Impacts of nitrogen and zeolite managements on yield and physicochemical properties of rice grain

Wu Qi[1], Xia Guimin[1], Chen Taotao[1], Chi Daocai[1*], Jin Ye[2], Sun Dehuan[2]

(1. *College of Water Conservancy, Shenyang Agricultural University, Shenyang 110866, China*;
2. *Experimental Irrigation Station, Water Conservancy Bureau of Donggang, Dandong 118000, China*)

Abstract: Zeolite (Z) can hold soil water and nutrient to obtain a higher yield on introduction into moist soil. However, the effects of Z and nitrogen (N) managements on rice grain quality is unclear. Therefore, the effects of different amounts of Z (Z_0: 0 t/hm^2; $Z_{0.9}$ and $Z_{0.22}$: 10 t/hm^2 in different particle sizes of 0.45-0.9 mm and 0.17-0.22 mm in diameter) and N (N_0, $N_{52.5}$, N_{105}, $N_{157.5}$: 0 kg/hm^2, 52.5 kg/hm^2, 105 kg/hm^2, 157.5 kg/hm^2), and Z (Z_0, Z_{10}: 0 t/hm^2, 10 t/hm^2) and application frequencies of N on rice yield and grain quality were investigated in 2014 and 2015 in Northeast coastal region of China where Z_{10} was extended to use in large areas. Results showed that both N and Z applications significantly increased the yields of rough rice (RRY), brown rice, milled rice and head rice. However, there was no significant difference between $Z_{0.9}$ and $Z_{0.22}$. The chalkiness area, length-width ratio and head rice rate were not influenced by Z and N applications. However, Z application significantly decreased the chalk rate and slightly increased amylose content (AC) but mattered little to taste value (TV) of rice and rice cooking quality. N could significantly increase rice protein content (PC) but lessen the TV and breakdown value; the order of influence degree on rice yield increasing was as follows: CRF2 (third-split fertilization with Z_{10}), CRF1 (basal fertilization one time with Z_{10}), U2 (urea: third-split fertilization without Z) and U1 (basal fertilization one time without Z). Both CRF1 and CRF2 greatly enhanced the RRY. However, CRF1 was recommended for clear decrease in labor and fuel for growers. Compared with treatments of U1 and CRF1, CRF2 and U2 significantly decreased the AC. PC exhibited significant negative relation to TV and greatly determined the rice eating quality and cooking quality.

Keywords: rice grain quality, rice yield, nitrogen, zeolite, physicochemical property
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1 Introduction

As a cereal crop, rice is one of most important and required food in the world since it provided beyond 21% of the daily calorific needs for the world population[1]. Therefore, there must be a big market for rice to trade and circulate. For business needs, processing and cooking quality of rice have played a decisive role[2,3].

Many results showed that changes in extraneous production practices such as nitrogen (N) application rates or N application frequencies could alter the physicochemical properties of rice grain and eventually impact the acceptance in global markets[4]. Several studies have shown that different N managements influenced the rice grain yield, protein concentration, pasting viscosity, amylose content of rice. Higher N application rates could result in an increase in protein content but a decrease in eating quality[5-7]. New

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Biographies: **Wu Qi**, PhD, research interests: agricultural water and soil engineering, Email: vichine_21@126.com; **Xia Guimin**, PhD, Associated Professor, research interests: agricultural water and soil engineering, Email: xiagm1229@126.com; **Chen Taotao**, PhD, research interests: agricultural water and soil engineering; **Jin Ye**, senior engineer, research interests: water conservancy engineering, Email: dgsyh@163.com; **Sun Dehuan**, senior engineer, research interests: water conservancy engineering, Email: 0415-7123605@163.com.
***Corresponding author: Chi Daocai**, PhD, Professor, research interests: agricultural water and soil engineering. Mailing address: College of Water Conservancy, Shenyang Agricultural University, Shenyang 110866, Liaoning, China. Tel: +86-13709810255, Email: daocaichi@vip.sina.com.

technologies of N managements are needed to improve rice grain quality and further increase rice grain yield.

