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Nutrient uptake, pH changes and yield of rice under slow release sulfur-coated urea fertilizers

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Abstract

Utilization of coated and uncoated urea fertilizers have impact on nutrient uptake, pH changes and nitrogen (N) release in tropical rice flooded soils, especially when coated with sulfur. Different coated fertilizers such as wax sulfur coated urea (WSCU), polymer coated sulfur coated urea (PCSCU), and uncoated fertilizers [urea, urea + sulfur (6% and 17%)] were applied on rice crop @ 60 and 120 N kg ha^{-1} as basal and split doses, respectively. The yield components of rice, nitrogen and sulfur concentration and their uptake in grain did not improve through the application of urea coated polymer and wax fertilizers. These fertilizers had no significant effect on soil content such as sulfur, nitrogen and soil pH. The results show that sulfur coated and slow release fertilizers are not effective in increasing rice yield and N uptake.

Keywords: Rice, coated fertilizer, release, nutrient, sulfur, soil, pH.
Abbreviations: MOP_muriate of potash; PCSCU_polymer coated sulfur coated urea; TSP_triple super phosphate; WSCU_wax sulfur coated urea, N_nitrogen; S_sulfur.

Introduction

Rice (*Oryza sativa* L.) is widely grown in tropical and subtropical regions (Singh et al., 2012) and is one of the main staple foods for nearly two-thirds of the population of the world (Roy et al., 2012). In rice, concerns about fertilizer management practices and nutrient nitrogen release are increasing. This is due to leakage of N fertilizers which contaminate the ground and surface water sources as well as degrade soils and environment. It has been observed that differences in yield after application of different fertilizers are related to N losses through volatization. denitrification and mobilization of N (Carefoot et al., 1990). This depends on the degree of contact between fertilizer, root and soil moisture levels. Lower recovery of N has been attributed to gaseous loss of N and immobilization of N with surface application of nitrogenous fertilizer (Rice and Symth, 1994). Among methods of N fertilizer application, split application is a common practice for higher crop yields, nitrogen use efficiency without potential leaching and run-off losses (Randall and Schmitt, 1998, PARC, 2005). Lammel (2005) claimed that a sigmoid pattern of nutrient supply could be obtained by applying N fertilizer during plant growth in several split applications. Similarly, application of the whole N fertilizer through conventional methods uses large amounts of fertilizer in the early growth stages and too little at later stages. This practice has greater chances of nutrient losses (Achilea et al., 2005). However, Lammel, (2005) claimed that nutrients should remain in excess amount in soil for the next crop especially phosphate and, to a lesser extent, potash. With mineral N, any surplus remaining in soil at harvest is likely to be lost by leaching and denitrification. In this situation, the use of slow release fertilizers could decrease nutrient losses by enhancing nutrient use efficiency.

The application of controlled-release or slow release fertilizers may reduce N losses and toxicity, particularly to young seedlings 4. It causes specific damage to plants at different sensitive growth stages. They may also reduce lodging and injury from ammonium ions. Thus, controlled-release fertilizers, especially those that release nutrients in a sigmoidal pattern, can contribute to improved agronomic safety (Shaviv, 2005; Shoji, 2005). The slow release fertilizers make it possible to meet the full nutrient requirements of crops and multiple cropping by making a single fertilizer application and subsequently soil built up of nutrients.

Urea management is critical to minimize potential N loss, especially through ammonia volatilization which has been shown to account for 20 to 80% of N loss in rice production (Griggs et al., 2007; Norman et al., 2009). The toxicity, plant nutrient uptake improvement, nutrient loss, particularly leaching of nitrate-N and volatilization of ammonia could be reduced through many standard coated fertilizers. Controlled-release fertilizers make it possible to meet the full nutrient requirements of crops and multiple cropping by making a single or split fertilizer application which substantially decreases the risk of environmental pollution (Zhang et al., 2001; Shaviv, 2005; Shoji, 2005). Their use also contributes to a reduction in N_2O emissions in the environment (Chu et al., 2004).

A reasonably good prediction of nutrient release is possible with controlled-release fertilizers coated with hydrophobic materials, particularly polymer-coated fertilizers because they are less sensitive to soil and climatic conditions (Shaviv, 2005; Shoji, 2005).

