Korean Journal Of Agricultural Science

pISSN : 2466-2402
eISSN : 2466-2410

PLANT&FOREST

An option to provide water and fertilization for rice production in alkaline soil: fertigation with slow release fertilizers (SRFs)

Young-Tae Shin[1], Kangho Jung[2], Chung-Keun Lee[3,*], Jwakyung Sung[1,*]

[1]Department of Crop Science, College of Agriculture, Life and Environment Sciences, Chungbuk National University, Cheongju 28644, Korea
[2]Research Policy Bureau, RDA, Jeonju 54875, Korea
[3]Division of Crop Production and Physiology, National Institute of Crop Science, RDA, Wanju 55365, Korea

*Corresponding authors: leegaka@korea.kr, jksung73@chungbuk.ac.kr

Abstract

An increasing global population requires a greater food supply, and accordingly there is demand for enhanced production of rice, as a major crop plant that covers half of the world's population. Rice production in arid area is extremely difficult due to poor soil fertility, salinity, deficit of irrigation water, and weather conditions. The aim of the present study was to determine whether various fertilization recipes could provide a countermeasure to allow rice production while also providing soil amendment such as soil pH adjustment. The study was conducted at an experimental field of the United Arab-Emirates (UAE) from January to April, 2022. Rice seedlings (cv. Asemi, alkaline-resistant) were transplanted in plastic containers, and different types of water and nutrient managements were employed as follows: water management (flooding and aerobic for NPKs treatment group) and nutrient management (NPKs, slow release fertilizers [SRFs] and SRFs + NPK-1 treatment groups with flooding). Water and nutrient management did not show any effect on soil pH adjustment. Rice growth was significantly enhanced in the flooding compared to the aerobic condition, whereas the effect of nutrient management clearly differed among the treatment groups, with SRFs + NPK-1 showing the best results followed by SRFs and NPKs. Most of the fertilization groups markedly accumulated soluble sugars in the shoots and grains of rice plants, but concomitantly a decrease in the roots. Overall, the level of starch showed a tendency of relatively slight perturbation by fertilization. Taken together, the results indicate that soil physical structure should be preferentially amended to find the key for suitable rice production.

Key words: alkaline soil, carbohydrates, fertilization, rice, water management

Citation: Shin YT, Jung K, Lee CK, Sung J. An option to provide water and fertilization for rice production in alkaline soil: fertigation with slow release fertilizers (SRFs). Korean Journal of Agricultural Science 49:871-879. https://doi.org/10.7744/kjoas.20220079

Received: October 13, 2022
Revised: November 08, 2022
Accepted: November 14, 2022

Introduction

The Food and Agriculture Organization (FAO) forecasted a 34% increase in the world population by 2050 (FAO, 2009), and this issue has led to a demand of approximately 43% increase in important cereal crop productivity such as rice (Powell et al., 2012). Of major crops, rice, a food for approximately half of the world population, should be increased by 0.6 - 0.9% annually until 2050 to satisfy global demand (Carriger and Vallee, 2007). Despite of a necessity of yearly 2.4 % yield enhancement until 2050, the one third of global rice production area is unfavorable conditions including extreme alkaline and or salinity to act as a limiting factor (Ray et al., 2013; Haefele et al., 2014). An alkali stress is a concern affecting negatively from cellular metabolism to growth and yield of agricultural crop plants (Wang et al., 2012), and, in particular, the higher soil pH (more than 8.0) leads to a poor rice growth and development by the restricted acquisition of essential elements including nitrogen and is followed by a toxicity and/or deficiency of certain nutrient (Msimbira and Smith, 2020).

Rice plants requiring more water compared to other cereal crops (Pimentel et al., 2004) is sensitive to water shortage during the whole growing season, and even moderate drought condition significantly and frequently reduce the growth and yield of rice (Farooq et al., 2009). Babu et al. (2000) demonstrated an effect on diverse soil water potentials; reduced germination, early seedling growth, vegetative growth (tillering) and yield. In addition, a limited water supply resulted in delayed flowering and lower grain filling (Farooq et al., 2009). Soluble carbohydrates play an important role as an osmoregulatory against a variety of abiotic stress including alkaline/salinity, and are largely accumulated to mediate physiological perturbation of plants (Kaplan and Guy, 2004; Skirycz et al., 2010; Siaut et al., 2011; Wang et al., 2013). In the context of the influence of adverse soil conditions, rice production in middle East Asia like the United Arab-Emirates (UAE) is an extremely challenging work due to higher soil pH and limited irrigation water as well as higher temperature. The climate of the UAE located in arid area is characterized by extremely higher temperature (daily average of 46℃) and humidity, and an imbalance between precipitation (yearly rainfall less than 160 mm) and evaporation. Even, soil texture of most of soils is sandy soil, which is showing greater permeability and lower water- and nutrients-holding capacity (Shahin and Salem, 2015).

