Korean J. Soil Sci. & Fert.(2000)
Vol. 33(2) : 100~108

Application Effect of Food Waste Compost Abundant in NaCl on the Growth and Cationic Balance of Rice Plant in Paddy Soil

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ABSTRACT

High sodium contents in food-waste compost(FWC) is the greatest limitation to recycle it to arable lands in Korea. The effects of the FWC application to paddy soil on the growth of rice plants, cationic balance in plants, and the sodicity of soil have been studied in pot trials. The effects of FWC application were compared with those of NaCl compound and swine manure compost(SMC) application. Na_2O contents of FWC were high as 2.2%. Immediately after transplanting, rice plants in three treatments showed severe wilting in the order of 40Mg FWC ha^{-1} 〉 NPK+900kg NaCl ha^{-1} 〉 20Mg FWC ha^{-1}. The high EC value and volatile acid contents of soil solution were regarded as the cause of severe wilting of young rice plants. Increase of NaCl application rate upto 900kg ha^{-1} showed no significant reduction of dry matter yield at harvesting stage. Regardless of application rates FWC reduced the dry matter yield at harvesting stage, while SMC increased it with increase of application rates upto 40Mg ha^{-1}. In NPK+NaCl and FWC treatments, Na contents and equivalent ratio in plants increased linearly with increase of Na application rates. Between Na and K equivalent ratio negative correlation with high significance was shown. In contrast to much difference of Na, K, and Na/K equivalent ratio among treatments, little difference of Na+K indicated the physiological substitution of Na for K in rice plants. Na use efficiency in NPK+NaCl and FWC treatments showed 12-22%.

Key words : Rice, FWC, NaCl, Cationic balance.

Introduction

The outflow of home-driven wastes per capita in Korea was up to 1.05kg day^{-1} in '99, among which the food wastes came under 27.3%. The food wastes are easily putrefied and bear high moisture content, which makes them hard to be buried or burned up. Although recycling of food wastes has been investigated for longtime, only 9.8% was recycled in '99(Ministry of Environment 1998).

The food wastes can be used as feeds and composts divided by their freshness(Kim 1995, Kim et al. 1995,). Though food wastes as raw materials for compost is not different from the normal compost materials in major ingredients, they have a lot more NaCl due to the salt-favored cooking than other by-products of bio-industry do. Therefore, FWC(food waste compost) made from these

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※ This research was carried out as an cooperative study of industry · academy · administration, and financial assistance through Rural Development Administration is greatly appreciated.

materials is coming out as a secondary pollutant. When Na is accumulated in soil, it brings out swelling of clay minerals, dispersion of soil particles, and subsequent closure of pore space in soil, which makes the physical properties of soil become not fit for cultivation(Sumner 1993).

The standard used for estimation of Na^+ accumulation in soil has been ESP(exchangeable sodium percentage). When its ESP is over 15, the soil is defined as sodic soil(U. S. Salinity Laboratory Staff 1954). In addition to ESP, SAR(sodium adsorption ratio) has been used for relative indicator of Na in irrigation water and soil solution. SAR is more easily and precisely measured than ESP(Sumner 1993). And it shows close relationships with ESP being applicable to an equation(U.S. Salinity Laboratory Staff 1954, Sumner 1993, Rengasamy et al. 1984).

Marschner(1971) classified plants into 4 groups as A, B, C and D, and added rice to the C group. In the C group, Na can limitedly substitute K not promoting the plant growth. Gupta and Sharma(1990) reported critical ESP of 20 crops in early growth stage on field and greenhouse, reduced rate of productivity according to the ESP increase, and ESP causing 50% decrease in products. The critical ESP of rice in the early stage was over 15, marking the salt-resistance in the second place among the 20 crops. The variance among the rice variety was also large reportedly due to the difference in ion valence and water adsorption capacity. After the study on the salt-resistance in different rice cultivars, Qudar(1995) reported that the cereal products rather than dry weight were more reduced by the salt stress varying on the cultivars. Qudar(1989) also reported that application of K(300kg ha^{-1}) on Na-accumulated soil improved the rice growth and product index presumably due to the recovery of ion valence by decreased Na in top parts.

