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ARTICLE

Feasibility of SRI methods for reduction of irrigation and NPS pollution in Korea

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Abstract An experimental study on the System of Rice Intensification (SRI) methods was conducted to investigate the feasibility of using them to conserve irrigation water and reduce non-point source (NPS) pollution in Korea. Eight experimental runoff plots were prepared at an existing paddy field. Runoff and water quality were measured during the 2010 growing season in which a Japonica rice variety was cultivated. The irrigation water requirements of SRI methods and conventional (CT) plots were 243.2 and 547.3 mm, respectively, meaning that SRI methods could save 55.6% of irrigation water. Runoff from SRI methods plots decreased 5–15% compared with that from CT plots. Average NPS pollutant concentrations in runoff from SRI methods plots during rainfall-runoff events were SS 89.4 mg/L, COD_{Cr} 26.1 mg/L, COD_{Mn} 7.5 mg/L, BOD 2.0 mg/L, TN 4.2 mg/L, and TP 0.4 mg/L. Except for COD_{Cr} and TN, these concentrations were significantly lower than those from CT plots. Measured pollution loads from SRI methods plots were SS 874 kg/ha, COD_{Cr} 199.5 kg/ha, COD_{Mn} 47 kg/ha, BOD 13 kg/ha, TN 36.9 kg/ha, and TP 2.92 kg/ha. These were 15.8–44.1% lower than those from CT plots. Rice plants grew better and healthier in SRI methods plots than in CT plots. However, rice production from SRI methods plots ranged between 76 and 92% of that of CT plots because the planting density in SRI methods plots was too low. It was concluded that SRI methods could be successfully adopted in Korea and could help save a significant amount of irrigation requirement in paddies and reduce NPS pollution discharge.

Keywords Plant spacing · Intermittent irrigation · Water quality · Pollution · Runoff plot

Introduction

The International Rice Research Institute in the Philippines has proposed eight objectives for the advancement of rice farming in underdeveloped and developing countries. These are increased land productivity, higher water productivity, technology that is accessible to the poor, technology that is environmentally friendly, greater resistance to pests and diseases, tolerance of abiotic stresses such as climate change, better grain quality for consumers, and greater profitability for farmers (Uphoff et al. 2002). System of Rice Intensification (SRI) is one of the alternatives that can satisfy all these objectives. SRI was developed in Madagascar by a French missionary before the 1980s, adopted by developing countries beginning in 1999, including China and Indonesia (Uphoff 2009), and is practiced by more than 40 countries as of 2010 (CIIFAD 2010). Since then, studies on SRI have been widely conducted by many researchers (Uphoff 1999; Wang et al. 2002; Yuan 2002; Barrett et al. 2004; Ceesay et al. 2006; McDonald et al. 2006; Kabir and Uphoff 2007; Satyanarayana et al. 2007; Sinha and Talati 2007; Namara et al.

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2008; Senthilkumar et al. 2008; Zhao et al. 2009). And in March, 2011, a special issue of 17 papers on Paddy and Water Management with SRI was published by Paddy and Water Environment, the Journal of the International Society of Paddy and Water Environment Engineering (PWE 2011). SRI has proven to be an effective rice farming method in terms of yield increase and saving water (Zhao et al. 2010). Uphoff et al. (2002) and Stoop et al. (2002) reported that the average rice production of SRI was more than twice that of conventional (CT) rice farming, while the use of irrigation water in SRI was significantly less than that in CT culture in developing countries. Zhao et al. (2010) also reported that SRI produced 26.4% more rice than CT culture and the water use efficiency of SRI increased 194.9% compared with CT culture.

SRI may not be a technology per se, but there are six principles for the successful SRI application: transplant young seedlings to preserve their growth potential, avoid trauma to the roots of cutting and drying of seedlings, give plants wider spacing between hills, keep paddy soil moist but unflooded, actively aerate the soil as much as possible, and enhance soil organic matter as much as possible. These SRI principles are not well understood by Korean administrators and researchers although rice production system in Korea is very well established. And SRI has not yet been tried in South Korea. However, Korea expects water shortages in the near future and the conservation of water resources in the agricultural sector is one of the most important pending issues. Water consumption by the agricultural sector in Korea is about 48% of the nation's water supply and about 90% of agricultural water use is consumed in paddy farming. The saving of irrigation water in paddy farming is very important in overall water resources management in Korea and SRI has a significant potential to reduce irrigation supply as well as to increase rice yields. It is also expected that because SRI uses less water, it would discharge less non-point source (NPS) pollutants from paddies. However, the effects of SRI on NPS pollution have not been reported yet. Therefore, the objectives of this research were to experimentally investigate the feasibility of applying SRI principles in Korea with a focus on water saving and to evaluate the potential for NPS pollution reduction by SRI. The research results could contribute to an understanding and adoption of SRI and to a conservation of agricultural water resources in Korea.