Therefore, the current study has tried to evaluate the effect of diverse combinations of water and nutrients and finally establish the optimal methodology for rice production in an arid area (higher soil pH). To achieve our goals, we performed the UAE-constructed experimental field, and investigated soil chemical adjustment, the growth and carbohydrate production of rice plants.

Materials and Methods

Experimental setup and treatment

The current study was conducted at the Center for Agricultural Innovation (CAI), Sharjah, United Arab Emirates (25° 16'09.1"N 55°55'49.7"E) from January to April, 2022. The seeds of rice (*Oryza sativa* L. cv. Asemi, alkaline-resistant) were germinated and uniformly growing twenty days-old seedlings were carefully transplanted into a Wagner pot (a/5,000, 3 plants·pot^{-1}). The pH of soil used for this study was 9.35 ± 0.01 (extreme alkaline), which is indicating inadequate condition for rice production. Water was supplied with a drip irrigation including different rates of NPK or slow release fertilizer (SRF), and divided into two different rates of watering, 1) flooding (300 - 400 mL, 2 times·day^{-1}) and 2) aerobic (150 - 200 mL, 1 times·day^{-1}). For chemical fertilizer (NPK) application, ammonium sulfate ($(NH_4)_2SO_4$), potassium phosphate (KH_2PO_4) and potassium sulfate (K_2SO_4) were used as a source of N, P_2O_5 and K_2O, respectively. A slow release fertilizer (SRF) containing different combinations of NPK was also applied. The detailed recipe is described on Table 1, and those are divided into three groups by fertilization; Group-A (NPKs), Group-B (SRFs) and Group-C (SRFs + NPK-1).

Table 1. Recipe for watering and fertilization.

Fertilization	Watering (mL·day^{-1})		$(NH_4)_2SO_4$ (mg·pot^{-1})	KH_2PO_4 (mg·pot^{-1})	K_2SO_4 (mg·pot^{-1})	SRF (g·pot^{-1}, N-P-K)		
	Flooding	Aerobic				18-7-9	30-6-6	20-0-0
No fertilization	800	400	-	-	-	-	-	-
NPK-1	800	400	32	6.16	13.12	-	-	-
NPK-2	800	400	-	6.16	13.12	-	-	-
NPK-3	800	400	32	-	17.76	-	-	-
NPK-4	800	400	32	6.16	-	-	-	-
NPK-5	800	400	64	6.16	13.12	-	-	-
NPK-6	800	400	32	12.32	8.48	-	-	-
NPK-7	800	400	32	6.16	30.88	-	-	-
SRF-1	800	-	-	0.5	-	1.8	-	-
SRF-2	800	-	-	1.0	-	-	2.0	-
SRF-3	800	-	-	0.8	-	-	-	1.2
SRF-4	800	-	-	-	-	3.8	-	-
SRF-5	800	-	-	1.0	-	-	4.0	-
SRF-6	800	-	-	0.6	-	-	-	2.4
SRF-1 + NPK-1	800	-	32	6.16	13.12	1.8	-	-
SRF-2 + NPK-1	800	-	32	6.16	13.12	-	2.0	-
SRF-3 + NPK-1	800	-	32	6.16	13.12	-	-	1.2
SRF-4 + NPK-1	800	-	32	6.16	13.12	3.8	-	-
SRF-5 + NPK-1	800	-	32	6.16	13.12	-	4.0	-
SRF-6 + NPK-1	800	-	32	6.16	13.12	-	-	2.4

N, ammonium sulfate; P, potassium phosphate; K, potassium sulfate; SRF, slow release fertilizer.

Sampling, agronomic parameters and C/N analysis

Soils and rice from each treatment group were carefully taken at the tillering and heading stages. The soil samples (n = 3) were air-dried at ambient temperature, and the pH and electrical conductivity (EC) were measured with a potable pH/EC meter after 30 min of shaking (soil : ddH_2O, 1 : 5). The agronomic parameters from the sampled rice plants (n = 3) were firstly measured, divided into the shoots, roots and grains (heading stage only), ground after oven-dried (80℃), and used for further analysis. The dried rice samples (0.1 g) were put in the customized containers, and were combusted at high temperature (1,000℃) (CN auto-analyzer, Primacs SNC 100, SKALAR, Breda, Noord-Brabant, Netherland). Total carbon and nitrogen were measured by non-dispersive infra-red (NDIR) and thermal conductivity detector (TCD) detectors, respectively.

