for irrigation and drainage was measured with a 75 mm pipe flowmeter and automatic water amount recording equipment (Parshall flume). The water-saving rate defined as the water ratio between the amount of water saved by VSII or SII to the water input in DWI. Therefore, it was calculated as {((Volume of water for DWI-Volume of water for SII or VSII)/Volume of water for DWI)×100}. The water-productivity, the grain yield per unit volume of water irrigated, was also calculated as (Rice yield /Volume of water irrigated). The root amount was surveyed by an improved monolith method at 30 days after heading; and the root system was divided into three parts at different depths from the soil surface. The roots were washed carefully on the net to remove the soil and the dry weight was determined.

Thirty days after heading, 10 plants were harvested from three hills for the measurement of culm traits related to lodging tolerance. The length from the culm base to the ear neck was measured for culm length. Lodging index was calculated as {(bending moment/ breaking weight)× 100}, and bending moment as (culm length × plant fresh weight) (Seko, 1962). The breaking weight is the force required to break the 4<sup>th</sup> internode, and was measured with a spring balance. Pushing resistance was measured at 10 cm above the soil surface bending the culm to an angle of 45 degree (Terashima et al., 1992). Field lodging was recorded at 40 days after heading.

Prior to harvest, the plants from 5 hills were obtained from three replications to measure yield components. The number of panicles in each sample was counted, and 20 average panicles selected were threshed by hand. The grains were divided into filled grains and unfilled grains using salt water with a gravity of 1.06 and the percentage of filled grain were determined. Using head brown rice 1000-grain weight was measured and grain weight was calculated to the



Fig. 2. Seasonal changes of mean air temperature and rainfalls during the rice growth in 2002 and 2003.

value at 14 % moisture content. The rice plants were harvested from 100 hills per replication, and the grain yield per ha was calculated.

To estimate grain quality, we examined the apparent rice quality (percentages of head rice, broken rice, chalky rice, etc.) with a grain inspector (Cervitec TM 1625, FOSS), the contents of protein and amylose with a Grain Analyzer using NIR (1241, FOSS) and palatability with a Rice Taste Measuring System (MA90, Toyo).

### **Results and Discussion**

# 1. Weather condition

In Korea, monthly mean air temperature usually ranges from 13 °C in April to 25 °C in August. The average rainfall is about 100 mm in April, but it reaches more than 250 mm in July and August (Lee, 2003). Fig. 2 shows the seasonal changes of mean air temperature and rainfall during the rice growth

period in 2002 and 2003. The mean air temperature in 2002 was higher than that in 2003. Rainfall in 2002 was concentrated in August, but that in 2003 was evenly distributed. The mean air temperature at the rooting stage in early June (21.9~24.9 °C) was suitable for rooting after transplanting. During the tillering stage, it ranged from 24.4 to 29.6 °C, which is optimum for tillering, in 2002 but it ranged from 21.9 to 23.7 °C in 2003. During the heading stage, it passed relatively low, ranged from 21.7 to 23.3 °C. The mean air temperature from early June to late June and from late August to late September, both in 2002 and 2003, was not different from that in normal years. From early July to middle August, it was somewhat higher than or similar to that in normal years in 2002, but, it was 0.8~3.3 °C lower in 2003.

### 2. Rice yield and water saving rate

Table 1 shows the amount of water irrigated, water productivity and the water-saving rate in the three water management treatments in rice field. There are two types of water input to the field, irrigation and rainfall. In each water management, fresh water was irrigated until the water reached the designated water depth. More water was irrigated in 2002 than in 2003 because of the less rainfall. The irrigation amount increased as the water depth increased; therefore, the mean amount of irrigated water during the ricegrowing period in the two years was 318, 391 and 469 mm in VSII, SII and DWI, respectively. The frequency of irrigation was 11 times in VSII, 11 times in SII and 13 times in DWI, respectively. Because of the relatively low mean air temperature, frequent rainfall and less sunshine hours, the rice yield in 2003 was lower than that in 2002. Among the water managements, rice

Table 1. The amount of water irrigated, water productivity and water saving as affected by three water management treatments in the rice field.

by three water management dedunients in the nee need.						
Treatment	Irrigation (mm)	Rainfall (mm)	Water saving <sup>1)</sup> (%)	Yield (t ha <sup>-1</sup> )	Water Productivity <sup>2)</sup> (kg m <sup>-3</sup> )	
2002						
VSII	381	870	25.7	$5.19{\pm}0.08$	1.36(133)	
SII	455	870	11.3	$5.25 \pm 0.11$	1.15(113)	
CWI	513	870	—	$5.24 \pm 0.16$	1.02(100)	
2003						
VSII	255	1028	40.0	$4.61 \pm 0.23$	1.81(159)	
SII	327	1028	23.1	$4.71 \pm 0.10$	1.44(126)	
DWI	425	1028	—	$4.84 \pm 0.11$	1.14(100)	

VSII: Very shallow intermittent irrigation (2 cm), SII: Shallow intermittent irrigation (4cm), DWI: Deep water irrigation (10 cm).