Materials and methods

Experimental runoff plot

Experimental plots were constructed at a university farm located at the north latitude (N) 37°55′57″ and the east longitude (E) 127°46′59″. Eight plots 5 × 15 m in size were prepared in an existing paddy field of 1,873 m^2. Irrigation pipes and drainage channels were constructed. Each plot was equipped with a flowmeter for irrigation measurement, a flume for drainage measurement, and a Coshocton wheel water sampler (Bonta 1999, 2002) for collecting composite water samples. An automatic rain gauge was also installed near the plot to measure rainfall.

Experimental treatment and management

Experimental treatments were CT and SRI methods. SRI methods were subdivided into three sub-treatments that were the transplanting spacing of 30 × 30, 40 × 40, and 50 × 50 cm, respectively. For CT culture, the spacing was 30 × 15 cm which was the typical spacing used in the region. All treatments were duplicated. Three to five seedlings per hill were mechanically transplanted for CT and one seedling per hill was manually transplanted for SRI methods. Seedlings were transplanted on May 21, 2010 for both CT and SRI methods plots. Older seedling age was used for SRI methods treatment because it was thought that the cold temperature at night may harm the younger seedlings. However, it is proposed to transplant younger seedling as recommended for SRI (8–12 days old) in the future studies if the seedlings grew well in this study.

Irrigation management of CT followed local rice culture guidelines, as shown in Table 1. For SRI methods, 4- to 7-day interval intermittent irrigation, depending on rainfall and growth stage, was practiced as suggested on the SRI homepage operated by CIIFAD (2010). For both SRI methods and CT, irrigation was ended at the late ripening stage of the rice. Weeding of SRI methods plots was conducted by hand three times. Active soil aeration by either hand or mechanical weeder was not included in the evaluation. And for CT plots, an herbicide was used to control weeds. Other management practices such as fertilization and disease control for both CT and SRI methods followed respective local guidelines. Recommended fertilization was 110–45–57 kg/ha as N–P_2O_5–K_2O. A locally bred Japonica rice variety Odaebyeo (*Oryza sativa* L.) which is known to be early maturing and cold tolerant, was cultivated in 2010 growing season. Crop growth monitoring was conducted periodically with respect to plant height and number of tillers throughout the growing season, according to the Research and Investigation Standard for Agricultural Science and Technology (RDA 2003). These data were used to evaluate the effectiveness of SRI methods on plant growth.

Sampling and analysis

Soil samples were collected in runoff plots and analyzed with respect to pH, water content, organic matter content, and particle size distribution according to Korean Standard

Table 1 Water management standard for CT by a local guide

Growing stage	Water management	Water depth (cm)
Transplanting	Shallow irrigation	2–3
Root development	Deep irrigation	5–7
Tillering	Shallow irrigation	2–3
End of tillering	Management drain (5–10 days): 30–40 days before heading	0
Panicle initiation/booting	AWD (30 days before heading): 3-days ponding and 2-days dry	2–4
Heading/flowering	Medium irrigation	3–4
Ripening	AWD (3-days ponding and 2-days dry)	2–3
Draining	No irrigation: 30–40 days after heading	0

AWD alternating wet and dry irrigation or intermittent irrigation

Table 2 Monthly average temperature, rainfall, sunshine duration, and relative humidity during the rice growing season in 2010

	May	June	July	August	September
Temperature (°C)	17.2	22.9	25.5	26.0	20.3
Rainfall (mm)	106.1	54.9	220.9	468.1	448.5
Duration of sunshine (h/month)	195.0	219.8	119.0	104.4	141.5
Relative humidity (%)	63.3	67.7	77.2	82.3	79.7

(Ministry of Environment 2009). Water samples taken from the plots and irrigation source which was a farm reservoir were analyzed with respect to BOD, COD, T–N, and T–P according to Korean Standard (Ministry of Environment 2007) and Standard Method (APHA et al. 2005). ANOVA with Minitab 16 software and Tukey's test were used to analyze the collected data.

