Journal of Soil Science and Plant Nutrition, 2016, 16 (3), 637-649
RESEARCH ARTICLE

Effects of new coated release fertilizer on the growth of maize

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Abstract

Slow or controlled release fertilizers have been researched and used more and more widely, developing new slow or controlled release fertilizers is very important. To improve the use efficiency of inorganic fertilizers through the use of coated fertilizer and nitrification inhibitors, 3 newly developed fertilizers (FCRF1:coated fertilizer + 1% DCD, FCRF2: coated fertilizer + 2% DCD and FCRF3:coated fertilizer + 4% DCD) amended with nitrification inhibitors (DCD, $C_2H_4N_4$), and coated with fly ash were prepared by coating conventional compound fertilizer (N-P-K: 15-6.55-12.4). Using a coated fertilizer (resin coated compound fertilizer, N-P-K: 15-6.55-12.4, 90 day, CRF) made in China and a conventional compound fertilizer (CCF) as checks, their effects on physiological characteristics, yield and quality of maize were examined in a field experiment. The results indicated that, compared to CCF, 3 new developed fertilizers kept higher ammonium nitrogen （NH_4^+-N）and nitrate nitrogen (NO_3^--N) content at later stages and FCRF3 had the highest content, being similar to CRF treatment. At tasselling stage (TS) and filling stage (FS), the chlorophyll content, photosynthetic rate, transpiration rate and chlorophyll fluorescence parameters were significantly increased upon FCRF1, FCRF2 and FCRF3 treatments. In addition, FCRF1, FCRF2 and FCRF3 treatments produced 24.0-35.8% more grain yield, 57.2%-74.4% more total yield, increased 11.20%-49.55% starch, 61.38%-113% protein and 2.67%-9.33% Vitamine C content than CCF，respectively. This product with excellent slow release capacity, being easy to get at a low price and environment-friendly, could be especially useful in agricultural application.

Keywords: Coated fertilizer, nitrification inhibitor, fly ash, physiological characteristics, maize

1. Introduction

Slow or controlled release fertilizers have been researched and used more and more widely, which can effectively reduce nutrition loss and one important type of them is coated fertilizer. Coated fertilizers are physically prepared by coating granules of conventional fertilizers with various materials that re-

duce their dissolution rate. The release and dissolution rates of water-soluble fertilizers depend on the coating materials (Wu *et al*. 2008). As the price of organic polymer coated fertilizer was too high, some inorganic materials and aldehydes were used to make new fertilizer. Paraformal-dehyde was also used to coat compound fertilizer, and the release amount of nutrient (N, P and K) in water and soil is lower than 75% on the 30 th day compared to uncoated fertilizer, being environmentally friendly (Zhao *et al*. 2010). Other new controlled or slowed fertilizers were reported, containing such coated materials as polymer (Du *et al*. 2006), fly ash (Qiu *et al*. 2011) and superfine phosphorus rock powder (SPRP) (Hou *et al*. 2014).

Improvement in fertilizer use efficiency of inorganic fertilizers through the use of N inhibitors may play a key role in increasing productivity as well as minimizing environmental damage (Chen *et al*. 2008). Nitrification inhibitor is not a new technology, and one of the most widely used inhibitor, dicyandiamide (DCD, $C_2H_4N_4$), was shown to affect plant growth in the 1920s (McGuinn 1924). Many studies have shown that DCD can significantly decrease NO_3^- leaching and N_2O emissions from cropping systems or grazed pasture systems (Di *et al*. 2007; Jumadi *et al*. 2008; Cui *et al*. 2011), which is a common nitrification inhibitor that is naturally broken down in the soil, with no traces of residue left beyond the cropping year (Singh and Verma, 2007). DCD inhibits the first stage of nitrification, the oxidation of NH_4^+ to NO_2^- , by rendering the bacteria's enzyme ineffective (Di and Cameron, 2003). Temperature is the factor having the most influences on the effectiveness of DCD; an increase in temperature can have a negative effect on the persistence of DCD in the soil, reducing the time frame in which it can be effective at reducing nitrification (Kelliher *et al*., 2008). Selbie *et al*. (2011) reported that DCD reduced NO_3^- leaching by 45% and N_2O emissions by 70% on dairy cow urine treatments on Irish soils. Richards *et al*. (2008) also reported that DCD application on urine patches reduced NO_3^- leaching, especially on Irish soils. Zaman and Blennerhassett (2010) reported that the application of DCD to spring deposited urine increased herbage production by an average of 12%.