Rice farmers have strong desires to obtain higher rice grain yield and grain quality with lower input costs. Several ways to reduce fertilizer inputs are split N fertilization, utilization of slow-release fertilizer and incorporation of soil amendment. Zeolite (Z) are crystalline, hydrated aluminosilicates that have three-dimensional crystal structures. N applied with Z (CRF: controlled-release fertilizer) which was comparable to the slow-release N fertilizer could decease N fertilizer inputs for enhancing the fertilizer efficiency[8]. There were additional potentials for CRF to save in labor and fuel because of extending the period of supplying nutrient. The process that N was slowly released to the soil surface through the exchange sits of Z could significantly improve the availability of N to the plant and eventually increase the rice production and improve rice grain quality[9,10]. During rice grain quality forming, moderate water status in soil could also obtain stable filling process and improve rice quality[11]. Z could improve soil water holding capacity and maintain soil moisture on introduction into soil[12]. Hence, the feasibility of using Z to improve rice grain quality should be stressed.

Therefore, the objectives of the experiments in this study are to investigate the different N managements based on Z on rice grain yield and quality in two growth seasons of 2014 and 2015 in Northeast coastal region of China. Z was only applied in 2014 and no additional Z was applied in 2015.

2 Materials and methods

2.1 Site description

The two field experiments were conducted from May 2014 to October 2015 at Donggang experimental irrigation station (40º22′N latitude, 113º33′E longitude and altitudes of 8.1 m). The area belongs to continental moist monsoon climatic region of temperate zone. It is affected by the Yellow Sea and characterized by the maritime climate. Its average annual air temperature is 8.4ºC. The precipitation is concentrated in the summer months (June to August) and the yearly average value is 967 mm. Physical and chemical properties of soil used are shown in Table 1. According to data in Table 1, the soil texture was silty clay loam.

Table 1 Physical and chemical properties of experimental soil

Soil properties	Content
Sand/%	11.4
Silt/%	66.7
Clay/%	21.9
pH	6.76
Bulk density/g·cm^{-3}	1.4
Available P/mg·kg^{-1}	32.33
Available K/mg·kg^{-1}	56.56
Alkali-hydrolysable N/mg·kg^{-1}	36.55
Total N/g·kg^{-1}	0.677
Organic matter/g·kg^{-1}	9.02

2.2 Treatments and design

Field experiment I was designed as a split plot design with three replications. N application rates (N_0, $N_{52.5}$, N_{105}, $N_{157.5}$, kg/hm^2) were the main plots. Z application rates were the sub plots and the particle sizes were in the following ranges: Z_0, 0 t/hm^2; $Z_{0.9}$ and $Z_{0.22}$, 10 t/hm^2 in different diameter of 0.45-0.9 mm and 0.17-0.22 mm, respectively. Field experiment II was designed as complete random design with three replications. There were four treatments in this experiment: urea used as basal fertilization one time (U1); urea used as basal fertilization one time with Z as controlled-released fertilizer (CRF1); urea used as third-split fertilization according to the traditional fertilization method below (U2); urea used as third-split fertilization with Z as controlled-released fertilizer (CRF2). Chen et al.[13] conducted field experiment in two rice growth seasons from 2012 to 2013 and found that Z at 10 t/hm^2 rate could significantly increase rice grain yield in this region under traditional N regimes. Therefore, Z was applied 10 t/hm^2 during both two experiments.

The natural Z used in this study originated from Liaoning province, China. Z had the following chemical composition (%): SiO_2=65.56, Al_2O_3=10.62, Na_2O=0.39, K_2O=2.87, CaO=2.59, Fe_2O_3=0.63, MgO=0.82, FeO=0.09, TiO_2=0.069, P_2O_5=0.001, MnO =0.01, H_2O=8.16, and Loss of Ignition (LOI)=16.59. Z was applied into near-surface soil as basal fertilizer with N. Based on the traditional fertilization method in the experimental station, N (urea) was applied into near-surface soil layer in three parts: 60% basal, 30% 10 days after transplanting and 10% 15 days after jointing-booting stage, respectively. K (K_2O, 72 kg/hm^2) was applied as potassium sulfate in two parts: 50% basal and 50% 15 days after jointing-booting stage, respectively. P (P_2O_5, 172 kg/hm^2) was all applied as the basal fertilizer. In experiment II, N was applied at 157.5 kg/hm^2 in all treatments.

