(Korean J. Crop Sci.) 44(1) : 38~43(1999)

Effects of Desalinization Management on Rice Yield in Sea Water Flooded Field

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ABSTRACT

Over 2,000 ha of rice fields in the western and southern coastal region of Korea were flooded with sea water during the spring tide, on August 19~21, 1997, and the rice plant at heading stage was injured. The field surveys were undertaken at the sea water flooded paddy fields in Chonbuk Province, to identify the injury symptoms and rice yield damage subjected to different flooding condition and desalinization methods. Five days after sea water flooding at heading stage, the flag leaves of rice plants flooded with 30 cm deep sea water withered from the tip, the withering progressed to the lower leaves in deeper flooding. The spikelets were spotted black and discolored from the tip at 50 cm deep flooded rice, and some panicles changed to white at 80 cm deep flooded rice. Most of the rice leaves submerged completely for an hour were withered and most of panicles changed to white. The milled rice yield, percentage of ripened grain, and 1000 grain weight of flooded rice decreased with deeper flooding water, higher water salinity and longer flooding time. Even under the same flooding conditions, the damage of rice yield varied with the growth stage: heading stage > dough stage > booting stage. Rice yield damage was less in the fields on the upper riverside than those of the fields on the estuary and seaside, because of lower water salinity. In a flooded field, the rice yield damages were reduced as the distance increased from the levees where the sea water inflowed and increased as the distance increased from the fresh water irrigation gate. The desalinization treatments consisting of frequent exchange of irrigation water and spraying with fresh water soon after flooding effectively reduced the rice yield damage.

Key words : injury symptom, rice, salt injury, sea water flooding, submergence, yield damage

In the western and southern coastal paddy fields in Korea, sea water flooding occasionally occurs during spring tide or the storm surge accompanied by a typhoon, and causes serious rice crop failure. Rice plants, when grown in salinity problem areas or flushed by sea water, usually suffer from salt injury (Lee, 1996). The severity of the occurrence of injury symptoms or the rice yield damage under salt stress condition varies with the degree of salinity, flooding condition, growth stage and genotype of rice plants, etc. (Cheong et al., 1995; Eo et al., 1982; Iwaki et al., 1952). The sea water shows about 3.5% salinity and 2.72% NaCl concentration (Park, 1988). The rice yields were decreased up to 10% and 50% when grown with 0.32% and 0.51% NaCl concentration solution, respectively (Carter, 1975). When the rice plants were grown with saline irrigation water at different growth stages, the yield damage (decrease of percentage of fertile grain and ripened grain) was most severe at the tillering stage, followed by rooting, panicle initiation and the heading stage (Eo et al., 1982; Pearson & Bernstein 1959).

Most studies have focused on the physiological mechanism and morphological change of salinity tolerance in plants grown by pot or solution culture with artificial treatment of saline water (Cui et al., 1995; Im et al., 1971; Iwaki et al., 1952; Takahashi & Ishizaka, 1964). Many investigations have been made after flooding with fresh water or by heavy rainfall (Cho et al., 1972; Choi et al., 1998; Kang et al., 1988), but field surveys on sea water flooding are relatively few (Kim et al., 1998; Ju et al., 1998). The investigation on the injury symptoms and yield damage of sea water flooded rice plants subjected to different flooding condition and desalinization treatments is important not only to take rehabilitation measures in a correct manner as early as possible but also to estimate the yield damage of rice injured by sea water flooding.

During the spring tide, on August 19~21, 1997, over 2,000 ha of paddy field along the western and southern seaside in Korea were flooded with sea water and rice plants were injured (Ju et al., 1998). At the flooded farmers' rice fields, a series of investigations in Chonbuk Province following the previous reports in Chonnam area (Kim et al., 1998), were conducted to evaluate the rice yield damage by sea water flooding.