However, the prices of slow release or controlled release fertilizers are much higher than that of normal fertilizer, which is hard to be accepted by farmers (Yan *et al*. 2008), and the coated fertilizer had other disadvantage such as complex making process, long degradation time and polluting the environment (Sartain *et al*. 2003). Fly ash as inorganic material was used to coat compound fertilizer, but the homemade fertilizer still never had more perfect effect than resin coated one (Qiu *et al*. 2011).

Moreover, coated fertilizers especially with inorganic material as coated material amended nitrification inhibitor to increase crop growth have been reported rarely. This paper studied physiological characteristics, yield and quality of maize under fly ash coated fertilizer amended with different added amount of DCD. The objective of this study was to find an effective coated fertilizer amending with appropriate DCD addition for improving maize growth and explore new style of nitrification inhibitor application.

2. Materials and Methods

2.1. Preparation of new developed fertilizer

Common compound fertilizer was used as core material, and the main coated material was fly ash. The common fertilizer was coated with fly ash, polyving akohol (one kind of organic binder bond) and so on,

which were all passed through a 0.1 mm sieve and determined for water release trial. The newly developed fertilizer was made by disk granulation. A disk granulator mainly included a disk with a diameter of 80 cm, a power motor of 0.55 kW, a governor, and stand composition (Figure 1). Coated materials accounted for 25% of the total mass, and fly ash (The fly ash took from thermal power plant of Tai'an city of Shandong province. Some physical properties of the fly ash, as follow: Bulk density (0.82 $g \cdot cm^{-3}$); Density (1.84 $g \cdot cm^{-3}$); Water content (0.17%); Panicle composition (1.00~0.05 mm: 245.86 $g \cdot kg^{-1}$; 0.05~0.01 mm: 468.84 $g \cdot kg^{-1}$; 0.01~0.005 mm: 220.36 $g \cdot kg^{-1}$; 0.005~0.001 mm :42.10 $g \cdot kg^{-1}$; <0.001 mm :22.84 $g \cdot kg^{-1}$). Some chemical properties of the fly ash, as follow: Total N (0.09 $g \cdot kg^{-1}$); Available N (15.30 $mg \cdot kg^{-1}$); Total P (1.90 $g \cdot kg^{-1}$); Available P (94.85 $mg \cdot kg^{-1}$); Total K (1.61 $g \cdot kg^{-1}$); Available K (173 $mg \cdot kg^{-1}$) ; Fe (2635 $mg \cdot kg^{-1}$); Zn (23 $mg \cdot kg^{-1}$); Cu (16 $mg \cdot kg^{-1}$); Cd (5.6 $mg \cdot kg^{-1}$); Pb (46 $mg \cdot kg^{-1}$) was added by 15% of the total mass. The adding rate of DCD was 1%, 2% and 4% of total coated fertilizer (w/w), respectively (Xu *et al*. 2002; Zhao *et al.* 1993). The newly developed fertilizer contained 24% coated materials +75% conventional compound fertilizer (N-P-K: 15-6.55-12.40) +1% dicyandiamide (FCRF1), 23% coated materials +75% conventional compound fertilizer (N-P-K: 15-6.55-12.40) +2% dicyandiamide (FCRF2) and 21% coated materials +75% conventional compound fertilizer (N-P-K: 15-6.55-12.40) + 4% dicyandiamide (FCRF3).

Figure 1. Disk granulator used to make the newly developed fertilizer.