Results and discussion

Weather and soil

The monthly average temperature, rainfall and duration of sunshine around the site during the rice growing season in 2010 are shown in Table 2. The duration of sunshine during July and August was very limited due to long cloudy and rainy days, resulting in photosynthesis that was insufficient to yield good quality rice. Rainfall in August and September were frequent and sufficient enough to minimize the amount of irrigation. Temperature was also below average. Therefore, the weather was not ideal for rice growth in 2010.

The water content of the soil before spring farming was 18.7 ± 1.0%. Particle size analysis showed that the soil was composed of 49.4% sand, 35.8% silt, and 14.8% clay and the soil texture was loam. Physicochemical analysis of the sampled soil showed that the organic matter content was 2.5 ± 0.03%, pH was 6.1 ± 0.2, and exchangeable cation Ca, Mg, and K contents were 4.6 ± 0.2, 1.7 ± 0.3, and 0.28 ± 0.1 cmol/kg, respectively (Table 3). Analyzed heavy metal contents are also shown in the table.

Crop growth monitoring

It was observed that the rice plants grew continuously until early August and the number of tillers per hill also increased until July 16, about 47 days since the May 21 transplanting. The highest plant height and the largest number of tillers per hill were measured at the 50 × 50 cm spacing of the SRI methods plot. The plant height and number of tillers per hill increased as the transplanting spacing increased, as shown in Table 4. The average height of rice plants of CT, SRI 30 × 30, SRI 40 × 40, and SRI 50 × 50 cm was 92 ± 1.2, 94 ± 1.9, 98 ± 2.3, and 101 ± 2.1 cm, respectively. ANOVA was performed to analyze the differences between average plant heights and number of tillers per hill with respect to the treatments. Residual analysis showed that the plant height satisfied the normality ($p > 0.05$) and homoscedasticity. And variance analysis showed that the number of tillers were significantly different among the different treatments mostly at the level of 5%. Tukey's test also showed that the height differences were significant. The number of tillers per hill in the SRI plots was 1.5 times more than that in the CT plots and the differences between SRI and CT were significant at the level of 1%. Therefore, it was concluded that the plant height and the number of tillers per hill in the SRI methods plots were taller and larger than those in the CT plots, and thus the rice plant grew better in

Table 3 Physicochemical properties of the soil before the beginning of rice culture

pH	OM (%)	Exchangeable cation (cmol/kg)		
		Ca	Mg	K
6.1 ± 0.2	2.5 ± 0.03	4.6 ± 0.2	1.7 ± 0.3	0.28 ± 0.1

Heavy metal (mg/kg)

Al	Cr	Cu	Cd	Zn	Ni	Pb	As	Hg
720	0.9	4.4	0.2	73	26	8.7	0.03	0.1

Table 4 Number of tillers and plant height of the rice during the 2010 growing season

Date		June 2	June 15	June 25	June 30	July 8	July 16	August 4
# of tillers (ea)	SRI 50 × 50 cm	4.2^{a}	16.3^{a}	19.4^{a}	21.0^{e}	22.4^{e}	34.4^{a}	34.6^{a}
	SRI 40 × 40 cm	4.4^{ab}	15.9^{ab}	18.6^{ab}	20.3^{ef}	21.8^{ef}	30.2^{b}	30.3^{b}
	SRI 30 × 30 cm	4.8^{b}	14.9^{b}	17.7^{bc}	19.6^{f}	21.1^{ef}	25.6^{c}	25.6^{c}
	CT 30 × 15 cm	3.7^{c}	11.3^{c}	17.4^{c}	19.2^{f}	21.5^{f}	24.4^{c}	22.6^{d}
Plant height (cm)	SRI 50 × 50 cm	22.3^{a}	41.6^{a}	55.4^{a}	62.1^{a}	75.5^{a}	78.6^{a}	101.1^{a}
	SRI 40 × 40 cm	21.3^{a}	39.9^{a}	54.3^{ab}	62.3^{a}	72.8^{ab}	78.3^{ab}	98.4^{b}
	SRI 30 × 30 cm	21.4^{a}	40.2^{a}	53.8^{b}	61.2^{a}	71.5^{b}	76.2^{b}	94.3^{c}
	CT 30 × 15 cm	17.8^{b}	32.4^{b}	51.7^{c}	56.9^{b}	60.2^{c}	73.6^{c}	91.5^{d}

Superscript a, b, c, d and e, f stand for significance level of 1% ($p < 0.01$) and 5% ($p < 0.05$), respectively

the SRI methods than in the CT method. These results were similar to the results of Thakur et al. (2010) and Satyanarayana (2005).