MATERIALS AND METHODS

Investigation fields with sea water flooding

In Chonbuk Province, about 310 ha of rice fields were totally damaged by the sea water flooding during the

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Received 5 Jan. 1999.

spring tide in August 1997. The flooded fields were located in the area of Kimje, Kunsan, and Puan, Korea. The investigation plots from each region were selected: 6, 5, and 10 sites, respectively. The sea water flooding occurred for 2~3 hours during the early morning of August 19~21, 1997, although the time was a little different by location and date. The weather data from the beginning to 5 days after the sea water flooding was obtained from the Meterological Station of Kunsan and Puan. The flooding and flooded field conditions such as rice culture methods, flooding water depth, times, duration, and desalinization treatments after flooding, were surveyed by listening to the farmers under the cooperation of officers from the Agricultural Technology Extension Center for each region.

According to farmers, the rice culturing outlines of the investigated rice fields with sea water flooding were as follows; (i) 'Dongjinbyeo' which is known as a medium-late maturing variety was mainly cultivated, (ii) the transplanting time was late May, and (iii) fertilizer amount of N-P_2O_5-K_2O was about 200-90-110 kg/ha. The flooding time was around the heading stage of rice plants in most of the flooded fields.

Injury symptoms and yield damage the of flooded rice

To investigate the occurrence of injury symptoms of rice plants due to the flooding condition, the flooded fields in Haseo-myon of Puan County were classified into 5 plots by the degree of sea water flooding depth and flooding times. At 5 days after the last flooding, the injury symptoms of flooded rice plants were observed by the naked eye. The salinity in each plot was measured by a conductivity meter (model YSI-32, YSI, USA).

The rice yield damages were investigated at the flooded fields; in Baeku-myon and Kongduk-myon of Kimje City with different depths and salinity of flooding water, and in Kunsan City with different distance (i.e., 5 m, 20 m and 40 m) from the levee where sea water inflowed or from the fresh water irrigation gate. In Haseo-myon of Puan County the yield damage was also investigated at flooded fields with different desalinization treatments, i.e., exchanging and spraying of fresh water just after sea water flooding. The grain yield was determined at physiological maturity stage by harvesting the 3.3 m² for each investigation plots with three replications. The investigation practices and methods for obtaining rice yield followed the RDA method (RDA, 1995).

Chemical property analysis of flooded soil

At the harvest stage of rice plants, the soil samples with a core of 5 cm diameter were taken at the 2~7 cm depth in flooded fields in Haseo-myon, Puan County with different desalinization treatments such as exchanging or spraying of fresh water. Soil chemical properties, i. e., oganic matter, total nitrogen and cations (K, Ca, Mg and Na), were analyzed following the methods of RDA (RDA-SCI, 1988).

RESULTS AND DISCUSSION

Weather condition

The weather conditions during and after the sea water flooding influenced the injury and recovery of the damaged rice plants (Lee, 1996). The mean and maximum daily temperatures during and at 5 days after flooding were higher in 1997 than those in a normal year (Table 1). Although it showed a cloudy and rainy day during August 21~22 in both Kunsan and Puan (data not shown), the precipitation and sunshine hours were less in 1997 than in a normal year during August 19~21.

Injury symptoms of flooded rice plant as affected by flooding degree

Table 2 shows that the burning or withering of plants was increased markedly with an increase of the flooded times, hours and water depth. At the heading stage, the rice plants flooded to 30 cm deep for 2 hours showed withering up to 0.5 cm from the tip of the flag leaf at 5 days after flooding. In plants flooded to 50 cm deep, the flag leaf withering was expanded to the middle part to 5~7 cm from the tip, and some of the spikelets showed black spots on the palea and lemma, and were discolored from the tip. In sea water flooding to 80 cm depth, the withering of leaves was expanded more and some of the

Table 1. Mean and maximum daily temperatures, sunshine hours, and precipitation during and 5 days after the sea water flooding.