2.2. Plant and fertilizer material and growth conditions

A field experiment was conducted on alfisol (named in The USDA-NRCS soil taxonomy nomenclature) during the growing season of maize in 2011 at College of Resources and Environment, Shandong Agricultural University, China. The topsoil (0-20 cm) had an EC of 197.1 μS cm^{-1} (soil water ratio 1:5), and contained 14.1 g kg^{-1} organic matter, 0.622 g kg^{-1} total nitrogen, 46.5 mg kg^{-1} available nitrogen, 22.5 mg kg^{-1} available phosphorus, 106.1 mg kg^{-1} available potassium. Maize *(Zea mays)* (Wuyue 206) was used.

Treatments consisted of 6 treatments: CK (a control without fertilizer), CCF (common compound fertilizer, N-P-K: 15-6.55-12.40), CRF (resin coated compound fertilizer, N-P-K: 15-6.55-12.40, 90 day,), FCRF1, FCRF2 and FCRF3. All fertilization treatments received the same amount of N (150 kg ha^{-1}), P (65.50 kg ha^{-1}) and K (123.97 kg ha^{-1}) at sowing. All fertilization treatments were applied with maize sowing once. The experiment was conducted in a 12 m^2 plot (10 m × 1.2 m) with completely randomized block design and 3 replications. Each plot had two rows 40 cm apart and each plant was 30 cm apart. There was a 20 cm wide ditch between the plots. Maize was sown on April 28, 2 granules per hole and each plot kept 1 better seeding. Plants were harvested on August 20. The measures of pest control and other management were same with the local field.

2.3. NH_4^+-N and NO_3^--N content measurement

A 50 mm diameter auger was used to collect the soil sample. At the maize stages of tasselling stage (TS), filling stage (FS) and maturity stage (MS), three composite soil samples were collected from all plots at depths of 0 to 20 cm. Three replicates of 10 g (fresh weight) portions of soils were extracted with 50 mL 2 mol /L KCl for 30 min to determine the concentrations of mineral N (including NO_3^- and NH_4^+) using a continuous-flow analyzer (Soil Science Society of China 1999, NADA, 2015).

2.4. SPAD index (chlorophyll relative content), net photosynthetic rate（Pn）, transpiration rate（Tr）measurement and determination of chlorophyll fluorescence

Three to five plants per plot were measured. A portable chlorophyll meter (SPAD502) was used to determine SPAD index throughout the growing season such as joining stage (JS), tasselling stage (TS), filling stage (FS) and maturity stage (MS), leaves in the upper part of the plants.

By using photosynthesis system (CIRAS-2, UK), the young leaves were selected to measure Pn and Tr between 9:00-10:00 AM at 4 stages. Chlorophyll fluorescence was measured with a pulse amplitude modulated system (model FMS2, Hanseatic Instruments, UK) according to Burzyriski and Klobus (2004).

2.5. Agronomic characters and plant yield measurement

At the physiological mature stage of maize, two adjacent rows in the middle of each replication were harvested (area = 5 m × 1.2 m). Five plants were selected at random in the harvested plants, and then divided into grains and stover (including stalk, leaves, husks and cob), and weighed separately.

The organ samples were put into oven to deactivate enzymes at 105 °C for 30 min, and then oven-dried at 80 °C for 72 h to determine dry matter yield.

After that, the agronomic characters (Rows per ear, Kernels per row, Ear length, Kernels per ear, 1000-kernel weight, Bulk density) of maize were measured separately.

2.6. Protein, oluble ugar, tarch, and vitamine C contents assay

Soluble sugar and Vitamine C in the maize were all analyzed in fresh plant samples. Grain protein concentration was calculated as N contents ×5.7. Water-soluble sugars were determined using the gravimetric Fehling's method, anthrone colorimetry method was adopted to measure the contents of starch, and VC was extracted with 0.22 M oxalic acid and analyzed by the 2,6-dichlorophenolindophenol sodium salt titrimetric method (Williams., 1984, Milošević. 2015).

2.7. Data analysis

The Tukey's test was used to test the effect of different treatments, and the least significant difference (LSD) was calculated to compare the differences between means in each treatment, correlative analysis using the SPSS software (SPSS 11.5).