The traditional variety (Japonica rice) used in the experimental station was Gangyu-6 both in the two years. Day of sowing begins in April 22, transplanting in May 28, respectively. Seeding recovery stage begins in May 29, tilling stage in Jun 5, jointing-booting stage in July 4-6, heading-flowering stage in August 3-7, milky ripening stage in August 23-28, yellow ripening stage in September 5-10 and rice harvest in September 16-20, respectively. Each hill had 3 rice seedlings (7×17 hills per plot). Plot sizes were 2.5 m × 2 m and rice was transplanted at 14×30-cm spacing. Plots were regularly hand-weeded and pesticides were used to prevent insect and pest damage. No noticeable crop damage was observed in the two experiments. The water layer in these plots was maintained at 1-7 cm in rice whole growth stages. Water was distributed by pipe to each plot for irrigation. Water depth was measured on a permanently fixed depth gauge. Excessive water was drained off through flumes if there was a heavy rainfall. Irrigation water was stopped 20 days before harvest.

2.3 Samples measurements

At the end of growing stage, rice grain yield (rice rough yield) was calculated based on 12%-14% moisture content. About 300 g of grains harvested from each plot were stored at 10ºC and 55% relative humidity until dehulling and milling. The brown rice rate, milled rice rate and head rice rate were expressed as percentage of total grain weights. The rice rough yield (RRY), brown rice yield (BRY), milled rice yield (MRY) and head rice yield (HRY) treated by FC-2K (Yamamoto, Japan) and VP-32 (Yamamoto, Japan) were calculated according to these rates of brown rice, milled rice and head rice rate above. Head rice rate (HRR) was expressed as percentage of total milled rice weights. The ratio of length and width (L/W), chalk rate (CR), chalkiness area (CA) and HRR were scanned and calculated using Rice Inspector ES-1000 (Shizuoka Seiki, Japan).

The representative milled rice samples were scanned to test amylose content (AC), and protein content (PC) using the method of Near Infrared Transmittance Spectroscopy based on standards by American Association of Cereal Chemists (AACC). The PC, AC and taste value (TV) were obtained using Foss Tecator Infratec 1241 Grain Analyzer and the TV was calculated based on PC and AC.

The milled samples were ground in a stainless steel grinder with a 0.25 mm sieve and then the pasting properties were tested by Rapid Viscosity Analyzer Super3 (Newport Scientific, USA) with Thermocline for Windows software to evaluate rice quality. Pasting properties included: (1) peak viscosity=the max viscosity during heating (MV); (2) trough=hot paste viscosity (HPV); (3) breakdown=peak–hot paste viscosity (BD); (4) final viscosity=cold paste viscosity (CPV); (5) setback= final–hot paste viscosity (SEB) and (6) Pasting Temperature (PT).

2.4 Statistical Analysis of the Data

All data were subjected to analysis of variance (ANOVA) and correlation analysis using SAS9.3 software. Bartlett's test showed homogeneity of variance in all terms. When an *F*-test indicated statistical significance at p<0.05, the Duncan method was used to separate the means of main effect and the interaction effects.

3 Results and analysis

3.1 Rice yield

In field experiment I, an analysis of variance showed that N and Z treatment significantly affected all the parameters including RRY, BRY, MRY and HRY. There was also significant N×Z interaction effect on rice yield based on Table 2. Mean comparisons in Table 3 showed that both N and Z application significantly increased RRY, BRY, MRY and HRY. But there was no marked difference between $Z_{0.9}$ and $Z_{0.22}$. Based on interaction effects analysis in Table 4, at N_0 and $N_{52.5}$ level, there was no significant effect on RRY, BRY, MRY, but at $N_{52.5}$ level, Z input significantly improved the HRY. At N_{105} and $N_{157.5}$ level, both $Z_{0.9}$ and $Z_{0.22}$

distinctly improved the rice yield. Rice yield under treatment of $N_{105}Z_{0.9}$ or $N_{105}Z_{0.22}$ was close to that under treatment of $N_{157.5}Z_0$.