In addition to Na, volatile fatty acids and phenolics, the by-products of composting can be harmful for plant growth. After the investigation into the effects of the organic acids outflowing from composting of food wastes, Chang et al.(1996) reported that acetic acid was the primary volatile organic acid detected during composting, and it showed reverse proportion to the G.I.(germination index). They also reported that when the volatile organic acids is produced over 300mg kg^{-1} corresponding to under G.I. 50 in composts, they can not be used for application. Yoshida(1981) reported that 10^{-1}~10^{-3}M of volatile fatty acids is toxic dose in rice. However, the toxicity of organic acids in flooding water which is neutralized within 3 weeks after irrigation is open to speculation, for the fatty acids have high toxicity in low pH where associated forms are easily absorbed.

In this study we investigated the effects of Na in FWC on the growth and cation valence of rice on paddy soil to gain the basal data for FWC application.

Materials and Methods

1. Treatments and sampling

Chisan series was used for soil material whose chemical properties were as in Table 1.

The experimental soil set were organized into 11 treatments as no application, control(N-P_2O_5-K_2O : 110-70-80kg ha^{-1}), NaCl application(300, 600, 900kg ha^{-1}), FWC application(10, 20, 40Mg ha^{-1}), and swine manure application(10, 20, 40Mg ha^{-1}). Each treatment was repeated 5 times. The FWC was made with woodchip as

Table 1. Some chemical properties of used soil

pH (1:5)	EC (dS m^{-1})	OM (g kg^{-1})	T-N (g kg^{-1})	Av. P_2O_5 (mg kg^{-1})	Exch. cations (cmol$^+$ kg^{-1}) K	Ca	Mg	Na
5.7	0.5	24	1.7	81	0.54	3.5	1.3	0.18

Table 2. Some chemical properties of food waste compost(FWC) and swine manure compost(SMC) used in the experiment

Kind of composts	pH (1:5)	EC (dS m^{-1})	T-C (%)	T-N (%)	C/N ratio	Inorg. N(%)	P_2O_5 (%)	K_2O (%)	CaO (%)	MgO (%)	Na_2O (%)
FWC	6.9	69	20.4	2.8	7.3	0.32	2.7	1.9	5.0	0.6	2.20
SMC	8.3	33	16.7	2.3	7.3	0.058	3.5	2.0	3.0	1.1	0.41

moisture controller, and the swine manure was with same amount of imbibed rice hulls in Anjung Agricultural Cooperation. The content of Na_2O was higher in FWC(2.2%) than in swine manure(0.41%).

Each compost application was added with 3.5kg of soil to a/5000 Wagner pot on May 30. On the next day, the pots were watered and chemical treatments were added on top 10cm region with gentle mixing. Urea, fused phosphate and potassium chloride were used for the chemical fertilizer, among which the urea was applied at beginning(50%), tillering stage(25%) and flowering(25%), and fused phosphate at beginning(100%), and potassium phosphate at beginning(70%) and flowering(30%). The rice plants(cv. Ilpumbyeo) were transplanted on the day, as the way that a plantlet was on a pot. On June 2, one more plantlet was supplemented on each pot, and former ones were excluded after 16 days after transplant during which the plants were stressed. The pots were drained for one week from July 9.

Just after flowering(August 28), two plant in each five repeat were collected and hot-air dried. The blended plant samples were used for analysis. The soil samples were collected at drainage(July 9), flowering, and harvesting stages. The soil solutions were gained with fluffy glass-covered and nylon-bound plastic pipes(16.5mm×25cm) placed inside the 13~14cm from tops. The soil solutions within the pipes were collected on June 11 and July 7.

2. Analysis of plants, soils and soil solutions

pH and EC of soil were measured after air-drying and cation concentration was analyzed in the wet condition. pH and EC were measured with same volume and five volume of water respectively. Exchangeable cations were analyzed by ICP(GBC Integra XM) after 1M ammonium acetate extraction.

pH and EC of the soil solutions were measured with pH meter and EC meter directly after sampling. For analysis of volatile organic acids, the auto kjeldahl analyser was used after the pH of solutions was adjusted to 10. The concentration of volatile organic acids was noted as the acetic acid content(NIAST 1988). The phosphate and cations of plant samples were analyzed by ICP after wet-degradation(NIAST 1988) with sulfuric acid and nitric acid. T-N contents were measured by Kjeldahl method after wet degradation with H_2SO_4 added by K_2SO_4 and $CuSO_4$.

3. Data analysis

Nutrition availability(NA) was gained by equation (1).

$$NA(\%) = \frac{\text{nutrients absorbed by plants(g pot}^{-1}) - \text{nutrients absorbed by not applied plants(g pot}^{-1})}{\text{added nutrients(g pot}^{-1})} \times 100 \quad (1)$$

In the equation (1), the nutrients correspond to the fertilizer elements for chemical fertilizer, and total weight for composts.