1) Water saving (%) = (Water irrigated in DWI-Water irrigated in SII or VSII)/ Water irrigated in DWI \* 100.

2) Water productivity = Rice yield / Water irrigated.

Each value is the mean±standard deviation.

Treat- ment	Culm length (cm)	Fresh weight (g)	Clm diameter (mm)	Weight of base culm (g culm <sup>-1</sup> )	Breaking weight (g panicle <sup>-1</sup> )	Pushing resistance (g hill <sup>-1</sup> )	Lodging index
2	2002						
VSII	$73.7 \pm 1.3$	$12.1 \pm 1.4$	$3.3 \pm 0.2$	$161\pm3$	$520\pm52$	$840\pm35$	$159 \pm 13$
SII	$73.2 \pm 1.0$	$12.4 \pm 0.5$	$3.3 \pm 0.1$	$156 \pm 4$	$387 \pm 35$	$730\pm21$	$232\pm20$
CWI	$74.8 \pm 1.7$	$12.5 \pm 0.8$	$3.1 \pm 0.2$	$144 \pm 3$	$311 \pm 41$	$520\pm18$	$258 \pm 17$
2	2003						
VSII	$68.6 \pm 1.6$	$14.7 \pm 0.7$	$3.6 \pm 0.2$	$209\pm5$	$617 \pm 19$	$1,097 \pm 37$	$163 \pm 9$
SII	$70.8 \pm 1.3$	$15.0\pm0.9$	$3.7 \pm 0.3$	$196 \pm 6$	$532 \pm 16$	$880 \pm 35$	$201\!\pm\!15$
DWI	$73.6 \pm 3.1$	$15.0\pm0.6$	$3.5 \pm 0.2$	$177 \pm 3$	$466 \pm 25$	$722 \pm 27$	$237 \pm 10$

Table 2. Lodging characteristics as affected by three water management treatments in the rice field.

Each value is the mean ± standard deviation.

Table 3. Vertical root distribution as affected by three water management treatments in the rice field at 30 days after heading.

Treatment	Root amount (D. W g $m^{-2}$ )						
meaument	$0 \sim 10 \text{cm}^{1)}$	0~20cm	20~30cm	Total			
2002		_					
VSII	$295(68.3) \pm 27$	$112(25.9)\pm 31$	$25(6.8)\pm 6$	432(100)			
SII	$322(82.1)\pm19$	$51(13.0) \pm 19$	$19(4.9) \pm 8$	392(100)			
CWI	$394(90.0)\pm15$	$36(8.2)\pm11$	$8(1.8)\pm 4$	438(100)			
2003		_					
VSII	$263(71.7)\pm25$	$87(23.7)\pm13$	$17(4.6) \pm 6$	467(100)			
SII	$273(79.8)\pm24$	$56(16.4) \pm 18$	$13(3.8) \pm 3$	342(100)			
DWI	$318(87.1) \pm 18$	$41(11.2)\pm 16$	$6(1.7)\pm 2$	365(100)			

1) Soil depth from surface.

Numbers in parentheses mean percentage of roots distributed.

Each value is the mean±standard deviation.

yield was not significantly different, but the yield in VSII was  $0.95 \% (2002) \sim 4.7 \% (2003)$  lower than that in DWI, traditional water irrigation in Korea. Although yield reduction was relatively small and statistically not significant among treatments, water input increased as the water depth increased. On the average, VSII reduced the amount of water for irrigation by 32.9 % and SII reduced it by 17.2 % compared with DWI.

Guera et al. (1998) defined water productivity as the amount of food produced per unit volume of water used. In the present experiment, the water productivity increased by 20 % in SII and by 46 % in VSII compared with that in DWI due to the large reduction in water input combined with only a slight reduction in grain yield.

# 3. Lodging

Culm length and fresh weight of the whole plant increased slightly as water depth increased but not significantly in 2002 and 2003 (Table 2). Water management had no effect on culm diameter. Longer culm and heavier fresh weight resulted in a larger bending moment (culm length  $\times$  plant fresh weight) in SII and DWI than in VSII. The lodging index was significantly different among treatments; the value increased with increasing water depth. The heavier weight of culm base and stronger breaking force resulted in the lower lodging index {(breaking weight/bending moment)×100} in VSII in both years. This result was also supported by a higher pushing resistance (969, 805, and 621 g hill<sup>-1</sup> in VSII, SII and DWI, respectively).