Determination of total soluble sugar and starch

In order to determine carbohydrate contents, the dried samples (0.1 g, shoots/roots/grains) were first boiled with 10 mL of 80 % ethanol in boiling water. The alcoholic extracts were evaporated under nitrogen stream, and the residues were re-dissolved with distilled water. The residue was digested with 2 mL of 9.3 N $HClO_4$, and the supernatant after a centrifugation was used for the determination of starch. Water extracts were mixed with 2 volumes of 0.2% anthrone in a concentrated H_2SO_4 followed by estimation of carbohydrate as described by Roe et al. (1955). The colorimetric quantification of the extracts was measured at 630 nm with a spectrophotometer (UV-1900i, Shimadzu, Kyoto, Japan). Glucose was used as standard for both soluble sugars and starch.

Statistical analysis

An analysis of variance was performed to compare the differences between treatments using a statistical program (R version 4.0.3, RStudio, Inc., Boston, MA, USA). Data were analyzed in a completely random design using ANOVA, and, if $p < 0.05$, were subjected with Tukey-HSD test to detect significant differences among the means.

Results and Discussion

Soil pH and EC

The soil pH used in this study was an extremely stronger alkaline (pH 9.35). An electrical conductivity (EC) was also relatively higher (1.69 ± 0.71) considering that the soil structure was sandy. The soil contained great amount of sulfur (145 ± 37 mg·L^{-1}) and chloride (76 ± 16 mg·L^{-1}) ions, whereas essential elements such as NO$_3$, PO$_4$, K and Ca were deficient for normal rice growth (Table 2). Water management and different types and rates of chemical fertilizers were employed as a measure to adjust soil pH and EC, and monitored both tillering and heading stages. The soil pH was not adjusted by different types of water and fertilization managements (Table 3). The EC was unchanged (tillering stage) or fluctuated (heading stage) under an aerobic soil condition regardless of the type of fertilization. In contrast, the continuous flooding (800 mL·day^{-1}) resulted in the significant increase by fertilization at heading stage.

Table 2. Soil chemical properties used in this study.

EC	K	Ca	NO$_3$	PO$_4$	SO$_4$	Cl
(1 : 5)	(mg·L^{-1})					
1.69 ± 0.71	11 ± 5	25 ± 7	4 ± 4	3 ± 2	145 ± 37	76 ± 16

EC, electrical conductivity.

Table 3. Effect of water and fertilization managements for soil pH and EC adjustments.

Fertilization	pH (1 : 5)				EC (dS·m^{-1}, 1 : 5)			
	Tillering stage		Heading stage		Tillering stage		Heading stage	
	Flooding	Aerobic	Flooding	Aerobic	Flooding	Aerobic	Flooding	Aerobic
No fertilization	9.17 ± 0.05	9.35 ± 0.01	8.89 ± 0.07	9.21 ± 0.05	1.6 ± 0.1	2.2 ± 0.1	4.0 ± 0.3	4.3 ± 0.3
NPK-1	8.82 ± 0.10	9.04 ± 0.02	8.73 ± 0.04	9.31 ± 0.03	3.5 ± 0.3	2.6 ± 0.0	3.3 ± 0.4	1.9 ± 0.1
NPK-2	9.06 ± 0.04	9.14 ± 0.07	8.73 ± 0.08	9.19 ± 0.04	2.2 ± 0.2	2.2 ± 0.1	4.0 ± 0.3	2.6 ± 0.2
NPK-3	9.01 ± 0.06	9.22 ± 0.05	8.74 ± 0.03	9.36 ± 0.08	1.8 ± 0.1	3.2 ± 0.4	3.9 ± 0.2	3.8 ± 0.5
NPK-4	9.01 ± 0.02	8.99 ± 0.04	8.54 ± 0.09	9.16 ± 0.09	1.8 ± 0.0	2.9 ± 0.1	6.7 ± 0.2	3.8 ± 0.3
NPK-5	9.07 ± 0.01	9.01 ± 0.03	8.88 ± 0.06	9.10 ± 0.09	2.3 ± 0.0	2.6 ± 0.1	3.2 ± 0.2	4.4 ± 0.4
NPK-6	9.15 ± 0.03	9.10 ± 0.02	8.95 ± 0.04	8.88 ± 0.06	1.5 ± 0.0	2.3 ± 0.1	3.8 ± 0.1	5.2 ± 0.2
NPK-7	9.18 ± 0.02	9.21 ± 0.05	8.82 ± 0.10	9.23 ± 0.06	2.4 ± 0.0	2.1 ± 0.1	4.4 ± 0.4	3.1 ± 0.4
SRF-1	9.13 ± 0.02		8.94 ± 0.04		1.6 ± 0.0		3.1 ± 0.3	
SRF-2	9.12 ± 0.04		8.80 ± 0.06		1.5 ± 0.1		2.0 ± 0.1	
SRF-3	9.02 ± 0.07		8.88 ± 0.02		2.7 ± 0.2		5.3 ± 0.2	
SRF-4	8.78 ± 0.02		8.99 ± 0.02		2.7 ± 0.2		3.2 ± 0.1	
SRF-5	9.10 ± 0.03		8.81 ± 0.07		1.4 ± 0.0		5.9 ± 0.2	
SRF-6	8.70 ± 0.04		9.05 ± 0.03		1.5 ± 0.0		3.3 ± 0.1	
SRF-1 + NPK-1	8.91 ± 0.02		8.38 ± 0.05		1.8 ± 0.1		9.3 ± 0.2	
SRF-2 + NPK-1	8.69 ± 0.11		8.46 ± 0.05		3.4 ± 1.0		4.4 ± 0.3	
SRF-3 + NPK-1	8.84 ± 0.13		8.55 ± 0.03		2.2 ± 0.2		3.7 ± 0.3	
SRF-4 + NPK-1	8.81 ± 0.07		8.41 ± 0.04		2.2 ± 0.2		8.0 ± 2.6	
SRF-5 + NPK-1	8.82 ± 0.01		8.50 ± 0.07		1.8 ± 0.1		3.3 ± 0.1	
SRF-6 + NPK-1	8.70 ± 0.04		8.48 ± 0.03		2.8 ± 0.1		10.0 ± 0.5	

