Increasing Water Productivity and Growth of Rice with Less Irrigation Water

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Abstract

To reduce water requirement and improve water productivity by water-saving irrigation techniques a field study was carried out with three water management treatments: very shallow intermittent irrigation (VSII, 2cm), shallow intermittent irrigation (SII, 4cm) and traditional deep water irrigation (DWI, 10cm) for two years. The total water input was 527, 654 and 777 mm in VSII, SII and DWI, respectively. Rice growth and grain yield in the three treatments were not significantly different. As the water input decreased the water-productivity (the grain yield per unit volume of water) increased. The water use efficiency, (ratio of evapotranspiration to total water input) when compared with DWI increased by 44% in VSII and 26% in SII. In the lodging characteristics, as the irrigation depth decreased the breaking weight and lodging resistance increased and more roots were deeper in the paddy soil. Due to the increase of chalky rice, the percentage of head rice decreased and the content of protein was higher in DWI, suggesting deterioration in the palatability of cooked rice. The water-saving in VSII was 32% and 16% in SII compared to typical deep water irrigation in Korea.

Media summary

A study for increasing water productivity without yield loss by Korean crop scientists will contribute to water savings, improving lodging resistance and grain quality in irrigated rice cultivation areas.

Key Words

Rice Growth, Water management, Water productivity, Water efficiency, Water Saving ratio

Introduction

Traditionally, during the rice growth period, farmers try to irrigate to maintain the depth of water near to 10 cm in order to control weeds and reduce the frequency of irrigation in Korea. Therefore, the amount of water usually irrigated is much more than the actual rice requirement. This leads to a high amount of surface runoff, and seepage and percolation (Bouman, 2001). Korea has a relatively high annual rainfall (1,283 mm) at 1.3 times of the world average (973 mm). However, the average amount of rainfall per capita per annum (2,700 m^3) shows only 10 percent of the world average (26,800 m^3) 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^3, which comprises 7.3 billion m^3 of municipal use, 2.9 billion m^3 of industrial use, 15.8 billion m^3 of agricultural use and 7.1 billion m^3 of in-stream flow augmentation (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. But the potential for new water resource development projects and expanding irrigated area are limited. Therefore, this study was conduced to find ways to increase water productivity by water management. The aim was to find water saving irrigation systems without yield losses and to examine the response to lodging, root distribution and rice quality.

Methods

This study was carried out in 2002 and 2003 at the field of Gyeongpuk ATA (Taegu, Korea, 35? 51` N latitude, 128? 35` E longitude; silty clay loam). Three water management treatments were used in this study, (1) very shallow intermittent irrigation (VSII, 2cm): after transplanting the water level was continued

4 or 5cm for 10 days to treat with herbicide, then irrigation water was applied to obtain 2cm floodwater depth after the disappearance of ponded water. The field was dried at the maximum stage for 10 days (midseason drainage), after that it was flooded again until the ripening period. (2) Shallow intermittent irrigation (SII, 4cm): the method of water management was same as that of VSII, except for water depth. (3) Deep water irrigation (DWI, 10cm): continuous standing water (maximum to 10 cm, minimum to 6 cm) until midseason. Values of rainfall amount, irrigation depth, irrigation and drainage water, evapotranspiration, and percolation were measured in the field every day. The evapotranspiration was measured by 1 m diameter PVC lysimeters. Irrigation and drainage water volume was measured by 75 mm pipe flowmeters and a recording Parshall flume. Thirty days after heading, 10 plants were obtained from three hills for the measurement of culm traits relation to lodging tolerance. The length from the culm base to the ear neck was measured for culm length, and the diameter. Lodging index was calculated {(bending moment/breaking weight) ? 100}, and bending moment as (culm length ? plant fresh weight). The breaking weight is the force required to break the 4^{th} internode, and was measured with a spring balance. Prior to harvest, the plants from 5 hills were obtained from each replication to measure yield components. The rice plants were harvested from 100 hills per replication, and the grain yield per ha was calculated. The data analyzed was the mean of the two seasons.

Results and Discussion

In Korea, monthly mean air temperature usually ranges from 13 ℃ in April to 25 ℃ in August. This higher mean air temperature in August is suitable for heading and ripening of the rice. Average rainfall is about 100 mm in April, but in July and August it reaches more than 250 mm (Lee, 2003). The mean air temperature in 2002 was higher than that in 2003. Rainfall in 2002 was concentrated in August, but that of 2003 was evenly distributed. The mean air temperature at the rooting stage in early June (21.9~24.9 ℃) was suitable for rooting after transplanting. Temperature during tillering, (24.4~29.6 ℃) was optimum for tillering in 2002 but in 2003 (21.9~23.7 ℃) it was below the optimum for rice. During heading, it was relatively low, (21.7~23.3 ℃), but not sufficient to affect heading and fertility.