3. Results

3.1. NH_4^+-N and NO_3^--N contents

As shown in Figure 2, compared to control, the other fertilization treatments variously increased NH_4^+-N and NO_3^--N content. At TS, the NH_4^+-N content of CRF was largest, whereas after that the NH_4^+-N content increased significantly in all treatments, especially at FS, the content of all coated fertilizer were in trend of FCRF3>FCRF2>CRF>FCRF1. At MS, the NO_3^--N content of all treatments were largest, while at FS, the critical stage, the content of all coated fertilizer treatments were in trend of FCRF3>CRF>FCRF2>FCRF1.

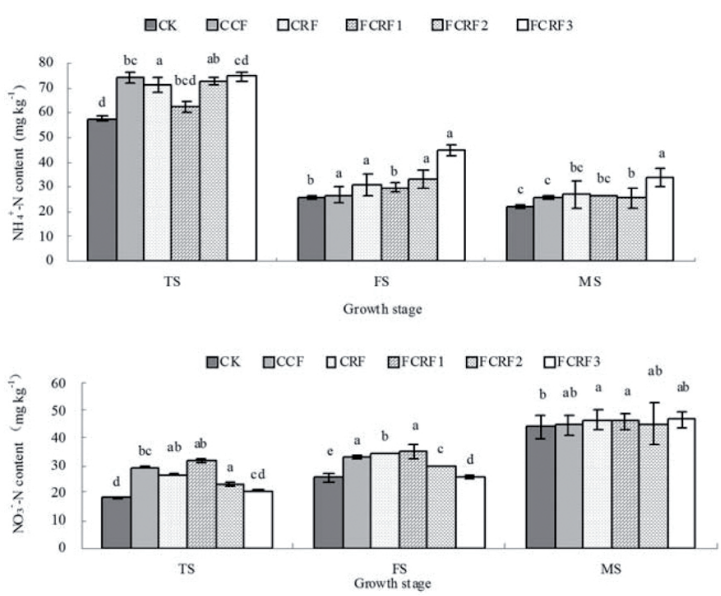

Figure 2. Effects of different fertilization treatments on NH_4^+-N and NO_3^--N contents of soil. The Tukey's test was used to test the effect of different treatments, and the least significant difference (LSD) was calculated to compare the differences between means in each treatment. Values are the means ± SD of three replicates. The values followed by the different letter show statistically significant differences at $P<0.05$.

3.2. SPAD index

Fertilizer type affected *SPAD index* differently at the sampling times (Table 1). Compared to CK, the other fertilization treatments increased the *SPAD index* of maize by a certain extent. At MS, FCRF1, FCRF2 and FCRF3 treatments had 29.38%, 27.73%, 27.49% higher content compared to CCF, even higher than CRF.

Table 1. Effects of different fertilizer treatments on SPAD index of maize leaves

Treatments	Joining stage	Tasselling stage	Filling stage	Maturity stage
CK	41.9±2.3c	46.0±0.3c	44.4±2.2d	36.0±2.8d
CCF	48.1±1.8ab	49.1±1.8bc	51.7±3.0c	42.2±1.6c
CRF	47.8±1.8ab	52.9±3.8ab	55.7±0.2ab	46.2±1.0b
FCRF1	49.7±1.3a	53.1±3.0ab	58.8±1.5a	54.6±1.6a
FCRF2	45.2±0.4bc	52.0±2.3ab	58.4±1.9a	53.9±2.5a
FCRF3	46.6±4.7ab	54.6±3.0a	54.4±0.7bc	53.8±1.7a

Notes: The Tukey's test was used to test the effect of different treatments, and the least significant difference (LSD) was calculated to compare the differences between means in each treatment.Values are the means ± SD of three replicates. The values followed by the different letter show statistically significant differences at P＜0.05.