EC, electrical conductivity; N, ammonium sulfate; P, potassium phosphate; K, potassium sulfate; SRF, slow release fertilizer.

In this study, the water and nutrient managements did not represent any effect on adjusting high saline soils containing Na and Cl, and thus it is suggested that, prior to improving chemical properties, it is necessary to improve soil structure for promising rice production.

Rice growth and soluble carbohydrates

The growth parameters measured at the heading stage remarkably differed from different types of water management, which indicated that the flooding was significant greater compared to the aerobic condition (Table 4; Fig. 1). Different rates of chemical fertilization (NPK-1 and -5) showed significant differences in growth parameters compared to no fertilization in the flooding condition, whereas the treatments (NPK-3 and -4) were greater in the aerobic condition. Therefore, an adjustment of chemical fertilizer (N, P or K) resulted in marginal effect, and, overall, the growth of rice plants largely depended on both water and nutrient managements. The reduction in growth and development of rice plants frequently takes place in higher salt-containing agricultural lands (Zeng et al., 2003). The application of different types of SRFs treatment didn't show significant effect on dry weight, whereas the SRFs containing higher N level markedly enhanced tillering compared to no fertilization. The supply of fertilizer in reclaimed saline soil increased growth and yield with a mitigation of salinity stress (Rady, 2012), and we also observed that the combination of SRFs and NPK-1 revealed the clear effect on the improvement of all growth parameters.