Crop water requirement

Average irrigation supply to the SRI and CT plots during the growing season was 547.3 and 243.2 mm, respectively (Fig. 1). This meant that the water requirements in the SRI methods plots were 55.6% less than that in the CT plots. This result was similar to that of Zhao et al. (2010), who reported an irrigation reduction of 57.2% with SRI. The irrigation water use efficiency (IWUE) defined as the ratio of total irrigation amount (m^3) per rice production (kg) of SRI methods increased about 88% compared with that of CT. However, it should be noted that the reduction of 55.6% might have been somewhat overestimated because of the small experimental plot size, in which water loss through levies by lateral infiltration could be influential to the irrigation requirements. To correct this problem, further research is necessary. However, it could be concluded that the irrigation requirement in the SRI methods plots could be substantially saved, which in turn would help secure water resources in the future in Korea.

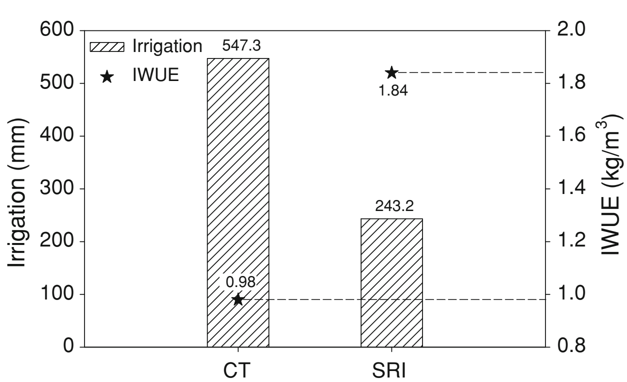

Fig. 1 Irrigation supply and IWUE of SRI and CT plots

Grain yield

Rice production in 2010 was relatively low compared with other years because of frequent rains and the lack of sunshine after August during the period of active reproductive growth of rice. The actual transplanting density of seedling for the CT plots was 1,430 hill/plot or 5,720 plant/plot if four plants per hill was transplanted. For the SRI methods plots, the density was 644, 385, and 232 hills/plot or plant per plot for 30 × 30, 40 × 40, and 50 × 50 cm spacing, respectively, because only one plant per hill was transplanted (Table 5). This meant that the transplanting density of the SRI culture was 45.0, 26.9, and 16.2% compared with that of the CT culture.

It was also known that the Japonica rice variety did not make tillers as much as the Indica variety. If SRI practiced with the Indica variety, the number of tillers per hill, even

Table 5 Comparison of grain yield from CT and SRI plots

Treatment	Average yield (kg/ha)	Yield ratio to CT (%)	# of hill per plot	Yield per hill (g)
SRI (50 × 50 cm)	4,084	76	232	93.6
SRI (40 × 40 cm)	4,413	82	385	65.3
SRI (30 × 30 cm)	4,903	92	644	43.4
CT (30 × 15 cm)	5,353	100	1,430	24.3

Table 6 Average NPS pollutant concentration in runoff during rainfall events from CT plots (unit: mg/L)

Date	SS	COD_{Cr}	COD_{Mn}	BOD	TN	TP
6.12–13	135 ± 21	40 ± 0.3	19 ± 1	4.0 ± 0.4	5.5 ± 0.1	0.9 ± 0.4
7.2–7.3	107 ± 38	46 ± 17	17 ± 6	2.5 ± 0.6	3.2 ± 0.7	0.7 ± 0.1
7.16–17	64 ± 14	11 ± 1	6 ± 1	2.8 ± 0.2	3.8 ± 0.3	0.3 ± 0.1
8.10–11	47 ± 7	18 ± 3	8 ± 1	2.7 ± 1.8	1.9 ± 0.4	0.6 ± 0.01
8.13–15	462 ± 124	33 ± 4	10 ± 3	4.0 ± 0.1	6.9 ± 0.5	0.6 ± 0.02
8.23–26	77 ± 49	18 ± 3	5 ± 0.1	2.2 ± 0.1	5.9 ± 0.4	0.4 ± 0.2
9.9–12	221 ± 56	45 ± 1	11 ± 0.1	3.2 ± 0.1	6.5 ± 0.1	0.5 ± 0.06
Average	159 ± 146	30.1 ± 14.7	10.7 ± 5.4	3.0 ± 0.9	4.4 ± 1.9	0.56 ± 0.2