#### 4. Root growth

Table 3 shows the effect of the treatment on root distribution within the soil depth. The total root amount was lowest in SII, but the difference was not significant. Hasegawa and Yoshida (1982) reported that one marked characteristic of the rice root system is the high root density in the soil surface. When water is uniformly supplied to all soil depths, rice roots extract water preferentially from the shallow layers. In

Treatment	Apparent rice quality(%)				D	A	
	Head rice	Chalky rice	Broken Rice	Others	(%)	(%)	Palatability <sup>1)</sup>
VSII	$95.1 \pm 1.5$	$3.1 \pm 0.7$	$1.6 \pm 0.3$	0.2	$7.4 \pm 0.3$	$15.9\pm0.7$	$76.3 \pm 2.5$
SII	$94.1 \pm 1.0$	$3.9\pm0.5$	$1.6 \pm 0.3$	0.4	$8.0\pm0.2$	$15.3 \pm 0.3$	$69.4 \pm 1.1$
DWI	$91.2 \pm 0.9$	$6.7 \pm 0.8$	$1.7 \pm 0.2$	0.4	$8.4 \pm 0.5$	$15.3 \pm 0.5$	$67.5 \pm 0.8$

Table 4. Physicochemical characteristics of milled rice as affected by three management treatments.

1) Analyzed by Toyo's Rice Taste Measuring System.

Each value is the mean  $\pm$  standard deviation.

this study, the same results were obtained; more than 80 % of roots distributed in the surface layer of soil (0 -10 cm depth) in all water management treatments in 2002 and 2003. However, water management affected the vertical distribution of roots in the soil. As the amount of water applied decreased, the root amount in the shallow layer decreased (88.6 %, 81.0 % and 70.0 % in DWI, SII and VSII, respectively). The root density in the deeper soil increased as the amount of water applied decreased. Sanches (1973) and Bhuiyan et al. (1995) also reported that with decreasing water input, direct wet-seeded rice can extract more water from the deep soil because of a better and more deeply developed root system. Terashima et al. (1995) insisted in their paper that the contribution of unit root weight to lodging tolerance was higher in deeper (including subsoil) than in shallower soil layers, and that the high ability to form roots in the subsoil with a high bulk density was one of the important characteristics for root lodging tolerance. Therefore, the denser roots in the deeper soil in VSII and SII than in DWI must have increased the pushing resistance and strengthened the resistance to lodging.

# 5. Rice quality

Table 4 shows the physicochemical characteristics of milled rice and palatability as affected by water management treatments. The treatments had a significant effect on the percentage of head rice and chalky rice. As the water depth increased, the percentage of chalky rice increased (3.1, 3.9 and 6.7 % in VSII, SII and DWI, respectively), decreasing the percentage of head rice (95.1, 94.1 and 91.2 in VSII, SII and DWI, respectively). The content of amylose was not affected by the treatments (water depth), but protein content of rice in VSII was lower than the other water management treatments suggesting better palatability of rice in VSII. Chalky rice (milky-white rice), which is partially unfilled due to nutrient deficiency, is believed to occur as a result of an abnormal process of ripening; such as when the nutrient translocation temporarily impeded while the clearing process in a rice grain is still proceeding (Nagato, 1952; Nagato and Kobayashi, 1958; Nagato

and Ebata, 1961). In VSII, a greater amount of root in deep soil layer promoted the absorption of nutrient; therefore, it may decrease the percentage of chalky rice and increase that of head rice. This result is supported by a report that in sandy, and gravelly paddy fields, 10 - 15 % of manganese, silicon, iron, nitrogen and potassium was absorbed from the subsoils below 25 cm; the percentage was greater under water-permeable conditions (Matsuura et al., 1977). Furthermore, brown rice from a lowland type cultivar grown under upland conditions with mulching had a higher protein content than that grown under ordinary upland conditions (Ono, 1970; Taira et al., 1972). This was explained to be because the leaching and the loss of soil nitrogen was less and the nitrogen content of the rice plant was kept higher under the mulched upland conditions. In this experiment, the leaching and the loss of soil nitrogen might be high in VSII with a shallow water depth, and low in DWI with a deep water depth, resulting in a low protein content of rice in VSII and high protein content in DWI.

Although the water-saving effect and important agronomic advantage of VSII were proved, there are some problems in applying VSII in a large area, because weeds would increase in shallower irrigation treatments (data was not shown), and more careful water management is required.

#### Conclusions

Large reduction in water input combined with a slight change in grain yield was attained in VSII and SII, where water productivity was increased by 46 % and 20 %, respectively, compared with that in DWI. The water-saving rate compared with typical deep water irrigation was 32.9 % in VSII and 17.2 % in SII. Denser root distributions in deeper soil in VSII and SII increased the pushing resistance and strengthened the lodging resistance as compared with DWI. Due to the decrease of chalky rice, the percentage of head rice was higher, protein content was lower and the palatability of cooked rice was increased in VSII.