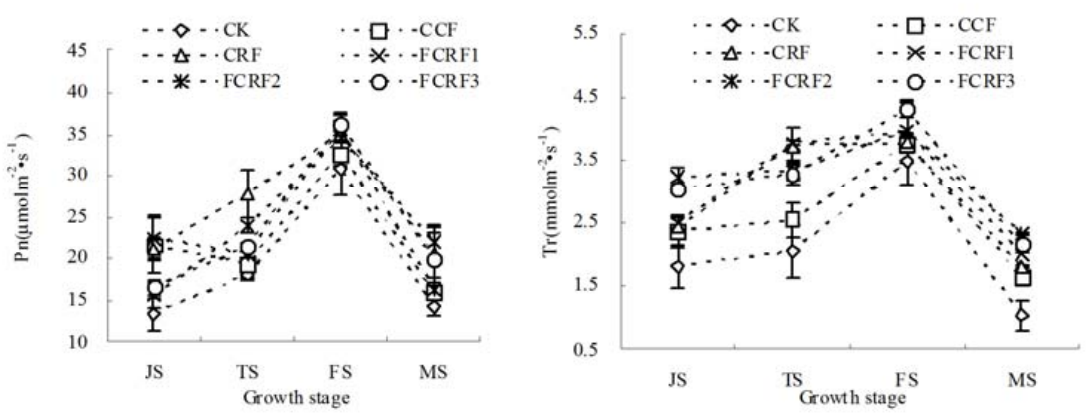

Figure 3. Effects of different fertilization treatments on net photosynthetic rate and transpiration rate of maize leaves. The Tukey's test was used to test the effect of different treatments, and the least significant difference (LSD) was calculated to compare the differences between means in each treatment. Values are the means ± SD of three replicates. The values followed by the different letter show statistically significant differences at P＜0.05.

Table 2. Effects of different fertilizer treatments on chlorophyll fluorescence parameters of maize leaves (Filling stage)

Treatments	Fo	Fm	Fv/ Fm	ΦPsII	qP	NPQ
CK	52.5±0.5c	258.5±1.5e	0.79±0.01b	0.57±0.08b	0.69±0.12c	0.71±0.16a
CCF	56.0±4.0bc	288.0±8.0d	0.80±0.01ab	0.62±0.06ab	0.89±0.05ab	0.51±0.08b
CRF	56.0±1.0bc	304.5±8.5c	0.82±0.00a	0.67±0.04a	0.83±0.08bc	0.26±0.01c
FCRF1	77.5±1.5a	326.5±6.5b	0.81±0.01ab	0.63±0.01ab	1.01±0.14a	0.53±0.06b
FCRF2	55.5±3.5c	307.5±3.5c	0.81±0.01ab	0.61±0.00ab	0.84±0.00b	0.51±0.05b
FCRF3	61.0±4.0b	348.5±3.5a	0.82±0.01a	0.69±0.02a	0.89±0.02ab	0.28±0.00c

Notes: The Tukey's test was used to test the effect of different treatments, and the least significant difference (LSD) was calculated to compare the differences between means in each treatment. Values are the means ± SD of three replicates. The values followed by the different letter show statistically significant differences at $P<0.05$.

3.3. Net photosynthetic rate (Pn) and transpiration rate (Tr)

There were significant differences in Pn and Tr in maize leaves in different treatments (Figure 3). From Fs to MS, Pn was decreased by a certain extent and was similar to the change of chlorophyll content (Table 1). This was due to chlorophyll was a limitation factor which affected photosynthesis, and had a good correlation with photosynthetic performance. The CCF treatment showed the highest at Js stage, but it became the lowest at the other three stages. Compared to CCF, Pn decreased slowly in the other coated fertilizer treatments, especially at later stages. At FS, FCRF1, FCRF2 and FCRF3 treatments promoted net Pn by 5.98%, 9.14% and 11.33% than treatment with CCF, and there were no significant difference between all these coated fertilizers; at MS, FCRF1, FCRF2 and FCRF3 increased Pn by 38.40%, 2.36% and 25.13% than CCF. This revealed under coalition of coated materials and nitrification inhibitor, homemade fertilizers made the nutrient gradually release to soil, and it furthermore affected Pn.