Indicator of soil sodicity, SAR(sodium adsorption ratio) was gained with equation (2).

$$SAR = \frac{[Na^+]}{\sqrt{[Ca^{2+}+Mg^{2+}]/2}} \quad (2)$$

In the equation (2), parentheses mean mmol$_c$ L^{-1}

Another indicator of soil sodicity, ESP(exchangeable sodium percentage) was computed by equation (3) (Summe r& Miller 1996)

$$\frac{ESP}{100-ESP} = 0.0145SAR \quad (3)$$

Results and Discussions

1. Growth response of rice plants to the application of FWC

Growing appearance of rice plants

Severe wilting phenomenon were observed in 20Mg ha^{-1} and 40mg ha^{-1} of FWC treatments, and in 40Mg ha^{-1} of compost treatment, all of which needed supplemental transplant. The most severe one was observed in 40Mg ha^{-1} of FWC treatment(100%), and 900kg ha^{-1} of NaCl and 40Mg ha^{-1} of compost treatment(20%) were marked next ones. Even among the supplemented plants, one of five repeats was wilted in 40Mg ha^{-1} of FWC treatment.

EC, a major factor of wilting at rooting stage was highest in 40Mg ha^{-1} of FWC treatment as 2.5dS m^{-1}(Table 3). Maas and Hoffman(1977) reported that being moderately sensitive to EC, rice shows 12% reduction in products responding to 1dS m^{-1} increase in EC, and the minimal EC affecting the rice growth is 3,0dS m^{-1}, which proposes that EC can be ignored in this experiment. However, in the region of near 13cm from top, EC was measured to be over 3dS m^{-1} in the three treatments particularly being 5,1dS m^{-1} in 40Mg ha^{-1} of FWC treatment. About 4 fold higher EC in deeper region seemed to be resulted from the low rate of solutes dispersion.

The higher the applied fertilizer content, the higher was the concentration of the volatile organic acids which has been known to inhibit the earlier growth of rice, on 37th day after transplant. However, In regard to the acid-favoring inhibition of organic acids(Yoshida 1981), the stresses observed at the early stage can not be attributed to the organic acids for soil pH was near neutral region from the early stage in this experiments(data not shown),

On the other hand, vapor was observed in the 40Mg ha^{-1} of FWC treatment for a long time suggesting another problem of H_2S toxicity. As in this case, more studies were required to elucidate the factors on the growth inhibition of rice. However, the results in this study that volatile organic acids were detected highly in FWC treatment even after 35day from transplant, proposed that reduced toxic chemicals such as H_2S as well as NaCl should be concerned when the FWCs were made and applied.

Flowering time and dry weight in harvesting stage according to the treatments

Only a little differences were observed in flowering time(August 21~23), and dry weight in flowering stage was also not varied extremely by NaCl application, as over 900kg

Table 3. EC and volatile acid contents of surface water and soil solution collected at 14㎝ depth

Treatment [a]	EC (dS m^{-1})				Volatile acid contents of soil solution at 35 DAT (mg L^{-1})
	Surface water		Soil solution		
	1 DAT	35 DAT	9 DAT	35 DAT	
Control	0.3	0.3	1.1	0.9	364
NPK	0.3	0.3	1.5	1.4	408
NPK+NaCl 300kg ha^{-1}	0.5	0.5	2.4	2.2	339
NPK+NaCl 600kg ha^{-1}	0.9	0.9	3.0	3.3	330
NPK+NaCl 900kg ha^{-1}	1.6	1.6	3.9	3.7	300
FWC 10Mg ha^{-1}	0.7	0.7	2.4	3.8	820
FWC 20Mg ha^{-1}	1.4	1.4	3.2	5.5	2,555
FWC 40Mg ha^{-1}	2.5	2.5	5.1	10.2	4,404
SMC 10Mg ha^{-1}	0.4	0.4	1.5	1.8	580
SMC 20Mg ha^{-1}	0.6	0.6	1.4	2.5	666
SMC 40Mg ha^{-1}	0.9	0.9	Fail [b]	4.0	1,444

[a] FWC : food waste compost; SMC : swine manure compost

[b] Fail to collect the soil solution sample

Table 4. Application effect of NaCl, food waste compost and swine manure compost on dry matter yield amd yield index of rice plants at panicle initiation and harvesting stage