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Therefore, in fertilizer management programmes and high technology farming systems, these fertilizers are useful in multiple cropping.

Rice has completely different soil-N fertilizer requirement than other crops (Allen, 1984; Bouldin, 1986). In flooded soils, urea has greater N losses through denitrification, and loss of ammonia-N in to the atmosphere (Fillery et al., 1986; IFA, 1992). The rapid urea hydrolysis creates high ammonium-N concentrations in the floodwater, and potentially large volatilization losses appear when weather conditions facilitate the removal of ammonia from the water-air interface (Byrnes et al., 1989). These losses could be minimized through slow release urea coated fertilizers. These fertilizers need comprehensive documentation of ammonium and pH changes in soil as well as nutrient uptake and yield of rice.

Results and Discussion

Effect of fertilizers on plant height (cm)

The taller plants were recorded for the treatments receiving sole urea, polymer and wax coated fertilizers, or urea + sulfur (without coating) @ 120 N kg ha^{-1} across fertilizer application time. However, shorter rice plants were observed due to the effect of lower rates of PCSCU and WSCU fertilizers @ 60 N kg ha^{-1} across application timing (Table 1). Plant height revealed the overall vegetative growth of the crop in response to N management practices. It has been widely reported that understanding N fertilizer response in rice can help producers to effectively manage N for high rice productivity while using different N sources. The increase in plant height in response to application of N fertilizers is probably due to enhanced availability of adequate nitrogen (120 kg N ha^{-1}) and assimilates, which enhance plant growth (Indira, 2005; Chaturvedi, 2005). Irshad et al. (2000) reported that plant height significantly increased by nitrogen application. Dastan et al. (2012) reported that plant height showed significant effect with nitrogen treatment. In this study, no significant differences was found in plant height due to fertiler timing. However, Islam et al. (2009) observed that the effect of split application of N fertilizer on plant height appeared to be considerable at 65 and 90 DAT, while it was statistically negligible at the maturity.

Effect of fertilizers on tillers plant^{-1} (no.)

This is an important yield component because; the final yield is mainly a function of the number of panicles bearing tillers per unit area (Baloch, 2006). Maximum tillers $plant^{-1}$ were recorded in the plots where urea, PCSCU, WSCU, and urea + sulfur (17%) without coating @ 120 N kg ha^{-1} applied. All these treatments had non-significant differences with each other. Application time viz. split and basal had non-significant effect in tiller number. However, minimum tillers $plant^{-1}$ were observed in the lower application rate @ 60 N kg ha^{-1}. The tillers $plant^{-1}$ was more responsive to 120 N kg ha^{-1}, whether applied in split or as basal. This indicates that adequate amount of N to rice increased number of tillers (Table 1). Chaturvedi (2005) also reported more tiller number due to the more availability of nitrogen in the soil.

Effect of fertilizers on panicles plant^{-1} (no.)

More panicles was found in all urea sulfur- coated fertilizers (PCSU and WSCU) and urea @ 120 N kg ha^{-1} applied as split or basal.

However, the decrease in the rate of these fertilizers (60 N kg ha^{-1}), significantly decreased panicle production. The application of U + S (6%) and U + S (17%) without coating @ 120 N kg ha^{-1} recorded the 2^{nd} lowest number of panicles among the treatments (Table 1). In rice, to obtain higher number of larger panicles, it is recommended that N should be applied in sufficient amount (Peng et al., 1998). Nitrogen is required by rice plants during the vegetative stage to promote growth and tillering, which determines the potential number of panicles (Mae, 1997). Given the importance of N fertilization for enhancement of panicles, it is necessary to know the best urea source and its application time (Jan et al., 2010). Nitrogen fertilizer sources, levels and application time have significant role in determining plant's fertilizer uptake as well as distribution in soil and plant (Kichey et al., 2007). According to Assefa et al. (2009) sulfur containing fertilizers may be good source for higher panicle number in rice crop.

Effect of fertilizers on panicle length (cm)

The higher panicle length was obtained with the application of urea, PCSCU, WSCU, U+S (6%), U+S (17%) without coating @ 120 N kg ha^{-1} across application times. Reducing N @ 60 kg ha^{-1}, significantly lowered panicle length in all fertilizer treatments. Similarly, Abd El-Maksoud (2008) found non-significant results for rice panicle length under the effect of N fertilizers applied in basal or split (Table 1). The panicle length obtained @ 120 N kg ha^{-1} was compatible with Witt et al. (2007) who reported that N absorbed at sowing, tillering and panicle initiation stage of rice ensured a sufficient panicle length. Metwally et al. (2011) also found significantly greater panicle length due to the role of nitrogen in crop maturation, flowering and seed formation.