Region	Period	Mean temp. (℃)		Max. temp. (℃)		Sunshine hours		Precipitation (mm)	
		1997	Normal†	1997	Normal	1997	Normal	1997	Normal
Kunsan	Aug. 19~21	27.9	25.4	32.3	30.1	12.7	23.8	9.4	39.3
(Kimje)	Aug. 22~26	25.0	24.2	31.3	28.7	42.4	31.2	24.2	52.6
Puan	Aug. 19~21	29.4	25.9	31.2	29.4	18.4	23.5	1.5	22.3
	Aug. 22~26	26.2	25.2	28.5	28.0	56.2	31.1	–	57.8

† : Mean of 5 years from 1992 to 1996.

Table 2. Injury symptoms of rice plants at five days after sea water flooding as affected by different flooding degree at heading stage.†

Flooding condition (flooded water depth, time and hours)	Injury symptoms
30 cm, once	Flag leaves burned about 0.5 cm from the tip
50 cm, once	Flag leaves withered about 7 cm, spikelets spotted black and discolored from the tip
80 cm, once	Flag leaves withered about 20 cm from the tip, some panicles changed to white head
Overhead, an hour	Most leaves withered and most panicles became white heads
Overhead, once, 4 hours	Most of plants were seriously withered

† Variety: Dongjinbyeo; Location: Haseo-myon, Puan County, Chonbuk Province; Salinity of flooding water : 3.1%.

panicles were changed to white heads. Furthermore, the rice plants which were overhead flooded even for one or two hours at the heading stage were seriously damaged. Most leaves were burned or withered and most panicles were changed to white heads.

Above results indicate that the severity of burning or withering of sea water flooded plants depends on the flooding times, flooded hours and water depth. Injury symptoms usually extend from the tip of the flag leaf and spikelet to the base of them and to the lower elder leaves within 5 days of flooding. Cui et al. (1995) also reported that in the higher salt treatments, the flag leaf burning with leaf rolling and aging emerged earlier than the burning of the lower leaves. The reason why the injury symptoms begin at the tip of the leaves and spikelets is that the transpiration of rice plants at heading stage is most active from these tip parts and thus the salts are highly accumulated there (Iwaki et al., 1952). When the rice plants at heading stage were submerged completely with sea water for only a few hours, most plant parts were seriously injured and died. Similar results were previously reported (Kim et al., 1998; Ju et al., 1998). These tendencies of sea water submergence differ from the overhead submergence with fresh water (Choi et al., 1998).

Yields affected by salinity and depth of flooding water

In Baeku-myon and Kongduck-myon of Kimje City, the salinity concentration of fields varied with flooding depth, showing the range of 0.75~0.84% below 80 cm and 1.45% at overhead flooded field (Table 3). These differences might have been caused by the different mixing rate of fresh and sea water. The flooded fields were located along the lower side of the Mankyong river. Therefore, it was assumed that the flooding sea water was mixed primarily with river water and secondarily with irrigated water in the fields.

The rice yield damages in Baegku-myon and Kongduk-myon were less than those in Haseo-myon of Puan County (Table 3; Table 5) where the fields were directly flooded with sea water. The milled rice yield with overhead flooding was higher in Baegku-myon and Kongduk-myon with 2.14 ton/ha (Table 3) compared to in Haseo-myon with 0.58 ton/ha (Table 5), while the perfect milled rice yields between both regions were not significantly different, at 0.19 ton/ha and 0.10 ton/ha, respectively. Although there were differences in cultivar, the severity of rice yield damage under 80 cm water depth with 0.84% of salinity was greater in the order of heading > dough ripe > booting stage. These results and the pre-

Table 3. Yield and yield components of rice as affected by the depth and salinity of sea water flooding.†