AS shown in Figure 3, fertilization increased Tr significantly, and the value of all treatments increased firstly and decreased later, the Tr was largest at FS, being similar to chlorophyll content and Pn (Table 1, Figure 3).

CCF increased Tr at TS, however, FCRF1, FCRF2 and FCRF3 increase Tr at later stages. They improved it by 5.03%, 5.42% and 14.02% at FS and 22.12%, 40.61% and 30.61% at MS compared to CCF.

3.4. Chlorophyll fluorescence parameters

Growth-dependent variations in the maximum quantum yield of PSⅡ photochemistry (Fv/Fm), actual efficiency of photochemical energy conservation in PSⅡ under steady-steady (light) conditions（ΦPSⅡ）, photochemical quenching coefficient Qp in response to different fertilizer treatments for leaves of maize were presented in Table 2.

Fertilization increased Fo and Fm value. FCRF1, FCRF2 and FCRF3 had higher Fo value than CCF, which increased by 13.37%, 6.77% and 21.01%.

Moreover, they increased Fv/Fm, ΦPSⅡ and Qp respectively, but decreased NPQ (Table 2).

3.5. Effects of different fertilizer treatments on agronomic characters

Fertilization significantly increased kernels per row and kernels per ear than CK (Table 3). Moreover, FCRF1, FCRF2 and FCRF3 had higher kernels per row and kernels per ear than CCF and CRF, and FCRF2 significantly increased kernels per ear than CCF. The weight per 1000-kemel of maize were in a trend of FCRF1>FCRF2>FCRF3>CRF>CCF>CK. Furthermore, fertilization increased bulk of maize significantly, especially in CRF, FCRF1 and FCRF2 treatments.

Table 3. Effects of different fertilizer treatments on agronomic characters of maize

Treatments	Rows per ear (No./Plant)	Kernels per row (No./Plant)	Ear length (No./Plant)	Kernels per ear (No./Plant)	1000-kernel weight (g)	Bulk density (g L^{-1})
CK	13.0±1.3b	20.3±4.2c	15.2±2.6d	264.5d	251.0c	614.2b
CCF	14.2±0.4ab	27.2±2.5b	17.7±0.9cd	387.0c	276.9bc	650.2b
CRF	15.4±1.2a	31.3±1.3b	20.2±0.3bc	480.1bc	284.4abc	700.1a
FCRF1	15.3±0.7a	39.1±4.0a	22.5±2.5ab	601.3a	335.1a	714.0a
FCRF2	14.7±1.5ab	39.4±4.1a	23.2±1.0a	576.4ab	325.7ab	715.9a
FCRF3	13.9±1.5ab	38.5±1.4a	22.4±0.4ab	536.1ab	311.9ab	660.7ab

Notes: The Tukey's test was used to test the effect of different treatments, and the least significant difference (LSD) was calculated to compare the differences between means in each treatment. Values are the means ± SD of three replicates. The values followed by the different letter show statistically significant differences at $P<0.05$.

3.6. Effects of different fertilizer treatments on yield

Coated fertilizers improved pod yield and total yield significantly (Table 4). The pod yield of maize were in trend of FCRF3>CRF>FCRF2>FCRF1>CCF>CK, and fertilization significantly increased grain yield by 21.9%-65.5% than CK, FCRF1, FCRF2 and FCRF3 increased grain yield by 24.0%, 31.4% and 35.8% than CCF.

Compared to CCF, FCRF1, FCRF2 and FCRF3 improved total yield by 57.2%, 64.6% and 74.4% , especially FCRF3 showed more obvious effect than CRF.

3.7.Effects of different fertilizer treatments on quality

Compared to CK, fertilization can improve starch, fat, protein, soluble sugar, and vitamin C (Table 5). Fertilization increased starch in grain by 18.12%～76.65%, FCRF2 and FCRF3 had more obvious effect on starch, fat and protein content.

Though fertilization increased soluble sugar content, it showed no significant difference in different treatments. While fertilization increased vitamin C by 3.45%-15.86%, especially FCRF1, FCRF2 and FCRF3 increased it by 6.00%, 2.67% and 9.33% than CCF (Table 5). In a word, FCRF1 did the best effect on fat, while FCRF2 and FCRF3 had more beneficial effect on other quality of maize.