if only one plant per hill was transplanted, would have ranged from 60 to 90 or more. However, the largest number of tillers per hill in this experiment was 35 in the 50 × 50 cm SRI methods plots. For this reason, rice production from the SRI plots was less than that from the CT plots, although the plants in the SRI methods plots were healthier and had more tillers than in the CT plots. Polished rice production from the SRI methods plots ranged from 76 to 92% depending on the transplanting spacing, compared with production from the CT plots (Table 5). However, rice production per hill in the SRI methods plots were about 1.8–3.9 times higher than that in the CT plots. It was thought that if seedlings were transplanted two to three plants per hill in the SRI plots described by Uphoff (2007), the plant density would be increased and rice production from the SRI plots would be higher than that from the CT plots with the Japonica rice variety.

Water quality and NPS pollution

The irrigation source for the plots was a small farm reservoir. The water quality of the reservoir was measured six times over the irrigation season and showed that the water quality satisfied the recommended quality for irrigation in Korea. The recommended and measured water qualities of the reservoir were pH 6.0–8.5 and 7.2 ± 0.1, BOD ≤ 8 and 1.6 ± 1.1 mg/L, COD ≤ 8 and 4.9 ± 0.8 mg/L, SS ≤ 100 and 16.1 ± 3.3 mg/L, and DO ≥ 2 and 8.4 ± 0.2 mg/L, respectively. However, TN concentration was relatively high at 2.067 ± 0.1. It is common for TN concentration in streams and reservoirs to be generally high and TN concentration of 2.067 mg/L measured in this study is not abnormal in Korea (Jung 2006; RDA 2008). Runoff volume and water quality from the plots were measured seven times during the 2010 growing season. The runoff coefficient of the SRI methods plots ranged from about 0.74–0.83 and was lower than that of the CT plots, which ranged from about 0.83–0.92. It was estimated that runoff from the SRI methods plots reduced by about 5–15% compared with that from the CT plots during rainfall events. Average concentration and pollution load of selected NPS pollutants from the CT are shown in Tables 6 and 7, respectively.

Average pollutant concentration of rainfall events from the CT plots were SS 42–550 mg/L, COD_{Cr} 11–46 mg/L, COD_{Mn} 5–21 mg/L, BOD 1.4–4.4 mg/L, TN 1.7–7.2 mg/L, and TP 0.3–1.2 mg/L. The concentration varied widely depending on rainfall characteristics as well as on the timing of fertilizer application. NIER (2005) reported that the concentration tended to be higher after fertilizer application and gradually fell as time went on. A similar trend was observed in this study as well. However, TP concentration did not vary as much as Yoon et al. (2002) reported. NPS pollution load from the CT plots in the 2010 growing season of June to September was SS 1,444 kg/ha, COD_{Cr} 242.5 kg/ha, COD_{Mn} 71.7 kg/ha, BOD 23.2 kg/ha, TN 43.8 kg/ha, and TP 3.76 kg/ha. It was thought that the load was largely influenced by the time of fertilization and rainfall. Large pollution loads occurred during the monsoon season when heavy rainfalls took place. The average concentration of selected NPS pollutants from the SRI methods plots is shown in Table 8. Pollutant concentrations from six SRI methods plots were similar and not significantly different. Therefore, the table values indicate the averages and the

Table 7 NPS pollution load in runoff during rainfall events from CT plots (unit: kg/ha)