Treatment [a)]	Panicle initiation stage		Harvesting stage	
	Dry matter [b)] (g pot^{-1})	Yield index [c)] (%)	Dry matter (g pot^{-1})	Yield index(%)
Control	39 bc	59	47 d	56
NPK	66 ab	100	84 b	100
NPK+NaCl 300kg ha^{-1}	67 ab	102	85 b	101
NPK+NaCl 600kg ha^{-1}	67 ab	102	88 b	105
NPK+NaCl 900kg ha^{-1}	55 bc	83	81 b	96
FWC 10Mg ha^{-1}	49 bc	74	62 c	74
FWC 20Mg ha^{-1}	48 bc	73	64 c	76
FWC 40Mg ha^{-1}	28 c	42	69 c	82
SMC 10Mg ha^{-1}	55 bc	83	66 c	79
SMC 20Mg ha^{-1}	67 ab	102	86 b	102
SMC 40Mg ha^{-1}	89 a	135	108 a	129

[a)] FWC : food waste compost; SMC : swine manure compost

[b)] Means followed by the same letter within a column are not significantly different at 5% level by DMRT

[c)] Yield index is percentage of dry matter yield of each treatment compared with the dry matter yield of NPK treatment

ha^{-1} treatment showed only 17% reduction in dry weight. Although this inclination was similar in the dry weight differences at harvesting time, only 4% was reduced in the treatment suggesting that the inhibitory effects of NaCl on growth inhibition was decreased as the growth proceeded(Table 4). However, in the case of FWC, 40Mg ha^{-1} of the treatment made dry weight at flowering reduced to 58%, which seemed to be resulted by method for data analysis that dry weight of wilted plants were regarded as 0, and the dry weight measured at harvesting stage was reduced much, showing only slight difference within the treatments varying contents. Both at flowering and harvesting stages, the dry weights were increased linearly by application of swine manure as 35% higher in 40Mg ha^{-1} treatment than control. The results could be explained by low availability of nitrogen in pots supplied by chemical fertilizer.

2. Competitive absorption of Na and k

As displayed in Table 5, soil pH at harvesting stage was increased by compost application. EC was also raised both in fertilizers+NaCl and FWC treatments but in swine

Table 5. Application effect of NaCl, food waste compost and swine manure compost on soil chemical properties at harvesting stage

Treatment [a)]	pH (1:5)	EC (dS m^{-1})	Ex. cations(cmol⁺ kg^{-1})			
			Na	K	Ca	Mg
Control	5.7	0.53	0.33	0.39	3.4	1.18
NPK	5.7	0.69	0.38	0.37	4.1	1.32
NPK+NaCl 300kg ha^{-1}	5.9	1.41	0.79	0.44	4.0	1.41
NPK+NaCl 600kg ha^{-1}	5.9	1.44	0.84	0.49	3.8	1.26
NPK+NaCl 900kg ha^{-1}	5.9	1.54	1.27	0.72	4.1	1.41
FWC 10Mg ha^{-1}	6.4	0.78	0.63	0.79	4.6	1.22
FWC 20Mg ha^{-1}	6.5	0.97	1.10	1.19	5.9	1.42
FWC 40Mg ha^{-1}	6.7	2.29	2.15	1.79	7.5	1.64
SMC 10Mg ha^{-1}	6.2	0.83	0.59	0.83	4.7	1.69
SMC 20Mg ha^{-1}	6.6	0.62	0.46	1.01	4.9	1.90
SMC 40Mg ha^{-1}	6.7	0.79	0.72	1.46	6.1	2.79

[a)] FWC : food waste compost; SMC : swine manure compost

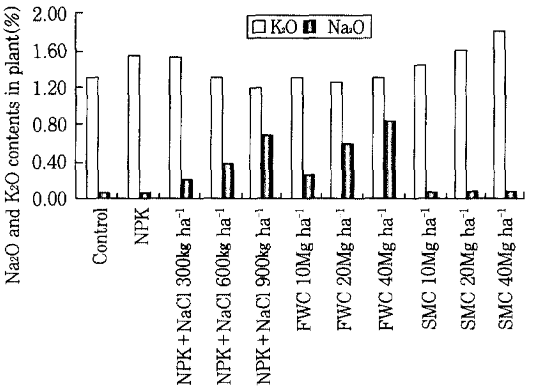

Fig. 1. Application effect of NaCl, food waste compost (FWC), and swine manure compost(SMC) on Na_2O and K_2O content in rice plants at harvesting stage.