Effect of fertilizers on 1000 grain weight (g)

There were no statistical difference between basal and split N applications; however, N rates had significant differences for 1000 grain weight. Across N sources and application time, the higher 100 grain weight (20.0 to 22.6 g) was obtained from urea, PCSCU, WSCU, U+S (6%), U+S (17%) without coating @ 120 N kg ha^{-1}. Availability of nutrients and better plant growth might be the reason for heavier grain with 120 N kg ha^{-1} (Table 1). Generally, grain weight is a genetically controlled trait, which is greatly influenced by environmental conditions prevailing during the process of grain filling (Kausar et al., 1993). Metwally et al. (2011) reported that increase in 1000 grain weight was due to sufficient amount of nitrogen in the soil. Thus, adequate N rate is needed for higher weight of grain (Hirzel et al., 2011).

Effect of fertilizers on straw yield

The maximum straw yield was found from PCSCU, WSCU, U+S (6%), U+S (17%) without coating @ 120 N kg ha^{-1} fertilizers; applied as basal or split (Table 1).

Table 1. Yield components and yield of rice grain as affected by different coated and uncoated urea fertilizers.

	Plant height (cm)	Tillers plant^{-1}	Panicles plant^{-1}	Panicle length (cm)	1000 grain weight (g)	Straw yield (ton/ha)	Grain yield (ton/ha)
Urea (Control)120kg/ha (split)	88.7 a	12.2 a	12.2 a	30.0 a	21.5 a	8.4 b	5.3 a
PCSCU 60 kg/ha (basal)	76.6 d	9.5 b	9.0 b	27.3 b	18.8 c	7.8 cd	3.4 ab
PCSCU 60 kg/ha (split)	73.7 c	9.1 b	8.6 c	27.9 b	18.4 c	8.1 b	3.5 ab
PCSCU 120 kg/ha (basal)	87.9 a	12.4 a	12.3 a	29.1 ab	19.0 bc	9.1 a	4.8 a
PCSCU 120 kg/ha (split)	85.2 a	12.2 a	12.1 a	26.2 bc	20.0 ab	9.9 a	4.7 a
WSCU 60 kg/ha (basal)	83.2 ab	7.9 c	7.7 c	27.1 b	18.5 c	8.1 b	3.4 ab
WSCU 60 kg/ha (split)	73.0 c	11.6 ab	11.6 ab	26.8 bc	19.4 bc	7.8 cd	3.5 ab
WSCU 120 kg/ha (basal)	87.6 a	12.5 a	12.2 a	29.1 ab	21.2 a	9.3 a	4.6 a
WSCU 120 kg/ha (split)	86.0 a	12.8 a	12.4 a	27.5 b	22.6 a	8.2 b	5.3 a
Urea + sulfur (6%) without coating + 120 kg/ha (split)	85.6 a	10.3 ab	10.1 ab	31.2 a	19.5 bc	9.5 a	5.1 a
Urea + sulfur (17%) without coating +120 kg/ha (split)	86.7 a	12.1 a	11.6 ab	28.6 ab	20.1 ab	9.6 a	5.2 a
LSD (5%)	3.01	1.9	2.16	2.45	2.14	1.13	1.21

In each column, means followed by a common letter do not differ significantly through LSD test, $p>0.05$.

Table 2. Nitrogen and sulfur content and uptake in rice plants under the influence of different coated and uncoated urea fertilizers.