Water balance components of three water management treatments in rice field are shown in Table 1. There are two types of water input into the field, irrigation and rainfall. The rainfall is divided into effective and non-effective, the former remained in field and used for rice growth, and the latter drained because the levee was designed to retain a specific depth (2, 4 and 10 cm for VSII, SII and DWI). Irrigation amount and effective rainfall increased as the water depth increased; therefore, the total water inputs during rice growing were 527.2, 654.3 and 777.2 mm in VSII, SII and DWI, respectively. It was difficult to find any trends in evapotranspiration due to water management over two years. The amount of percolation decreased remarkably as water input and irrigation depth decreased in the field. Guera et al. (1998) also reported that percolation rate increases as the depth of water standing in the field increases. From these data, we could understand why the water balance was near to zero in SII (0), the shortage of water was in VSII (−61) and the excess of water in DWI (145).

Table 1. Water balance components as affected by three different water management treatments in the rice field, (unit: mm)

Water management	Irrigation	Drainage	Rainfall	E R[1)]	E T[2)]	Percolation	Change in storage[3)]
VSII	318	736	949	209	404	184	−61
SII	391	680	949	263	439	215	0

DWI	469	642	949	308	416	216	145

1) Effective rainfall= Rainfall – Drainage, 2) Evapotranspiration,

3) Change of storage = (Irrigation + ER) – (ET + Percolation)

Whereas yield reductions were relatively small and statistically not significant among treatments, water input increased as the treatment water depth increased. VSII reduced water input by 32.2% and SII reduced by 15.9 %. Guera et al. (1998) discussed the concept of water productivity and water use efficiency.

Table 2. Yield of rice and on-farm water productivity and efficiency in three different water management treatments.

Water management	Yield (t / ha)	Water input[1)] (mm)	Water saving (%)	Water Productivity[2)] (kg / m^3)	Evapor-transpiration (mm)	Water-use efficiency[3)]
VSII	4.90 a[4)]	527	32.2	0.93 a	404	0.77
SII	4.98 a	654	15.8	0.76 b	439	0.67
DWI	5.04 a	777	–	0.65 c	416	0.53

1)Water input = Irrigation + Effective rainfall, 2) Water productivity = Rice yield / Water input

3)Water use efficiency = Evapotranspiration / Water input

a, b, c; Means followed by the same letter are not significantly different at 0.05 level according to DMRT.

Water productivity, when compared with DWI, increased by 19% in SII and 48% in VSII due to the relatively large reduction in water input combined with the slight reduction in grain yield. Water is released into the air by evaporation (E) from the ponded water layer and transpiration (T) by the crop. Of all outflows of water from a rice field, only T is “productive” water use as it leads directly to crop growth and yield formation. Transpiration is essential to crop growth because it provides cooling and is the driving process for water flow in plants that carries nutrients from the roots to the shoot. However, Seepage and percolation are unproductive as they do not contribute to crop growth and yield formation (Bouman, 2001). Water use efficiency (ratio of evapotranspiration to total water input), when compared with DWI, increased by 26% in SII and 44% in VSII.

Culm length and fresh weight of whole the plant increased slightly as water depth increased but not significantly in 2002 and 2003 (Table 3). Water management had no effect on culm diameter. Longer culm and heavier fresh weight resulted in a larger bending moment (culm length ? plant fresh weight) in SII and DWI. The lodging index was significantly different in each treatment with lodging increasing with water depth. The heavier weight of culm base and breaking force produced the lower lodging index {(breaking weight / bending moment) ? 100} at the shallowest water in the two years. This result was also supported by larger pushing resistance (969, 805, and 621 g / hill in VSII, SII and DWI, respectively). These lager pushing resistances in VSII and SII may be caused by the higher root density in the deeper soil compared to the root distribution in the shallow soil layer in DWI (Table 4).

Table 3. Lodging characteristics as affected by three different water management in rice field.

Water manage-ment	Culm length (cm)	Fresh weight (g)	Culm diameter (mm)	Weight of base culm (g / culm)	Breaking weight (g / panicle)	Pushing resistance (g / hill)	Lodging index
VSII	71.2 a	13.4 a	3.5 a	185 a	569 a	969 a	161 c
SII	72.0 a	13.7 a	3.5 a	176 ab	460 b	805 ab	217 b
DWI	74.2 a	13.8 a	3.3 a	161 b	389 c	621 b	246 a

a, b, c; Means followed by the same letter are not significantly different at 0.05 level according to DMRT.