Variety	Growth stage	Flooding depth (cm)	Water salinity (%)	Percent ripened grain (%)	1,000 grain weight (g)	Milled rice (ton/ha)	Percent perfect grain (%)	Perfect milled rice (ton/ha)	Yield index
Dongjinbyeo	H.S‡	None	–	94	24.8	5.73	92	5.27	100
Dongjinbyeo	H.S	30	0.75	90	22.0	5.56	85	4.73	90
Dongjinbyeo	H.S	80	0.84	64	20.8	3.74	84	3.14	60
Gancheogbyeo	B.S§	80	0.84	78	21.0	5.32	85	4.52	86
Sinkeumobyeo	D.S¶	80	0.84	68	21.5	4.39	82	3.60	68
Dongjinbyeo	H.S	Over head	1.45	14	19.3	2.14	9	0.19	4

† Location : Baegku-myon and Kongduk-myon in Kimje City, Chonbuk Province; Water management after drain : 2 times exchanging the irrigation with fresh water, but no exchange at overhead flooding fields.
‡ H.S : heading stage, § B.S : booting stage, ¶ D.S : dough ripe stage.

Table 4. Changes of yield and yield components of rice as affected by water management methods and position in a sea water flooded field.†

Water exchange times	Distance	Percent ripened grain (%)	1,000 grain weight (g)	Milled rice (ton/ha)	Percent perfect grain (%)	Perfect milled rice (ton/ha)	Yield index
No-flood	–	94	24.8	5.73	92	5.27	100
5 times	–	57	19.7	3.57	76	2.71	51
3 times	–	53	17.6	3.30	47	1.55	29
None	–	30	14.3	1.48	9	0.13	2
2 times	5 m‡	0	0	0	0	0	0
2 times	20 m‡	20	20.3	3.65	49	1.79	34
2 times	40 m‡	54	21.6	4.07	84	3.42	65
3 times	5 m§	79	21.7	5.33	78	4.16	78
3 times	20 m§	77	21.3	4.67	75	3.50	66
3 times	40 m§	71	20.4	3.68	72	2.65	50

† Flooding condition: flooded up to 2/3 of flag leaf with 2.5% salinity water for 3 hours; Location : Daeya-myon, Kunsan City, Chonbuk Province; Cultivar : Dongjinbyeo.
‡: Distance from the sea water inflow levee, §: Distance from the fresh water irrigation gate.

vious reports (Kim et al., 1998; Ju et al., 1998) indicate that the overhead flooding by sea water within a few hours at the heading stage of rice plants may cause almost zero yield.

Yield damages affected by distance from inflow site of sea water and irrigation water

After sea water flooding, frequent exchange irrigation with fresh water ameliorated the reduction of the percent ripened grain and 1000 grain weight. Therefore, the yield index of perfect milled rice, calculated with the no-flooded field as the standard was 51 % at the flooded field with exchange irrigation, occurring 5 times while it was 2% at the flooded field without exchange irrigation (Table 4).

In the sea water flooded field from the destroyed levee, the rice yield damage was greater closer to the levee. The yield reduction was caused mainly by a large decrease in the percentage of ripened and perfect grain. Compared with the no-flooded field, the perfect milled rice yield in the flooded field was reduced to 34% at 20 m distance and 65% at 40 m distance from the levee.

On the other hand, in the field with exchange irrigation water occurring 3 times after sea water flooding the percent ripened and perfect grain and 1,000 grain weight were reduced according to the distance from the fresh irrigation water gate. The yield index as compared to that of the no-flooded field was 50% at 40 m distance where the drainage gate was located nearby and 78% at 5 m from the irrigation water gate. These results indicate that in a flooded field the yield damage increases near the inflow site of sea water, and the desalinization effect decreases at long distances from the irrigation water gate.

Rice yields and soil properties as affected by desalinization methods

In flooded fields in Haseo-myon of Puan County, the rice plants at the heading stage were flooded once with 3.1% salinity sea water. We investigated the change of rice yield and soil properties as affected by flooding water depth and water management for desalinization after retreat of the sea water. The results are shown in Table 5 and Table 6.