Table 2 Analysis of variance for the effects of nitrogen and zeolite on rice yield

t·hm^{-2}

Source	RRY	BRY	MRY	HRY
Block	1.84^{ns}	0.17^{ns}	0.18^{ns}	0.05^{ns}
N	9127.59**	1866.69**	2265.98**	4946.69**
Z	173.96**	39.22**	65.12**	63.97**
N*Z	53.92**	11.34**	19.92**	19.99**
Root MSE	0.08	0.14	0.09	0.07
CV.%	1.44	2.97	2.21	1.91

Note: *Significant at the 0.05 probability level; **Significant at the 0.01 probability level; ^{ns} non-significant. Hypotheses test for Block and N using Block*N as an error term. RRY, BRY, MRY and HRY: rough rice yield, brown rice yield, milled rice yield and head rice yield, respectively. CV is for coefficient of variation, in order to be the same below.

Table 3 Mean comparison of nitrogen and zeolite main effect

t·hm^{-2}

Source	RRY	BRY	MRY	HRY
N_0	3.19Dd	2.49Dd	2.23Dd	2.08Dd
$N_{52.5}$	4.58Cc	3.6Cc	3.24Cc	3.06Cc
N_{105}	7.12Bb	5.69Bb	5.08Bb	4.78Bb
$N_{157.5}$	8.19Aa	6.58Aa	5.88Aa	5.49Aa
Z_0	5.46Bb	4.35Bb	3.89Bb	3.68Bb
$Z_{0.9}$	5.93Aa	4.68Aa	4.20Aa	3.95Aa
$Z_{0.22}$	5.94Aa	4.75Aa	4.22Aa	3.92Aa

Note: Within each column, means followed by the same small letter are not significantly different at 5% level of probability; means followed by the same capital letter are not significantly different at 1% level of probability, in order to be the same below.

Table 4 Mean comparison of interaction effects between nitrogen and zeolite application

t·hm^{-2}

	Source	N_0	$N_{52.5}$	N_{105}	$N_{157.5}$
RRY	Z_0	3.26e	4.43d	6.69c	7.45b
	$Z_{0.9}$	3.14e	4.65d	7.38b	8.53a
	$Z_{0.22}$	3.18e	4.67d	7.30b	8.59a
BRY	Z_0	2.54f	3.48e	5.38c	6.01b
	$Z_{0.9}$	2.47f	3.65de	5.83b	6.78a
	$Z_{0.22}$	2.48f	3.70d	5.87b	6.94a
MRY	Z_0	2.27f	3.10e	4.82d	5.38b
	$Z_{0.9}$	2.19f	3.29e	5.24bc	6.08a
	$Z_{0.22}$	2.21f	3.32e	5.17c	6.18a
HYR	Z_0	2.13h	2.94g	4.55e	5.11b
	$Z_{0.9}$	2.04h	3.12f	4.97c	5.68a
	$Z_{0.22}$	2.06h	3.12f	4.81d	5.70a

Note: Means followed by the same small letter are not significantly different at 5% level of probability.

In field experiment II, compared with U1, treatments of U2, CRF1 and CRF2 significantly increased the rice yield (Table 5). The influence degree of each treatment on rice yield increasing was as follows: CRF2, CRF1, U2 and U1. The function of controlled-release fertilizer (CRF) was better than that of traditional fertilizer method with urea (U). There was no significant difference between CRF1 and CRF2 on RRY. Therefore, CRF1 was recommended to increase RRY for potentials to decrease the labor and fuel for growers.

Table 5 Mean comparison of different nitrogen managements on rice yield

t·hm^{-2}

Source	RRY	BRY	MRY	HRY
U1	7.28Cc	5.76Bb	5.21Bc	4.87Bb
CRF1	7.90ABab	6.29Aa	5.61Aab	5.29Aa
U2	7.74Bb	6.24Aa	5.55Ab	5.21Aa
CRF2	8.06Aa	6.39Aa	5.75Aa	5.33Aa
Root MSE	0.10	0.10	0.08	0.09
CV/%	1.31	1.61	1.40	1.72

Note: U1, CRF1, U2 and CRF2: urea used as basal fertilization one time; urea used as basal fertilization one time with Z as controlled-released fertilizer; urea used as third-split fertilization according to the traditional fertilization method; urea used as third-split fertilization with Z as controlled-released fertilizer, respectively, in order to be the same below.