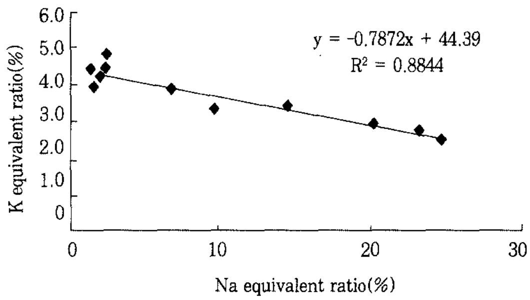

Fig. 2. Relationship between Na and K equivalent ratio in rice plants at harvesting stage.

manure treatments. Ex. Na contents of soil samples were same to applied Na contents being a lot higher than Ex. K in fertilizers+NaCl and FWC treatments.

Na contents in plants at harvesting stage were increased linearly by fertilizers+NaCl and FWC treatments(Figure 1), and K contents showed inverse proportion to Na contents in fertilizers+NaCl treatments but FWC treatments. Taken together with luxury absorbing behavior of plants on K^+(Mengal & Kirkby 1987), the K contents should have been increased by FWC application. In this case, however, competitive absorption might cause such a low K contents.The cation equivalent ratio of Na was increased by Na application(Table 6). The equivalent ratio of K showed inverse proportion to Na' s with high significance(Figure 2) being decreased linearly by FWC, which confirmed the competitive absorption between Na and K.

To see the cation equivalent ratios according to the treatments, equivalent ratios of K, Na and Na/K were 25~48, 1~25 and 3~99, respectively, and K+Na' s was 41~50 showing little variance presumably due to the physiological substitution of K for Na. These results agreed with the Table 4. However, the results are open to debate, for the high degree of the substitution did not resulted in dry weight decrease partially disagreeing with the earlier

Table 6. Application effect of NaCl, food waste compost and swine manure compost on cation equivalent ratio in rice plants at harvesting stage

Treatment [a)]	Contents of Σcations (mmol g^{-1})[b)]	Equivalent ratio to the contents of Σcations(%)					
		Ca	Mg	K	Na	K+Na	Na/K
Control	0.35	35	25	39	2	41	5
NPK	0.40	33	24	41	2	43	5
NPK+NaCl 300kg ha^{-1}	0.42	31	24	38	7	45	18
NPK+NaCl 600kg ha^{-1}	0.40	28	23	34	15	49	43
NPK+NaCl 900kg ha^{-1}	0.47	28	22	27	23	50	86
FWC 10Mg ha^{-1}	0.41	32	25	33	10	43	29
FWC 20Mg ha^{-1}	0.46	26	25	29	10	49	70
FWC 40Mg ha^{-1}	0.56	25	26	25	25	49	99
SMC 10Mg ha^{-1}	0.36	28	27	44	1	45	3
SMC 20Mg ha^{-1}	0.38	25	28	45	2	47	5
SMC 40Mg ha^{-1}	0.41	20	30	48	2	50	5

[a)] FWC : food waste compost; SMC : swine manure compost

[b)] Σcations is sum of calcium, magnesium, potassium and sodium contents represented by equivalence report(Marshner 1995). Na-resistant characteristics of cv. Ilpumbyeo(Lee et al, 1998) may be a reason of that(Marshner 1995).

3. Nutrient availability among the treatments

The nitrogen use efficiency was about 50% in chemical fertilizer treatment and about 10% in swine manure and FWC treatments(Table 7).

K, as the most available nutrient, marked 100% of efficiency, though decreased with NaCl application. This agreed with earlier study(Jung et al 1983) which gain high K use efficiency reportedly because K in soil solution balanced with both exchangeable and nonexchangeable K as well as applied one. Qadar(1995) reported that increase in K application alleviated the Na toxicity in rice plants agreeing with the lowered K use efficiency in this experiment, and alkaline soil made with $NaHCO_3$ treatment needed more P and K application. In the FWC treatments the potassium use efficiency was low as 1~28%, and in the swine manure treatments it was high as about 45%.

The sodium use efficiency was 12~20% in NPK+NaCl and FWC treatments.

4. Na accumulation in soil by FWC application.

To investigate the alkalinization of soil by the treatments, SAR, ESP were measured in soil solution collected in near 14cm from top of pots(Fig. 3). SAR and ESP increased in NPK+NaCl and swine manure treatments, and ESP marked the critical level of alkali soil(15%) in FWC 40Mg ha^{-1} treatment.