	Grain N concentration (%)	N uptake (kg ha^{-1})	Grain S concentration (%)	S uptake (kg ha^{-1})
Urea (Control) 120 kg/ha (split)	2.5 a	127.9 a	0.23 a	46.9 e
PCSCU 60 kg/ha (basal)	2.4 a	78.4 e	0.14 d	28.6 f
PCSCU 60 kg/ha (split)	0.7 c	29.4 f	0.21 ab	62.9 d
PCSCU 120 kg/ha (basal)	2.5 a	122.1 a	0.23 a	22.6 f
PCSCU 120 kg/ha (split)	2.3 a	106.1 b	0.24 a	85.3 bc
WSCU 60 kg/ha (basal)	2.5 a	98.0 c	0.22 a	101.2 b
WSCU 60 kg/ha (split)	1.5 b	83.0 d	0.24 a	75.9 c
WSCU 120 kg/ha (basal)	2.4 a	112.9 ab	0.20 a	98.8 b
WSCU 120 kg/ha (split)	2.4 a	84.3 d	0.16 c	123.6 a
Urea + sulfur (6%) without coating + 120 kg/ha (split)	2.3 a	118.2 a	0.17 c	60.4 d
Urea + sulfur (17%) without coating +120 kg/ha (split)	2.3 a	122.8 a	0.22 a	92.6 b
LSD (5%)	1.11	7.33	0.24	20.66

In each column, means followed by a common letter do not differ significantly through LSD test, $p>0.05$.

The increase in straw yield might be attributed to taller plants, greater tiller and panicle number. Chaturvedi (2005) and Watkins et al. (2010) also reported that appropriate rate of N fertilizer and source should be taken into consideration for higher yield. However, Maragatham et al. (2010) found lowest straw yields of rice from recommended $(NH_4)_2SO_4$ treatment.

Effect of fertilizers on grain yield

Regardless of N sources and time of application, significantly higher grain yields were recorded from PCSCU, WSCU, U+S (6%), U+S (17%) without coating @ 120 N kg ha^{-1} fertilizers, applied as basal or split.

However, lowest grain yields were recorded when crop was fertilized with lower N rates @ 60 N kg ha^{-1}. The result for N application time showed that splitting urea, U+S (6%) and U+S (17%), in equal doses during crop growth, enhanced grain yield of rice, and whereas all coated fertilizers showed no statistical yield difference in terms of N application timing (Table 1).

Jadhav et al. (2004) also noticed significant increase in grain and straw yield of rice with levels of nitrogen @ 120 kg ha^{-1}. Sallam (2005) and Abd El-Maksoud (2008) found splitting N, provided the rice plants with N throughout the vegetative growth period. The other possible reason in yield enhancement might be due to continuous and steady supply of N into the soil by coated fertilizers to meet the required nutrients for physiological processes, which in turn improves grain yield (Reddy, 2006).

However, Chaturvedi (2005) reported that sulfur-containing N fertilizer had significant effect on rice grain yield than non-sulfur containing nitrogenous fertilizers.

Effect of fertilizers on nitrogen concentration (%) and uptake in grain

All N fertilizer sources @ 120 kg ha^{-1} increased N concentration and uptake in grain across the application time. However, PCSCU and WSCU at lower N rate (60 kg ha^{-1}) resulted in lower N concentration as well as uptake in grain (Table 2).

Table 3. Ammonium (μ/g) content in soil during the rice growing period.

	Days after sowing					
	Sowing	28	44	64	78	94
Urea (Control)120kg/ha (split)	21.86 a	28.78 a	20. 32 cd	41.74 c	26.72 e	15.24 bc
PCSCU 60 kg/ha (basal)	21.25 a	21.85 c	15.88 e	30.94 e	31.04 c	16.55 b
PCSCU 60 kg/ha (split)	21.56 a	21.70 c	21.22 bc	20.52 f	30.15 c	14.66 c
PCSCU 120 kg/ha (basal)	21.47 a	28.23 a	22.11 b	31.31 e	31.32 c	19.12 a
PCSCU 120 kg/ha (split)	20.89 a	28.85 a	22.33 b	50.82 a	33.17 b	19.11 a
WSCU 60 kg/ha (basal)	21.29 a	22.53 c	16.79 e	22.20 f	25.52 e	15.80 bc
WSCU 60 kg/ha (split)	21.40 a	22.70 c	18.73 d	20.39 f	28.24 d	15.78 bc
WSCU 120 kg/ha (basal)	21.04 a	28.30 a	28.21 a	59.44 a	35.48 a	19.15 a
WSCU 120 kg/ha (split)	21.79 a	28.28 a	28.22 a	40.58 c	33.29 b	19.22 a
Urea + sulfur (6%) without coating + 120 kg/ha (split)	22.01 a	25.52 b	21.02 bc	37.93 d	20.95 g	15.57 bc
Urea + sulfur (17%) without coating +120 kg/ha (split)	21.27 a	25.50 b	18.83 d	40.17 c	23.19 f	16.56 b
LSD (5%)	1.04	1.37	1.57	1.64	1.51	1.47

In each column, means followed by a common letter do not differ significantly through LSD test, p>0.05.