3.2 Appearance quality

In field experiment I, based on Table 6, the CA, L/W and HRR were not influenced by Z and N application. However, Z application significantly influenced the CR. Table 7 showed that $Z_{0.22}$ could apparently decrease the CR, which may lead to better rice appearance quality. In field experiment II, although treatments of CRF1 and CRF2 decreased CR, the effect was not apparent according to Table 8. Different N managements mattered little to CA, L/W and HRR.

Table 6 Analysis of variance for the effects of nitrogen and zeolite on appearance and eating quality

Source	CR	CA	L/W	HRR	PC	AC	TV
Block	1.24^{ns}	0.37^{ns}	0.27^{ns}	3.91^{ns}	1.42^{ns}	0.01^{ns}	1.57^{ns}
N	7.23^{ns}	6.16^{ns}	0.27^{ns}	1.53^{ns}	58.11**	7.58^{ns}	12.29*
Z	4.84*	4.41^{ns}	1.00^{ns}	1.92^{ns}	1.46^{ns}	7.35*	3.08^{ns}
N*Z	0.16^{ns}	0.31^{ns}	1.01^{ns}	0.74^{ns}	2.69^{ns}	4.08^{ns}	1.99^{ns}
Root MSE	1.23	0.32	0.04	1.22	0.07	0.09	1.12
CV.%	27.57	29.22	1.78	1.30	1.23	0.68	1.58

Note: CR, CA, L/W, HRR, PC, AC and TV: chalk rate, chalkiness area, length-width ratio, head rice rate of total milled rice weights, protein content, amylose content, taste value, in order to be the same below.

Table 7 Mean comparison of nitrogen and zeolite main effect

Source	CR/%	PC/%	AC/%	TV	BD/cP
N_0	4.9	5.7Bc	13.62	75.4Aa	1603Aa
$N_{52.5}$	4.8	5.8Bc	13.53	74.5Aa	1608Aa
N_{105}	4.4	6.2Ab	13.30	69.2Aab	1506ABb
$N_{157.5}$	3.8	6.4Aa	13.45	64.9Ab	1420Bb
Z_0	5.2Aa	5.99	13.38Bb	71.4	1607Aa
$Z_{0.9}$	4.8Aa	5.95	13.54Aa	70.2	1451Ab
$Z_{0.22}$	3.4Ab	6.01	13.51ABa	71.3	1546Aab

Note: The full marks of TV are 100, in order to be the same below.

Table 8 Mean comparison of different nitrogen managements on appearance and eating quality

Source	CR/%	CA/%	L/W	HRR/%	PC/%	AC/%	TV
U1	3.5Aa	1.0Aa	1.95Aa	93.9Aa	6.40Ab	13.50Aa	66.7Aa
CRF1	3.1Aa	0.8Aa	1.90Aa	94.4Aa	6.65Aab	13.45Aa	58.9Ab
U2	3.7Aa	1.4Aa	1.95Aa	94.2Aa	6.65Aab	13.05Ab	59.9Ab
CRF2	3.4Aa	1.4Aa	1.95Aa	93.1Aa	6.75Aa	13.15Ab	57.2Ab
Root MSE	0.92	0.273	0.068	0.88	0.09	0.11	1.82
CV/%	27.2	24.5	3.49	0.93	1.35	0.80	3.01

3.3 Eating quality

In field experiment I, Table 6 showed that N application significantly influenced rice PC and TV while Z application clearly influenced the AC. There was no interaction effect on PC, AC and TV between Z and N application rates. Table 7 showed that N application greatly enhanced rice PC but Z mattered little to it. Z input significantly increased the AC but mattered little to TV of rice. N inputs could clearly decrease the TV of rice. It indicated that N application had negative effects on rice TV increasing.

In field experiment II, Table 8 and Table 5 might indicate that higher rice yield could lead to a decrease in rice TV. Compared with U1, CRF1, CRF2 and U2 obviously decreased the rice TV but statistically significantly improved the PC. Compared with treatments of U1 and CRF1, treatments of CRF2 and U2 significantly decreased the AC.

3.4 Cooking quality

In field experiment I, Table 9 showed that there was no significant effect between Z and N application on MV, HPV, CPV, SEB and PT. An analysis of variance showed that N and Z treatment significantly influenced the rice quality index of BD value. Based on Table 7, it showed that both Z and N application significantly decreased the BD value and the results might lead to a decrease in rice viscosity. In field experiment II, Table 10 also showed that CRF1 and CRF2 decreased the BD value but the effect was not significant.