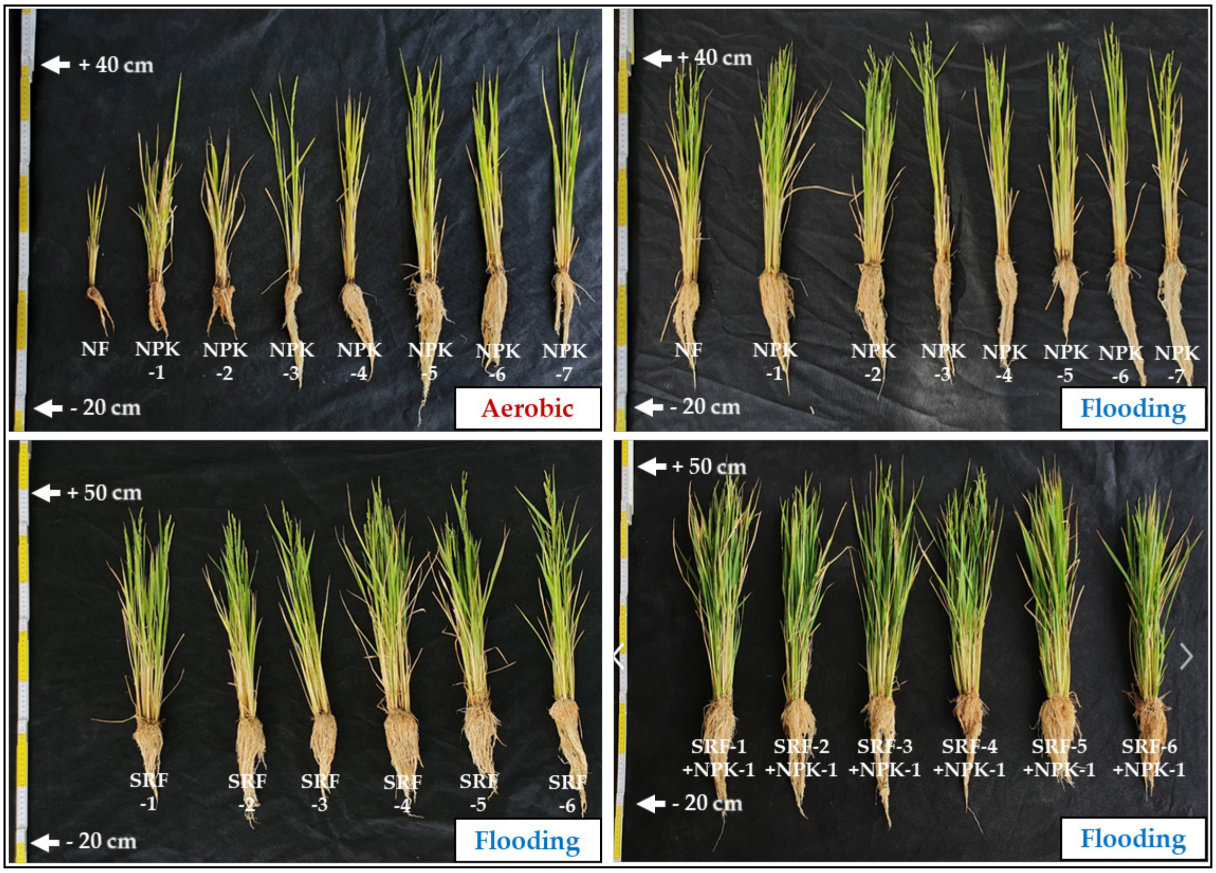

Fig. 1. Difference in growth of rice plants (cv. Asemi) affected by different types of watering and fertilization at the heading stage.

Table 4. Effect of water and fertilization managements on rice growth at the heading stage.

Fertilization	Flooding			Aerobic		
	Plant height (cm)	Tiller (No.·plant^{-1})	Dry weight (g·plant^{-1})	Plant height (cm)	Tiller (No.·plant^{-1})	Dry weight (g·plant^{-1})
No fertilization	34.4 ± 0.5cd	9.3 ± 1.0c	6.8 ± 1.3bc	14.5 ± 2.1b	3.0 ± 1.0ns	0.4 ± 0.1c
NPK-1	36.8 ± 1.3a	13.5 ± 1.3a	9.2 ± 3.4ab	21.8 ± 4.4ab	7.0 ± 3.6	3.6 ± 0.7ab
NPK-2	34.8 ± 0.7bc	12.5 ± 2.4ab	10.3 ± 1.1a	21.6 ± 2.1ab	6.0 ± 2.0	1.2 ± 0.5bc
NPK-3	31.4 ± 1.4e	9.3 ± 1.0c	5.7 ± 0.3c	31.1 ± 2.2a	8.0 ± 0.0	4.3 ± 1.8a
NPK-4	33.8 ± 1.5cd	11.0 ± 0.8bc	7.0 ± 0.5bc	29.0 ± 6.5a	8.3 ± 1.2	4.6 ± 0.8a
NPK-5	36.2 ± 1.4ab	12.5 ± 2.1ab	6.2 ± 0.9c	26.2 ± 5.9ab	8.0 ± 2.6	5.1 ± 1.6a
NPK-6	32.8 ± 1.9de	11.0 ± 0.29bc	5.9 ± 1.0c	27.0 ± 6.9ab	10.3 ± 3.0	5.0 ± 2.0a
NPK-7	34.6 ± 0.4bcd	10.8 ± 0.5bc	5.1 ± 0.6c	25.3 ± 3.3ab	8.0 ± 1.0	4.9 ± 2.5a
F-value	7.7	3.28	4.62	3.39	2.37	4.58
No fertilization	34.4 ± 0.5bc	9.3 ± 1.0b	6.8 ± 1.3ns			
SRF-1	39.5 ± 1.6ab	15.2 ± 2.3a	11.4 ± 3.1	-	-	-
SRF-2	39.1 ± 1.0ab	12.4 ± 1.1ab	9.7 ± 1.6	-	-	-
SRF-3	32.4 ± 1.8c	11.0 ± 2.0ab	8.7 ± 2.7	-	-	-
SRF-4	39.1 ± 5.5ab	14.8 ± 2.9a	16.3 ± 6.9	-	-	-
SRF-5	41.5 ± 2.0a	14.4 ± 3.0a	16.3 ± 3.4	-	-	-
SRF-6	40.6 ± 1.1ab	15.0 ± 1.9a	11.1 ± 1.8	-	-	-
F-value	5.65	5.098	3.293			
No fertilization	34.4 ± 0.5c	9.3 ± 1.0b	6.8 ± 1.3b			
SRF-1 + NPK-1	45.6 ± 1.9a	19.2 ± 2.3a	21.3 ± 4.8a	-	-	-
SRF-2 + NPK-1	40.2 ± 2.4b	19.2 ± 2.5a	20.3 ± 1.9a	-	-	-
SRF-3 + NPK-1	40.1 ± 2.4bc	18.8 ± 1.6a	19.1 ± 1.8a	-	-	-
SRF-4 + NPK-1	39.3 ± 4.3bc	21.8 ± 2.6a	14.4 ± 3.5ab	-	-	-
SRF-5 + NPK-1	38.8 ± 3.7b	19.8 ± 3.7a	19.3 ± 3.3a	-	-	-
SRF-6 + NPK-1	40.1 ± 2.3bc	19.4 ± 1.9a	14.6 ± 2.1ab	-	-	-
F-value	6.834	11.4	9.033			