Table 4. pH changes in soil during the rice growing period as affected by different coated and uncoated fertilizers.

	Days after sowing					
	Sowing	28	44	64	78	94
Urea (Control)120 kg/ha (split)	4.4 a	5.8 ab	5.7 bc	5.6 b	6.4 ab	5.8 bcd
PCSCU 60 kg/ha (basal)	4.5 a	5.2 c	5.9 b	5.5 b	6.4 ab	5.0 f
PCSCU 60 kg/ha (split)	4.5 a	5.6 bc	5.7 bc	5.8 a	6.5 ab	5.9 abc
PCSCU 120 kg/ha (basal)	4.5 a	5.9 ab	5.7 bc	5.6 b	6.4 ab	5.8 bcd
PCSCU 120 kg/ha (split)	4.4 a	5.9 ab	5.8 b	5.8 a	6.4 ab	5.8 bcd
WSCU 60 kg/ha (basal)	4.5 a	6.2 a	5.5 c	5.3 c	6.7 a	5.9 abc
WSCU 60 kg/ha (split)	4.6 a	5.8 ab	6.1 a	5.6 b	6.6 ab	6.0 ab
WSCU 120 kg/ha (basal)	4.5 a	6.0 ab	5.7 bc	5.5 b	6.4 ab	5.6 de
WSCU 120 kg/ha (split)	4.4 a	5.8 ab	5.7 bc	5.2 c	6.3 b	5.7 cd
Urea + sulfur (6%) without coating + 120 kg/ha (split)	4.5 a	6.0 ab	5.8 b	5.5 b	6.3 b	6.1 a
Urea + sulfur (17%) without coating +120 kg/ha (split)	4.5 a	5.7 b	5.5 c	5.0 d	6.3 b	5.4 e
LSD (5%)	0. 70	0.44	0.19	0.14	0.31	0.28

In each column, means followed by a common letter do not differ significantly through LSD test, p>0.05.

The recovery of N fertilizer applied to the rice crop would range from 30 to 40%. However, with improved cultural practices, such a recovery can increase up to 65% (De Datta, 1981). Adequate fertilizers resulted in increased crop yields by improving nutrient concentration in plant tissue and soil (Adediran et al., 2004) and gives 67% more yield over control (Taiwo et al., 2001).

Application rates that precisely match crop needs has less residual N (Andraski et al., 2000). Therefore, amount of fertilizer, time of application and absorption pattern reflect amount of N in plants leading to profound effect on N use efficiency (Sta. Cruz and Wada, 1994).

Effect of fertilizers on sulfur concentration (%) and uptake in grain

The fertilizer whether applied @ 60 or 120 kg ha^{-1} either as split or basal, increased sulfur concentration in grain except PCSCU @ 60 kg ha^{-1} and U+S (6%) without coating @ 120 N kg ha^{-1}. However, sulfur uptake in grain was higher in WSCU @ 120 N kg ha^{-1} (split).

Similarly, WSCU @ 60 and 120 N kg ha^{-1} applied as basal, and U+S (17%) without coating @ 120 N kg ha^{-1} (split) recorded 2nd lowest values of sulfur uptake in rice (Table 2). The sulfur requirement of rice varies according to the nitrogen supply. When sulfur becomes limiting, addition of N does not change the yield or protein level of plants. Sulfur is required early in the growth of rice plants. If it is limiting during early growth, then tiller number and final yield may reduce (Blair and Lefroy, 1987).

As observed in this study, sulfur coated urea fertilizers increased sulfur concentration in grain, which is also supported by (Rahman, 2007).

Effect of fertilizers on ammonium content in soil during rice growing period

On day 28 after sowing, the fertilizers viz. urea, PCSCU and WSCU applied @ 120 N kg ha^{-1} as split or basal had higher NH_4^+-N release compared to @ 60 N kg ha^{-1}. The NH_4^+-N release decreased at day 44 after sowing in all fertilizer treatments.