Date	Rain (mm)	Runoff (mm)	Runoff coeff.	SS	COD_{Cr}	COD_{Mn}	BOD	TN	TP
6.12–13	47	39	0.83	52.7	15.6	7.41	1.56	2.15	0.35
7.2–7.3	29.5	25.5	0.86	27.3	11.7	4.34	0.64	0.82	0.18
7.16–17	119	109.5	0.92	70.1	12.0	6.57	3.07	4.16	0.33
8.10–11	21.5	18.6	0.86	8.7	3.35	1.49	0.50	0.35	0.11
8.13–15	119	107.5	0.90	497	35.5	10.8	4.30	7.42	0.65
8.23–26	175	158	0.90	122	28.4	7.90	3.48	9.32	0.63
9.9–12	343	301.8	0.88	667	136	33.2	9.66	19.6	1.51
Total (June–September 2010)				1,444	242.5	71.7	23.2	43.8	3.76

Table 8 Selected NPS pollutant concentration in runoff during rainfall events from SRI plots (unit: mg/L)

Date	SS	COD_{Cr}	COD_{Mn}	BOD	TN	TP
6.12–13	105 ± 40	30 ± 7	7.6 ± 1.6	2.5 ± 1.6	3.1 ± 0.3	0.2 ± 0.1
7.2–7.3	28 ± 14	41 ± 10	14.0 ± 3.3	2.4 ± 2.2	3.0 ± 0.3	0.4 ± 0.1
7.16–17	27 ± 13	12 ± 3	5.3 ± 3.3	0.6 ± 0.3	3.5 ± 0.3	0.3 ± 0.06
8.10–11	41 ± 23	17 ± 8	6.8 ± 1.3	1.5 ± 1.3	1.6 ± 0.3	0.3 ± 0.08
8.13–15	171 ± 115	22 ± 6	6.0 ± 3.4	3.8 ± 0.3	6.6 ± 0.4	0.5 ± 0.1
8.23–26	45 ± 10	18 ± 2	4.6 ± 0.8	1.7 ± 0.4	5.7 ± 0.7	0.4 ± 0.1
9.9–12	208 ± 106	43 ± 9	8.2 ± 3.5	1.7 ± 1.3	6.2 ± 2.5	0.5 ± 0.1
Average	89.4 ± 90.1	26.1 ± 13.2	7.5 ± 3.7	2.0 ± 1.5	4.2 ± 2.0	0.4 ± 0.2

Table 9 Comparison of average pollutant concentrations from CT and SRI plots

Treatment	SS	COD_{Cr}	COD_{Mn}	BOD	TN	TP
CT	159 ± 146[a]	30.1 ± 14.7[c]	10.7 ± 5.4[a]	3.0 ± 0.9[a]	4.4 ± 1.9[c]	0.56 ± 0.2[d]
SRI	89.4 ± 90.1[b]	26.1 ± 13.2[c]	7.5 ± 3.7[b]	2.0 ± 1.5[b]	4.2 ± 2.0[c]	0.4 ± 0.2[e]

Superscript a, b and d, e stand for significance level 5% ($p < 0.05$) and 1% ($p < 0.01$), respectively. c stands for not significant at 5%

standard deviations of the measured concentrations. Measured concentrations in the SRI methods plots varied widely, similar to those in the CT plots. The range of measured concentration of SRI methods plots were SS 13–328 mg/L, COD_{Cr} 4–56 mg/L, COD_{Mn} 3.6–16.9 mg/L, BOD 0.1–5.3 mg/L, TN 1.1–9.7 mg/L, and TP 0.08–0.7 mg/L. However, the concentrations from the SRI plots were lower than those from the CT plots as shown in Table 9. The SS, COD_{Mn}, and BOD concentrations from the SRI plots were significantly lower than those from the CT plots at $p < 0.05$. The TP concentration from the SRI plots was significantly lower than that from the CT plots at $p < 0.01$. The COD_{Cr} and TN concentrations from the SRI methods and CT plots were not significantly different ($p > 0.05$) but the concentrations from the SRI plots were lower than those from the CT plots.

Pollution load from the SRI methods plots is shown in Table 10. During the 2010 growing season of June to September, the measured pollution loads were SS 874 kg/ha, COD_{Cr} 199.5 kg/ha, COD_{Mn} 47 kg/ha, BOD 13 kg/ha, TN 36.9 kg/ha, and TP 2.92 kg/ha. It was thought that because very little or no runoff occurred during the non-growing season of October through April from the plots, the pollution load might represent the annual pollution load. Table 11 shows the differences in NPS pollution load from the CT and SRI methods plots. The SRI methods plots could reduce NPS pollution load by 15.8–44.1% over CT plots. It was also noted that the SRI treatment applied to this experiment could not follow the full principles of SRI. And yet the results were quite promising in terms of the reduction of irrigation requirement and NPS pollution. It was expected that the results could be further enhanced if the full principles of SRI were applied in the future experiments.