N, ammonium sulfate; P, potassium phosphate; K, potassium sulfate; SRF, slow release fertilizer.

a - e: Different letters in a same row of each treatment group mean significant difference by Tukey-HSD test ($p < 0.05$).

Based on the result of growth parameters, soluble carbohydrates, soluble sugars and starch, were measured from the shoot, root and grain of rice plants treated with SRFs and SRFs + NPK-1 at the heading stage (Table 5). Indeed, SRFs (-2, -5, and -6) containing the relatively higher N resulted in significant abundant level of soluble sugars in the shoot and grain, whereas those in the root was not differ. In contrast, the level of starch was not remarkable in the shoot and grain between treatments, however, an abundance was significantly reduced in the root. An application of SRFs + NPK-1 also represented the similar trends to SRFs treatments. Indeed, soluble sugars were greatly accumulated in the shoot and grain by an input of SRFs + NPK-1, on the other hand, the level in the root was largely decreased in some treatments. The concentration of starch showed organ-specific different patterns by treatment, although SRF-1 + NPK-1 led to the noticeable decrease in all organs compared to no fertilization. An accumulation of non-structural carbohydrates provides an energy for suitable plant growth and development, and, moreover, those play an essential role to regulate the homeostasis and protect from the damage against adverse growth environments like salinity (Khelil et al., 2007; Bagheri and Sadeghipour, 2009; Naureen and Naqvi, 2010). In this study, we observed a marked accumulation of soluble sugars in the shoot and grain of rice plants by most of the fertilization group, by contrast, showed a decreasing pattern in the root. A large accumulation of soluble sugars in the shoot and grain was considered as a result of higher photosynthetic activity, and the driving force was due to the N supply by fertilization. The limited photosynthesis under salinity caused a decrease in the carbohydrate level and followed by reduced plant growth (Pattanagul and Thitisaksakul, 2008). Overall, the level of starch remained unchanged or smaller fluctuation in the shoot and grain. Starch biosynthesis is greatly affected by K, an essential element to activate starch biosynthetic-enzymes, however the uptake of K is frequently limited under salinity (Moradi et al., 2003; Dkhil and Denden, 2010). The shortage of an acquisition of essential mineral nutrients in plants is as a consequence of an antagonism by higher Na$^+$ and Cl$^-$ under salinity, and this results in an adjustment of carbohydrate partitioning between source and sink tissues to increase root biomass (Hermans et al., 2006). This study also confirmed that starch in root was significantly accumulated under no fertilization. Therefore, the carbohydrate metabolism such as synthesis and partitioning under salinity was in line with our observation. Our result demonstrated that the reduced carbohydrate production could be partly compensated by fertilization, and the effect of fertilization was noticeable in soluble sugars.

Table 5. Partitioning of soluble carbohydrates in rice plants affected by different types of fertilization recipe.