Table 4. Effect of different fertilizer treatments on yields of maize

Treatments	Grain yield (kg hm^{-2})			Total yield (kg hm^{-2})		
	Yield (kg/hm^2)	Compare to CK (±%)	Compare to CCF (±%)	Yield (kg/hm^2)	Compare to CK (±%)	Compare to CCF (±%)
CK	4685.0d	—	—	16658.3e	—	—
CCF	5710.5c	21.9	—	33354.2d	18.3	—
CRF	7621.7ab	62.7	33.5	50725.4c	38.4	17.0
FCRF1	7078.6b	51.1	24.0	68171.6b	86.0	57.2
FCRF2	7504.8ab	60.2	31.4	71379.4b	94.7	64.6
FCRF3	7753.9a	65.5	35.8	83938.6a	106.2	74.4

Notes: The Tukey's test was used to test the effect of different treatments, and the least significant difference (LSD) was calculated to compare the differences between means in each treatment. Values are the means ± SD of three replicates. The values followed by the different letter show statistically significant differences at $P<0.05$.

Table 5. Effects of different fertilizer treatments on quality of maize

Treatments	Starch (%)	Fat (%)	Protein (%)	Soluble sugar (mg g^{-1})	Vitamine C (mg kg^{-1})
CK	17.99±3.14d	9.35±0.51d	1.74±0.58c	70.23±1.85c	14.50±0.50c
CCF	21.25±0.65cd	9.64±0.39bcd	2.46±0.44c	77.65±4.17ab	15.00±0.60bc
CRF	24.70±2.51b	9.91±0.13abc	4.33±0.66b	76.31±6.24abc	16.80±1.20a
FCRF1	23.63±0.52bc	10.22±0.10a	3.97±0.29b	77.42±4.14abc	15.90±0.50abc
FCRF2	26.60±1.98b	10.08±0.24ab	4.29±0.44b	73.29±2.04bc	15.40±0.60abc
FCRF3	31.78±0.49a	9.55±0.09cd	5.26±0.01a	81.99±4.61a	16.40±1.60ab

Notes: The Tukey's test was used to test the effect of different treatments, and the least significant difference (LSD) was calculated to compare the differences between means in each treatment. Values are the means ± SD of three replicates. The values followed by the different letter show statistically significant differences at $P<0.05$.

4. Discussion

The main obstacle of the resin-coated CRF is the greater coating cost than CCF and FCRF fertilizer used in this experiment, which has prevented their extensive use in agricultural fields (Yang *et al*., 2012). Recently, a new CRF coated with Inorganic materials is being extended to farmers in China because of its low cost and ease of application (Hou *et al*., 2014). The main coating material is fly ash, a kind of industrial waster. Because of unique characteristics, the full dose of this FCRF can be provided in a single dose during the maize growing season. Because of this new FCRF's relatively low cost, its very low labor requirement, and its placement as fertilizer prills commingled with the seeds, it has the potential to be used extensively in the future production of maize and other cereal crops.

This study showed that coated fertilizers with inorganic materials amended with nitrification inhibitors increased inorganic nitrogen (NH_4^+-N and NO_3^--N) content in soil especially at TS and PS stages of maize (Figure 2). Nitrification inhibitors reduced nitrate losses in subsurface drainage or leachate by retaining N in the form of NH_4^+-N (Randall *et al*. 2003; Di and Cameron 2005), so inorganic nitrogen in soil can

be lowered and the loss of ammonia by volatilization would be reduced. FCRF3, to be similar to CRF, had the higher inorganic nitrogen compared to other fertilization. It's found that the combination of coating material and nitrification inhibitors had more significant effects of keeping higher nitrogen content at later stages. Jiao *et al*. (2004) and Chen *et al*. (2005) indicated the DCD combination decreased the soil activity of urease that restrained the oxidation of urea hydrolysis, which was similar to our results. Moreover, it's helpful in that SPRP or the fly ash as coated material had controlled release effect at some degree (Hou *et al*. 2012; Qiu *et al*. 2011).