The percent ripened and perfect grain, and the 1,000 grain weight were reduced as the flooding sea water depth increased, although the degree of reduction also changed with the water management. The frequent irrigation water exchange and water spraying ameliorated the yield reduction due to sea water flooding. Within the same flooding depth, the yield damage varied with the exchanging and spraying frequency of fresh water, for example, in flooded fields with depths of 50 cm and 80 cm the rice yield damage was less when fresh water was exchanged or sprayed 5 times compared to 3 times. Similar results of water management effects in saline water irrigated fields was reported by Eo et al. (1982).

Soil analyses are often required to confirm the degree of salt injury. The differences in soil properties affected by flooding water depth and water management for desalinization after retreat of sea water in the flooded fields of Haseo-myon in Puan County are shown in Table 6.

The concentration of cations (K, Ca, Mg, and Na) in flooded soil were higher in deeper flooding depth and lower in more frequent water exchange and spraying treatments within the same flooding depth. The Cl^- concentration in the soil was lowest for the no-flooded field at 0.093%, increased with flooding depth, and was highest at 0.135% in overhead flooding field without desaliniz-

Table 5. Yield and yield components of sea-water flooded rice at heading stage as affected by flooded water depth and disalnization methods.†

Flooded water depth	Water management	Percent ripened grain (%)	1,000 grain weight (g)	Milled rice (ton/ha)	Percent perfect grain (%)	Perfect milled rice (ton/ha)	Yield index
No flood	–	96	24.7	5.70	94	5.35	100
30 cm	2‡ + once§ times	92	23.0	5.23	92	4.81	90
50 cm	3 times§	66	19.8	4.10	75	3.08	58
50 cm	5 times§	87	20.2	5.72	76	4.35	81
70 cm	None	34	17.6	2.02	59	1.19	22
80 cm	3 times‡	64	19.5	2.93	66	1.93	36
80 cm	5 times‡	69	19.8	3.55	81	2.88	54
Overhead	2 times‡	9	14.3	0.58	17	0.10	2

† Location: Haseo-myon; Puan County, Chonbuk Province; Cultivar: Dongjinbyeo.
‡ : Water exchange, § : Water spray, Salinity of flooded water : 3.1%,

Table 6. Difference of chemical properties of sea water flooded paddy soil as affected by flooded depth and desalinization methods.†

Flooded water depth (cm)	Water management	OM (%)	T-N (%)	Ex.-cation ($cmol^+/kg$)				Cl^- (%)
				K	Ca	Mg	Na	
No flood	Normal	2.1	0.33	0.20	2.20	1.87	2.10	0.093
30	2‡ +once§ times	2.2	0.32	0.22	2.33	1.96	2.29	0.109
50	5 times§	2.4	0.40	0.25	2.16	1.98	2.75	0.120
50	3 times§	2.6	0.43	0.31	2.43	2.01	3.15	0.125
80	5 times‡	2.7	0.36	0.30	2.30	2.02	3.44	0.123
80	3 times‡	2.7	0.38	0.32	2.45	2.45	3.47	0.130
100	None	2.8	0.42	0.34	2.51	2.05	4.80	0.135

† Location: Haseo-myon; Puan County, Chonbuk Province; Cultivar: Dongjinbyeo.
‡ : water exchange times, § : water spray times; Salinity of flooding water : 3.1%,

ation treatments. The frequent water management slightly decreased the Cl^- concentration. Ju et al. (1998) reported that the Na^+ and Cl^- were highly accumulated in the rice plants with sea water flooding and these caused the plant injury.

In conclusion, the flooding by sea water caused severe injury to rice plants within a short time. These investigation results suggest that the desalinization methods of exchanging irrigation or spraying of fresh water on sea water flooded rice are very important to reduce the growth injury and yield damage.

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*: Translated froms Korean by the present authors.