#### References

Bhuiyan, S.I., Sattar, M.A. and Khan, M.A.K. 1995. Improving

water use efficiency in rice through wet seeding. Irrig. Sci. 16 : 1-8.

- Borell, A., Garside, A. and Fukai, S. 1997. Improving efficiency of water for irrigated rice in a semi-arid tropical environment. Field Crop Res. 52 : 231-248.
- Bouman, B.A.M. 2001. Water-efficient management strategies in rice production. International Rice Research Notes 16.2 : 17-22.
- Bouman, B.A.M. and Tuong, T.P. 2001. Field water management to save water and increase its productivity in irrigated rice. Agric. Water Manage. 49 : 11-30.
- Cheong, B.H. 2003. Recent status of water resources and its prospect and efficient use of agricultural water resources in Korea. Proc. Int. Symp. on Enhancement of Water Use Efficiency in Lowland Rice Cultivation. Iksan, Korea. 19-38.
- Guerra, L.C., Bhuiyan, S.I., Tuong, T.P. and Barker, R. 1998. Production more rice with less water from irrigated systems. SWIM pater 5. IWMI/IRRI, Colombo, Sri Lanka : 1-24.
- Gleick, P.H. (Ed.). 1993. Water Crisis: a Guide to the World's Fresh Water Resources. Pacific Institute for Studies in Development, Environment, and Security. Stockholm Environment Institute. Oxford University Press, New York. 1-473.
- Gupta, R.K., Naresh, R.K., Hobbs, P.R. and Ladha, J.K. 2002. Adopting conservation agriculture in the rice-wheat system of the Indo-Gangetic Plains: new opportunities for saving water. Proc. Thematic Workshop on Water-wise rice production. IRRI, Los Banos (Philippines). 207-222.
- Hasegawa, S. and Yoshida, S. 1982. Water uptake by dryland rice root system during soil drying cycle. Soil Sci. Plant Nutr. 28 : 191-204.
- Lee, J.T. 2003. Efficient use of irrigation water in paddy rice system related to the pattern of rainfall in Korea. Proc. Int. Symp. on Enhancement of Water Use Efficiency in Lowland Rice Cultivation. Iksan, Korea. 19-38.
- Matsuura, K., Tukunaga, A. and Sakanoue, Y. 1977. A modeled expreriment on contributions of the subsoil layer to the growth and mineral nutrient absorption of rice plants. J. Sci. Soil Manure, Japan 48 : 19-24.\*

- Nagato, K. 1952. The occurrence of white core, milk-white and white belly grains in rice plants. Proc. Crop Sci. Soc. Jpn. 21 : 26-27.\*
- Nagato, K. and Kobayashi, Y. 1958. The development of starchcell tissues in rice kernels. Proc. Crop Sci. Soc. Jpn. 27 : 204-206.\*
- Nagato, K. and Ebata, M. 1961. The grain quality of paddy rice cultivated in upland fields. Proc. Crop Sci. Soc. Jpn. 30 : 79-82.\*
- Ono, Y. 1970. Nutriophysiology in paddy rice plants grown under upland conditions with mulching. Agri. & Hort. 45 : 91-94.\*
- Sanches, P.A. 1973. Puddling tropical rice soils. Part 2: effects of water loss. Soil Sci. 115: 303-308.
- Seko, H. 1962. Studies on lodging in rice plants. Bull. Kyushu Agri. Exp. Stn. 7 : 419-499.
- Taira, H., Taira, H. and Furusawa, F. 1972. Protein content of brown rice grains produced under mulching conditions with a polyethylene film in upland fields. Proc. Crop Sci. Soc. Jpn. 41 : 160-165.\*
- Terashima, K., Akita, S. and Sakai, N. 1992. Eco-physiological characteristics related with lodging tolerance of rice in direct sowing cultivation. I. Comparison of the root lodging tolerance among cultivars by the measurement of pushing resistance. Jpn. J. Crop Sci. 61 : 380-387.\*
- Terashima, K., Akita, S. and Sakai, N. 1995. Eco-physiological characteristics related with lodging tolerance of rice in direct sowing cultivation. III. Relationship between the characteristics of root distribution in the soil and lodging tolerance. Jpn. J. Crop Sci. 64 : 243-250.\*
- Thompson, J. 1999. Methods for increasing rice water use efficiency. Proc. on Rice Water Use Efficiency Workshop. CRC for Sustainable Rice Production. Yanco, Australia. 45-46.

\* In Japanese with English abstract.