Table 9 Analysis of variance for the effects of nitrogen and zeolite on cooking quality

Source	MV	HPV	BD	CPV	SEB	PT
Block	1.78^{ns}	0.03^{ns}	8.71^{ns}	0.16^{ns}	3.12^{ns}	1.08^{ns}
N	3.45^{ns}	0.15^{ns}	16.46^{*}	0.34^{ns}	3.91^{ns}	3.99^{ns}
Z	1.40^{ns}	0.46^{ns}	4.53^{*}	0.14^{ns}	1.05^{ns}	3.83^{ns}
N*Z	0.32^{ns}	0.25^{ns}	0.53^{ns}	0.38^{ns}	1.06^{ns}	6.03^{ns}
Root MSE	158.36	81.00	104.55	100.26	33.02	0.16
CV/%	4.35	3.85	6.81	3.02	2.72	0.20

Note: MV, HPV, BD, CPV, SEB, PT: the max viscosity, hot paste viscosity, breakdown, cold paste viscosity, setback, pasting temperature, in order to be the same below.

Table 10 Mean comparison of different nitrogen management on cooking quality

Source	MV/cP	HPV/cP	BD/cP	CPV/cP	SEB/cP	PT/ºC
U1	3619Aa	2208Aa	1411Aa	3432Aa	1224Aa	79.6Aa
CRF1	3056Aa	2175Aa	1332Aa	3373Aa	1199Aa	80.0Aa
U2	3587Aa	2117Aa	1470Aa	3352Aa	1236Aa	79.6Aa
CRF2	3513Aa	2218Aa	1295Aa	3436Aa	1218Aa	80.0Aa
Root MSE	91.85	100.86	79.81	118.65	23.37	0.38
CV/%	2.58	4.63	5.80	3.49	1.92	0.47

3.5 Correlation analysis between taste value and main quality traits

Based on the two experiments, correlation analysis was used to test the correlation between rice main quality traits and TV. Table 11 indicated that rice TV significantly and positively related to MV and BD but negatively related to PC. Among the three items, the PC had the most significantly negative relation and the correlation coefficient was −0.94.

Table 11 Correlation analysis between taste value and other main quality traits

	PC	AC	CR	CA	HRR	MV	BD	TV
PC	1							
AC	-0.47^{*}	1						
CR	-0.37^{ns}	0.06^{ns}	1					
CA	-0.31^{ns}	0.01^{ns}	0.87^{**}	1				
HRR	-0.08^{ns}	-0.25^{ns}	0.22^{ns}	0.06^{ns}	1			
MV	-0.49^{*}	-0.03^{ns}	0.36^{ns}	0.35^{ns}	0.15^{ns}	1		
BD	-0.51^{**}	-0.08^{ns}	0.24^{ns}	0.28^{ns}	0.28^{ns}	0.91^{**}	1	
TV	-0.94^{**}	0.33^{ns}	0.33^{ns}	0.32^{ns}	0.05^{ns}	0.57^{**}	0.63^{**}	1

4 Discussion

4.1 Effects of different nitrogen managements on rice yield

Urea as an ordinary but very important fertilizer for most crops is widely used in China. The dissolved urea in soil can stimulate biomass and total N accumulation in crops such as rice[14]. Long-term excessive N application in paddy soil significantly increase rice grain yield, but lead to contamination in groundwater and decrease in soil pH[8]. CRF could be used as effective mitigation alternatives to control N supply and slow the contamination of environment. Several studies have shown that the CRF based on Z not only increased crop production but also ameliorated the unnaturally acidic soil[15,16]. Gao et al.[17] found that the N release rates from CRF synchronized the N requirement of plant and this process resulted in a great increase in crop production. Similar results were also discovered by Yang et al.[18] and showed that the CRF synchronized the requirement of N uptake at the whole rice growth stages and eventually significantly increased rice yield. Applying Z to acidic pastoral soils have been reported to shift the balance between N_2O:N_2 ratio and increase soil pH to reduce N_2O emission and increase N availability for crops growth[19]. The addition of Z under higher N application rates could lower the soil pH to enhance the content of available N, P, K and hence greatly improved crop production[20]. In this experiment, compared with U2, CRF2 could increase RRY by 14.5%-15.3% across different particle sizes of Z. Compared with U1, CRF1 significantly increased RRY by 8.5%. However, at low N application rates of N_0 and $N_{52.5}$, Z contributed little to RRY increasing. Similar impacts were also found in BRY, MRY and HRY. Some other researches indicated that CRF significantly increased the rice effective tillers although there was a decrease in rice total tillers and eventually clearly improved rice grain yield[21].