Conclusion

An experimental study was conducted to experimentally investigate the feasibility of SRI methods, focusing on irrigation water saving, and to evaluate the potential of NPS

Table 10 Selected NPS pollution load in runoff during rainfall events from SRI plots (unit: kg/ha)

Date	Rainfall (mm)	Runoff (mm)	Runoff coeff.	SS	COD_{Cr}	COD_{Mn}	BOD	TN	TP
6.12–13	47	37.1	0.79	39.0	11.1	2.82	0.93	1.15	0.07
7.2–7.3	29.5	22.7	0.77	6.4	9.3	3.18	0.54	0.68	0.09
7.16–17	119	95.7	0.80	25.8	11.5	5.07	0.57	3.35	0.29
8.10–11	21.5	15.9	0.74	6.5	2.7	1.08	0.24	0.25	0.05
8.13–15	119	93	0.78	159	20.5	5.58	3.53	6.14	0.47
8.23–26	175	145.2	0.83	65	26.1	6.68	2.47	8.28	0.58
9.9–12	343	275	0.80	572	118.3	22.6	4.68	17.1	1.38
Total (June–September, 2010)				874	199.5	47.0	12.96	36.9	2.92

Table 11 Reduction rate of NPS pollution loads of SRI plot with respect to CT plot

Treatment	SS	COD_{Cr}	COD_{Mn}	BOD	TN	TP
CT (kg/ha)	1,444	242.5	71.7	23.2	43.8	3.76
SRI (kg/ha)	874	199.5	47.0	12.96	36.9	2.92
Reduction (%)	39.5	17.7	34.4	44.1	15.8	22.3

pollution reduction in Korea. Eight experimental runoff plots 5 × 15 m in size were prepared at an existing paddy field. Each plot was equipped with precise irrigation and drainage measuring devices and the volume of irrigation and drainage and water quality were measured during the 2010 growing season. A Japonica rice variety was cultivated. The irrigation water requirements of the SRI and CT plots were 243.2 and 547.3 mm, respectively, which meant that SRI culture could save 55.6% of the required irrigation water. Runoff coefficients of the SRI plots were smaller than those of the CT plots and runoff from SRI plots decreased from about 5–15% compared with that from the CT plots during rainfall events. The average NPS pollutant concentration in runoff from the SRI methods plots during rainfall-runoff events was SS 89.4 mg/L, COD_{Cr} 26.1 mg/L, COD_{Mn} 7.5 mg/L, BOD 2.0 mg/L, TN 4.2 mg/L, and TP 0.4 mg/L. These concentrations were significantly lower than those from the CT plots except for COD_{Cr} and TN. Measured pollution loads from the SRI plots were SS 874 kg/ha, COD_{Cr} 199.5 kg/ha, COD_{Mn} 47 kg/ha, BOD 13 kg/ha, TN 36.9 kg/ha, and TP 2.92 kg/ha. These loads were about 15.8–44.1% smaller than those from the CT plots. The number of tillers per hill and plant height in the SRI methods plots were greater than and taller than those in the CT plots, meaning that rice plants grew better and healthier in the SRI plots than in the CT plots. However, rice production from the SRI methods plots ranged from 76 to 92% compared with the CT plots because the planting density in the SRI methods plots was too low, the seedling age at transplanting was much higher, and the Japonica variety could not make tillers as the Indica variety. It was thought that if the planting density were increased through closer spacing (e.g., 25 × 25 cm) and younger seedlings were used, rice production from the SRI methods plots would be higher than that from that CT plots. It was concluded that SRI methods could be successfully adopted in Korea and could help save irrigation requirement in the paddy significantly and reduce NPS pollution discharge. It was suggested that SRI treatment of closer transplanting spacings, transplanting with younger seedlings, different varieties of rice, and increased organic fertilization be needed to describe the full advantages of SRI in the future. These research results contribute to understanding and adopting SRI methods in Korea.

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