Fertilization increased SPAD index in comparison to CK, and coated fertilizers with inorganic material amended with nitrification inhibitor increased more (Table 1). SPAD index can be used to monitor leaf N status, and guide fertilizer-N timing on rice, cotton, oil seed rapes (Peng *et al*. 2002; Zhu *et al*. 2006; Wood *et al*. 1992). That indicated the combination of coated material and physiological inhibitor can improve nutrient release effectively. What's more, FCRF2 and FCRF3 also increased Pn and Tr in leaves of maize at later stages, compared to CCF or FCRF1 (Figure 3). A similar observation was made by Haghighi *et al.* (2010), on corn from effects of biological fertilizer. The results also similar with Lone and Khan (2007), which showed that fertilizer treatment accounts for 40-60% increases in crop yields with the main mechanisms driven by nutrition involving plant photosynthesis, respiration and physical synthesis.

Furthermore, coated fertilizers with inorganic material amended with nitrification inhibitor increased chlorophyll fluorescence parameters at different degree (Table 2). Chlorophyll fluorescence parameters are sensitive, convenient, and non-intrusive indicators in studying photosynthetic regulation and responses to the environment of plants (Schreiber *et al*. 1995), and larger values of Fv/Fm indicate the higher energy capture efficiency of PSⅡ reaction center (Xu *et al*. 2002); the higher level of ΦPSⅡ indicates the strong electron transport ability of the photosynthetic apparatus and the larger proportion of absorbed light energy to be used for photochemical reaction (Genty *et al*. 1989); the qP is an indicator of the open proportion of PSⅡ reaction center (Maxwell and Johnson 2000). The well situation above also indicated the nice effect on maize growth existed at various aspects. Moreover, fertilization can increased chlorophyll fluorescence parameters compared to CK, which was in agreement with findings of Zhao *et al*. (2011).

The results of this study showed that, almost all kinds of agronomic characters of maize were in a trend of FCRF3>FCRF2>FCRF1>CRF>CCF>CK (Table 3 and Table 4). Different fertilizers or fertilization methods have different effects and mechanisms on crop growth (Elkoca *et al*. 2008; Samiullah *et al*. 1996). Application of DCD is a nitrification inhibitor and the promoting effect on growth of crop has been reported (Arshad et al. 1999; Reeves and Touchton 1989). Moreover, fertilization can improve crude fat, protein, soluble sugar, and decrease NO_3^--N content in different degree (Table 5), which was similar to the agronomic characters (Table 5). Fertilization increased nitrate content in crops compared with control, as found by various researchers, who studied the NO_3^--N content in cabbage (Turan and Sevimli 2005), Chinese cabbage and spinach (Chen *et al*. 2004), which were different to our results. The reason may be greengrocery is more sensitive to nitrogen and has inferior nitrogen assimilation than other crops like maize. The grain yield of maize were in trend of FCRF3>CRF>FCRF2>FCRF1>CCF>CK, CRF and FCRF3 significantly increased protein compared to CCF (Table 5). That indicated the combination of coating and nitrification inhibitor can make nutrient release more reasonably for maize growth, which had similar effect compared to CRF.

5. Conclusions

Inorganic materials as membrane has some obvious advantages than organic polymer. Fly ash as a membrane has obvious advantages: firstly, it reduces nutrient loss and improves maize yield; secondly, it can be used as a micronutrients fertilizer and easy to decompose after applying into soil, so it could be also beneficial to environment without extra expenses. Thirdly, it can be widely applied for all farmland and crops and needs the unrestricted production equipment and relative simple techniques. By amending physiological inhibitors, the newly developed urea had more perfect effects than CCF. In this study, FCRF3 had the best effects, being similar to organic polymer coated fertilizer (CRF), while keeping the advantages of inorganic materials.

Acknowledgements

This work was financially supported by the Chinese National Basic Research Program (2015CB150404) and the Bohai sea granary engineering saline and alkaline land use program (75030).

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