4.2 Effects of different nitrogen managements on rice appearance grain quality

Rice quality can be defined in many methods, depending on the end-use industry segment using the rice. For the appearance point, factors like discoloration, CA, CR and L/W are of complete concern[22]. In our study, both N and Z have not significantly influenced the L/W, HHR and CA. However, Z inputs significantly decreased CR. N application almost significantly decreased CR and CA (p=0.051). CR and CA were mainly affected by sink and source process during rice quality forming[23]. At N_0 and $N_{52.5}$ rates, the lack of source and unstable grain filling process may result in an increase in CR and CA. However, Z application in paddy soil that could slowly release N to meet rice plant requirement may exhibit a stable grain filling process and decrease the CR and CA[24,25]. Therefore, CRF based on Z may have the advantages to obtain better rice appearance quality.

4.3 Effects of different nitrogen managements on rice eating and cooking quality

The chemical compositions have constituted the materials of rice grain kernels. Based on 14% moisture content, many results showed that the grain kernels were composed of 76.7%-78.4% starch and 6.3%-7.8% protein[23]. And the AC and PC determined the eating and cooking quality[24]. In our research, there was no clear difference on AC with treatment of N and Z application could increase AC. Although there was a positive relation between AC and TV, but the correlation coefficient was only 0.33 (p>0.05). The results were in accord with recently related viewpoints. Scholars suggested that rice grain cooking and eating quality were determined by the proportion of amylose to amylopectin rather than by the AC only[26,27]. Compared with AC, PC was low but seemed to determine the rice eating quality[24]. The energy consumption to produce protein was more than twice than that to produce equal parts starch[28]. And, the process might lower the rice eating quality with increase of N. In this paper, N application clearly decreased eating quality. Z lowered the rice yield and PC but obtained a higher TV at N application rates from N_0 to $N_{52.5}$. At N_{105} and $N_{157.5}$ rates, Z increased the PC and rice yield but led to a decrease in TV. There was an extremely remarkably negative relation between PC and TV. The correlation coefficient was −0.94 (p<0.01). Several research results showed that TV had positive relation to rice viscosity and negative relation to rice hardness[28]. In this paper, based on the main effects analysis, Z and N application lowered the BD value and MV. There were significantly positive relation between BD value, MV and TV. The correlation coefficient were 0.63 and 0.57, respectively (p<0.01).

5 Conclusions

The results herein indicated that in field experiment I, both N and Z application significantly increased RRY, BRY, MRY and HRY. But there was no significant difference between $Z_{0.9}$ and $Z_{0.22}$. At N_0 and $N_{52.5}$ rates, there was no significant effect on RRY, BRY, MRY. At N_{105} and $N_{157.5}$ rates, both $Z_{0.9}$ and $Z_{0.22}$ distinctly improved the rice yield. The CA, L/W and HRR were not influenced by Z and N application. However, Z application significantly influenced the CR. Z input significantly increased the AC but mattered little to TV of rice. N inputs could clearly decrease the TV of rice and BD value. It indicated that N application had negative effects on rice TV increasing.

In field experiment II, the influence of each treatment on rice yield increasing was as follows: CRF2, CRF1, U2 and U1. There was no significant difference between CRF1 and CRF2 on rice yield. Therefore, CRF1 was recommended for potentials to decrease labor and fuel for growers. Compared with U1, treatments of CRF1, CRF2 and U2 obviously decreased the rice TV but statistically significantly improved the PC. Treatments of CRF2 and U2 significantly decreased the AC compared to treatments of U1 and CRF1. PC had the significantly negative relation to TV and greatly determined the rice grain eating quality and cooking quality.

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