Fertilization	Soluble sugars (mg·g^{-1}, DW)			Starch (mg·g^{-1}, DW)		
	Shoot	Root	Grain	Shoot	Root	Grain
No fertilization	298 ± 17c	382 ± 20abc	186 ± 23d	226 ± 5ab	145 ± 23a	69 ± 11ab
SRF-1	334 ± 23c	306 ± 21c	254 ± 16cd	282 ± 28a	92 ± 18b	88 ± 20a
SRF-2	482 ± 22ab	341 ± 19bc	290 ± 17bc	273 ± 29a	50 ± 2b	47 ± 9b
SRF-3	490 ± 35ab	408 ± 22ab	251 ± 17cd	290 ± 37a	72 ± 13b	68 ± 17ab
SRF-4	387 ± 44bc	337 ± 30bc	293 ± 28bc	228 ± 23ab	75 ± 11b	47 ± 7b
SRF-5	550 ± 26a	446 ± 65a	336 ± 21b	2,616 ± 43ab	59 ± 20b	35 ± 8b
SRF-6	524 ± 81a	316 ± 29bc	530 ± 44a	188 ± 30b	49 ± 7b	60 ± 17ab
F-value	17.18	7.313	55.98	4.601	14.28	5.193
No fertilization	298 ± 17d	382 ± 20a	186 ± 23c	226 ± 5a	145 ± 23a	69 ± 11bc
SRF-1+NPK-1	388 ± 21d	360 ± 19ab	251 ± 4b	112 ± 12c	76 ± 12bc	24 ± 3d
SRF-2+NPK-1	570 ± 31a	279 ± 1c	258 ± 16b	88 ± 11c	121 ± 25ab	46 ± 8cd
SRF-3+NPK-1	539 ± 11ab	317 ± 27bc	306 ± 17b	166 ± 20b	107 ± 14ab	84 ± 11abc
SRF-4+NPK-1	490 ± 44bc	312 ± 25bc	233 ± 26bc	208 ± 14ab	108 ± 16ab	93 ± 24ab
SRF-5+NPK-1	439 ± 35cd	264 ± 37c	234 ± 13b	204 ± 32ab	98 ± 20ab	88 ± 12ab
SRF-6+NPK-1	411 ± 26cd	180 ± 13d	331 ± 12a	219 ± 18a	44 ± 6c	115 ± 20a
F-value	32.56	25.78	24.29	28.75	10.06	14.32

DW, dry weight; N, ammonium sulfate; P, potassium phosphate; K, potassium sulfate; SRF, slow release fertilizer.

a - e: Different letters in a same row of each treatment group mean significant difference by Tukey-HSD test ($p < 0.05$).

Table 6. Statistical difference in growth parameters and soluble carbohydrates between fertilization groups.

Fertilization	Growth parameters			Soluble sugars			Starch		
	Plant height (cm)	Tiller (No.·plant^{-1})	Dry weight (g·plant^{-1})	Shoot	Root	Grain	Shoot	Root	Grain
NPK	34.3 ± 2.0c	11.2 ± 2.1c	7.0 ± 2.1c	-	-	-	-	-	-
SRF	38.0 ± 4.0b	13.3 ± 2.9b	10.9 ± 4.5b	461.3 ± 86.1	358.9 ± 59.7	325.5 ± 101	253.8 ± 45.4	66.2 ± 19.1	57.4 ± 21.3
SRF + NPK-1	40.4 ± 3.6a	18.3 ± 4.2a	15.3 ± 6.0a	472.8 ± 72.3	285.4 ± 61.2	268.8 ± 40.2	166.3 ± 53.7	92.1 ± 29.7	75.0 ± 33.9
F-value	27.44	43.65	20.29						
T-test				0.437	3.651	2.210	5.277	3.117	1.865

N, ammonium sulfate; P, potassium phosphate; K, potassium sulfate; SRF, slow release fertilizer.

a - c: Different letters in a same row of each treatment group mean significant difference by Tukey-HSD test ($p < 0.05$).

Conclusion

The current study was tried to investigate the effect of an application of chemical fertilizers (various types and rates) to promote rice production in arid areas, where have higher soil pH due to salinity. Any chemical fertilization was not effective to adjust soil pH. Rice growth was noticeably promoted by fertilization, especially slow release fertilizers (SRFs) and SRFs + NPK-1, with sufficient watering (flooding). Therefore, despite of a fertilization with an irrigation could be a great challenge to cultivate rice, it is firstly required to amend soil physical structure to promise suitable rice production.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgements

This work was supported by the "Research Program for Agriculture Science & Technology Development (Project No. PJ016256)", Rural Development Administration, Republic of Korea.

Authors Information

Young-Tae Shin, Department of Crop Science, Chungbuk National University, Master student
Kangho Jung, Research Policy Bureau, Rural development admistration, Senior Researcher
Chung-Keun Lee, Division of Crop Production and Physiology, National Institute of Crop Science, Senior Researcher
Jwakyung Sung, https://orcid.org/0000-0002-0758-6644

References

Babu RC, Nguyen BD, Chamarerk V, Shanmugasundaram P, Chezhian P, Jeyaprakash P, Rathinasabapathi B. 2000. Metabolic engineering for stress tolerance: Installing osmoprotectant synthesis pathways. Annals of Botany 86:709-716.

Bagheri A, Sadeghipour O. 2009. Effects of salt stress on yield, yield components and carbohydrates content in four hullless barley (*Hordeum vulgare* L.) cultivars. Journal of Biological Science 9:909-912.