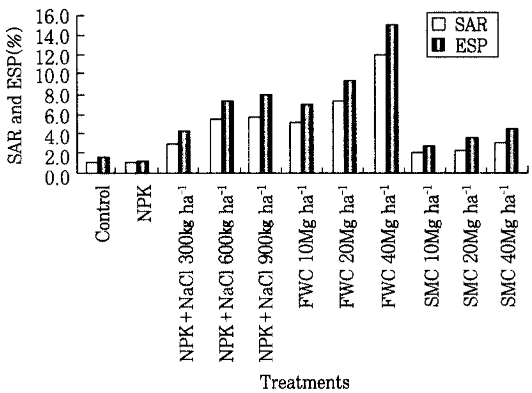

Fig. 3. Application effect of NaCl, food waste compost (FWC), and swine manure compost(SWC) on SAR and estinmated ESP at 35 days afyer transplanting.

Table 7. Nutrient use efficiency at different treatments

Treatment [a]	Nutrient use efficiency (%)				
	N	Ca	Mg	K	Na
NPK	51	-	-	167	-
NPK+NaCl 300kg ha^{-1}	52	-	-	162	12
NPK+NaCl 600kg ha^{-1}	53	-	-	128	13
NPK+NaCl 900kg ha^{-1}	50	-	-	87	16
FWC 10Mg ha^{-1}	11	4	23	28	16
FWC 20Mg ha^{-1}	10	2	17	15	22
FWC 40Mg ha^{-1}	4	1	15	11	17
SMC 10Mg ha^{-1}	6	2	10	47	2
SMC 20Mg ha^{-1}	16	3	13	50	9
SMC 40Mg ha^{-1}	10	2	11	44	8

[a] FWC : food waste compost; SMC : swine manure compost

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韓土肥誌(2000)
Vol. 33(2) : 100~108

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NaCl을 다량 함유한 음식물쓰레기 퇴비 시용이 논 토양에서 벼의 생육과 체내 양이온 균형에 미치는 영향

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음식물쓰레기 퇴비 시용이 담수 조건의 벼 생육과 수량, 체내 양이온 균형 및 토양의 Na 집적 등에 미치는 영향을 밝히고자 폿트 실험을 하였다. 처리로는 무처리, NPK, NPK에 NaCl을 3수준(300, 600, 900kg ha^{-1})으로 시용한 처리, 음식물쓰레기 퇴비와 돈분발효 퇴비를 각각 3수준(30, 60, 90Mg ha^{-1})으로 한 처리 등을 두었다. 음식물쓰레기 퇴비는 Na_2O 함량이 2.2%로 높았다. 이앙 직후 활착기간 중 음식물쓰레기 퇴비 40Mg ha^{-1} 〉 NPK+NaCl 900kg ha^{-1} 〉 음식물쓰레기 퇴비 20Mg ha^{-1} 순으로 심한 위조 현상을 보였으며, 그 원인으로 판단되는 토양용액 중의 EC와 유기산 함량이 음식물쓰레기 퇴비 40Mg ha^{-1} 처리에서 매우 높았다. NaCl을 900kg ha^{-1} 까지 시용하여도 대조구인 NPK구에 비하여 유의성 있는 수확기 건물중의 감소가 일어나지 않았다. 음식물쓰레기 퇴비 시용은 시용량에 관계없이 수확기 건물중을 감소시킨 반면, 돈분발효퇴비는 40Mg ha^{-1} 까지 시용량이 증가될수록 건물중을 증가시켰다. NPK + NaCl 처리들과 음식물쓰레기 퇴비 처리들에서 Na 시용량이 증가될수록 수확기 식물체 중 Na 함량이 직선적으로 증가되었다. Na 당량비도 Na 함량과 같은 경향이었으며, Na 당량비와 K 당량비 사이에는 고도의 유의성있는 부의 상관관계를 보였다. Na와 K의 당량비 및 Na/K 당량비 비율은 처리간 편차가 매우 컸던 반면, Na+K 당량비 합은 편차가 적어 상당부분 Na의 K에 대한 생리적 대체가 인정되었다. Na 이용률은 NaCl과 음식물쓰레기 퇴비 처리들에서 12~22%를 나타내었다.

Key word : Rice, FWC, NaCl, Cationic balance.

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※ 이 연구는 농촌진흥청 산 · 학 · 관 공동연구로 수행되었으며, 연구비를 지원한 농촌진흥청에 깊은 감사를 드리는 바이다.