The effect of the treatments on root distribution within the soil depth is shown in Table 4. Total root density was lowest in SII, but the difference was not significant. Hasegawa and Yoshida (1982) reported that one remarkable characteristic of the rice root system is the high root density in the soil surface. In this study, the same results were obtained with more than 80% of roots distributed in the soil surface (0~10 cm soil depth) in all water management treatments. However, water management affected root distribution with soil depth.. As the water amount and depth decreased the root amount in the shallow layer also decreased (88.6 %, 81.0 % and 70.0 % in DWI, SII and VSII, respectively). The root density in the deeper soil increased as the water amount and depth 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 soil profile because of a better and more deeply developed root system. Therefore, the denser roots in the deeper soil in VSII and SII than in DWI increased the pushing resistance and strengthened the resistance to lodging.

Table 4. Root distribution as affected by three water management treatments in rice field at 30 days after heading.

Water management	Root density (D.W g / m^2)			
	0~10㎝[1)]	10~20㎝	20~30㎝	Total
VSII	279 (69.8) b	100 (24.9) a	21 (5.3) a	400 (100)
SII	298 (81.0) ab	56 (14.6) b	16 (4.4) ab	367 (100)
DWI	356 (88.7) a	39 (9.6) b	7 (1.7) b	402 (100)

1) Soil depth from surface

a, b, c; Means followed by the same letter are not significantly different at 0.05 level according to DMRT.

Physicochemical characteristics of milled rice and palatability as affected by the water management treatments are shown in Table 5. Among the apparent rice quality characteristics, the treatments had a significant effect on head rice and chalky rice amount. The increase in chalky rice amount (3.1, 3.9 and 6.7 % in VSII, SII and DWI, respectively), as water input amount and depth increased, resulted in decreasing the amount of head rice (9.1, 94.1 and 91.2 in VSII, SII and DWI, respectively). The content of amylose was not affected, but protein content of VSII was lower than other water management treatments suggesting the better palatability in VSII. Chalky rice is believed to occur as a result of an abnormal process of ripening; with the nutrient translocation temporarily impeded while the clearing process in a rice grain is still proceeding (Nagato, 1952). A report by Matsuura et al. 1977 supports this result. In a sandy, gravelly paddy field, they found, 10~15% of the absorbed amounts of manganese, silicon, iron, nitrogen and potassium originated from subsoils below 25 cm; the percentage was greater under water permeable conditions. Furthermore,. brown rice from a lowland type cultivar grown under upland conditions modified by mulching exhibited a higher level of protein content than the rice grown under ordinary upland conditions (Taira et al., 1972; Ono, 1970). They explained the reason that the leaching and the loss of soil nitrogen was less under the mulched upland conditions, and hence, the nitrogen content in the rice plant remained at a higher level. In this experiment, the leaching and the loss of soil nitrogen might be high in VSII (shallow water depth) and exposure of soil, and low in DWI (deep water depth), suggesting low protein content in VSII and high protein content in DWI.

Table 5. Physicochemical characteristics of milled rice as affected by three different water management treatments.

Water management	Apparent rice quality (%)				Protein (%)	Amylose (%)	Palatability[1)]
	Head rice	Chalky rice	Broken Rice	Others			
VSII	95.1 a	3.1 b	1.6 a	0.2	7.4 b	15.9 a	76.3 a
SII	94.1 a	3.9 b	1.6 a	0.4	8.0 a	15.3 a	69.4 b
DWI	91.2 b	6.7 a	1.7 a	0.4	8.4 a	15.3 a	67.5 b

1) Analyzed by Toyo's Rice Taste Measuring System

a, b, c; Means followed by the same letter are not significantly different at 0.05 level according to DMRT.

Conclusion

From these results, the relatively large reduction in water input combined with the slight changes in grain yield and evapotranspiration led to an increase in water productivity of 48% in VSII and 19% in SII when compared with DWI. Similarly, water efficiency increased by 44% in VSII and 26% SII. Denser root distribution in the deeper soil of VSII and SII increased the pushing resistance and strengthened the lodging resistance compared to DWI. Due to the decrease of chalky rice, the ratio of head rice was increased in VSII and the relatively low content of protein improved the palatability of cooked rice in VSII.

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