Carriger S, Vallee D. 2007. More crop per drop. Rice Today 6:10-13.

Dkhil BB, Denden M. 2010. Salt stress induced changes in germination, sugars, starch and enzyme of carbohydrate metabolism in *Abelmoschus esculentus* (L.) moench seeds. African Journal of Agricultural Research 5:408-415.

FAO (Food and Agriculture Organization). 2009. How to feed the world in 2050. Accessed in https://www.fao.org on 10 October 2022.

Farooq M, Wahid A, Kobayashi N, Fujita D, Basar S. 2009. Plant drought stress: Effects mechanisms and management. Sustainable Agriculture 2009:153-188.

Haefele SM, Nelson A, Hijmans RJ. 2014. Soil quality and constraints in global rice production. Geoderma 235:250-259.

Hermans C, Hammond JP, White PJ, Verbruggen N. 2006. How do plants respond to nutrient shortage by biomass allocation? Trends in Plant Science 11: 610-617.

Kaplan F, Guy CL. 2004. β-amylase induction and the protective role of maltose during temperature shock. Plant Physiology 135:1674-1684.

Khelil A, Menu T, Ricard B. 2007. Adaptive response to salt involving carbohydrate metabolism in leaves of a salt-sensitive tomato cultivar. Plant Physiology and Biochemistry 45:551-559.

Moradi F, Ismail AM, Gregorio GB, Egdane JA. 2003. Salinity tolerance of rice during reproductive development and association with tolerance at the seedling stage. Indian Journal of Plant Physiology 8:276-278.

Msimbira LA, Smith DL. 2020. The roles of plant growth promoting microbes in enhancing plant tolerance to acidity and alkalinity stresses. Frontiers in Sustainable Food Systems 4:106.

Naureen G, Naqvi FN. 2010. Salt tolerance classification in wheat genotypes using reducing sugar accumulation and growth characteristic. Emirates Journal of Food and Agriculture 22:308-317.

Pattanagul W, Thitisaksakul M. 2008. Effects of salinity stress on growth and carbohydrate metabolism in three rice (*Oryza sativa* L.) cultivars differing in salinity tolerance. Indian Journal of Experimental Biology 46:736- 742.

Pimentel D, Berger B, Filiberto D, Newton M, Wolfe B, Karabinakis E, Clark S, Poon E, Abbett E, Nadagopal S. 2004. Water resources: Agricultural and environmental issues. Bioscience 54:909-918.

Powell N, Ji X, Ravash R, Edlington J, Dolferus R. 2012. Yield stability for cereals in a changing climate. Functional Plant Biology 39:539-552.

Rady MM. 2012. A novel organo-mineral fertilizer can mitigate salinity stress effects for tomato production on reclaimed saline soil. South African Journal of Botany 81:8-14.

Ray DK, Mueller ND, West PC, Foley JA. 2013. Yield trends are insufficient to double global crop production by 2050. PLoS One 8:e66428.

Roe JH. 1955. The determination of sugar in blood and spinal fluid with anthrone reagent. Journal of Biological Chemistry 212:335-343.

Shahin SM, Salem MA. 2015. The Challenges of water scarcity and the future of food security in the United Arab Emirates (UAE). Natural Resources and Conservation 3:1-6.

Siaut M, Cuiné S, Cagnon C, Fessler B, Nguyen M, Carrier P, Beyly A, Beisson F, Triantaphylidès C, Li-Beisson Y. 2011. Oil accumulation in the model green alga *Chlamydomonas reinhardtii*: Characterization, variability between common laboratory strains and relationship with starch reserves. BMC Biotechnology 11:7.

Skirycz A, De Bodt S, Obata T, De Clercq I, Claeys H, De Rycke R, Andriankaja M, Van Aken O, Van Breusegem F, Fernie AR. 2010. Developmental stage specificity and the role of mitochondrial metabolism in the response of Arabidopsis leaves to prolonged mild osmotic stress. Plant Physiology 152:226-244.

Wang H, Wu Z, Han J, Zheng W, Yang C. 2012. Comparison of ion balance and nitrogen metabolism in old and young leaves of alkali-stressed rice plants. PLoS One 7:e37817.

Wang X, Chang L, Wang B, Huang Q, Peng M, Gup A. 2013. Comparative proteomics of *Thellungiella halophila* leaves from plants subjected to salinity reveals the importance of chloroplastic starch and soluble sugars in halophyte salt tolerance. Molecular and Cellular Proteomics 12:2174-2195.

Zeng L, Lesch SM, Grieve CM. 2003. Rice growth and yield respond to changes in water depth and salinity stress. Agricultural Water Management 59:67-75.