However, gradual increase in the release of NH_4^+-N at 64th day of sowing was observed, which could be due to the second fertilizer application (45 days after sowing). Similarly, urea, PCSCU and WSCU fertilizers @ 120 N kg ha^{-1}, whether applied as split or basal had higher NH_4^+-N release, compared to low fertilizer rates. Again, gradual decrease in NH_4^+-N was noted when crop proceeded towards physiological maturity (94 days after sowing). On day 94, the higher content of NH_4^+-N was found in coated fertilizers viz. PCSCU and WSCU, compared to uncoated fertilizers (Table 4).

Effect of fertilizers on pH changes in soil

When sulfur is mixed into soil, sulfur-oxidizing microorganisms utilize the sulfur and convert it to sulfate, and in the process generate acid-forming hydrogen ions, which decrease the soil pH. In this study, urea coated with sulfur did not drastically reduce soil pH. The pH of soil was increased from initial (4.5) after each fertilization. After rice harvest it was significantly higher in the plots treated with sulfur coated urea, especially in WSCU @ 120 N kg ha^{-1} .

Materials and Methods

Plant material and growing conditions

The field experiment was conducted at Lubok Itek soil series, located at Kalantan, Kota Bharu, Peninsular Malaysia (latitude 5°15'N, 102°0′E5.25). The experimental soil was sandy loam, with pH=4.5, 1.43% organic carbon, 0.13% total nitrogen, 0.11% total sulfur, and 0.11, 0.16 and 1.31 cmol/kg K, Mg and Ca, respectively. Rice seeds of variety MR220 was used in this experiment which is also widely used by the local farmers. The seed were soaked in water for 24 hrs followed by 12 hrs incubation. The seeds were sown in well prepared nursery bed for germination. The 22-day-old seedlings were transplanted in the well puddled plots. A standard package of practices was used to maintain the experimental area.

Fertilizers treatments

The treatments were: (1) urea coated and uncoated fertilizer such as common urea (control) @ 120 N kg ha^{-1} (split), (2) polymer coated sulfur coated urea (PCSCU) @ 60 N kg ha^{-1} (basal), (3) PCSCU @ 60 N kg ha^{-1} (split), (4) PCSCU @ 120 N kg ha^{-1} (basal), (5) PCSCU @ 120 N kg ha^{-1} (split), (6) wax sulfur coated urea (WSCU) @ 60 N kg ha^{-1} (basal), (7) WSCU @ 60 N kg ha^{-1} (split), (8) WSCU @ 120 N kg ha^{-1} (basal), (9) WSCU @ 120 N kg ha^{-1} (split), (10) urea + sulfur (U+S) (6%) without coating @ 120 N kg ha^{-1} (split), and (11) U+S (17%) without coating @ 120 N kg ha^{-1} (split).

Physico-chemical properties of fertilizers

Physico-chemical properties of fertilizers showed that urea was a white crystalline prill or granules, organic and non-electrolyte solid which produced through the reaction of ammonia and carbon dioxide at high pressure at temperatures between 132^{o}C to 182 ^{o}C. Total nitrogen was 46%. Wax sulfur coated urea (WSCU) was prepared through coating urea with sulfur and then coated with a proprietary polymeric wax sealant with total nitrogen and sulfur of 37% and 17%, respectively.

Polymer coated sulfur coated urea (PCSCU) was small yellow solid sphere, with slight sulfur odor, which can consistently release its nitrogen over time for up 12 weeks of feeding. It can easily be mixed with other nutrient, with 42% and 6% total N and S content, respectively.

Fertilizer application

All fertilizers were applied according to treatments. In split fertilizer treatments out ot total fertilizer dose, 2/3rd was applied during final harrowing and the remaining 1/3rd was top-dressed 5 days before panicle initiation of the crop. However, whole P_2O_5 (60 kg ha^{-1}) as Triple Superphosphate (TSP) and K_2O (90 kg ha^{-1}) as Muriate of Potash (MOP) were applied during final harrowing (Dobermann and Fairhaurst, 2000).

Determinations

In soil, pH was determined using pH meter (Mettler Toledo MP 120). Both, total N and S content in soil were determined using air dried samples , followed by grinding, and passed through 2 mm sieve. Total N and S content in soil were determined using the Dumas Method CHNS Elemental Analyzer (Model VarioEL). Nitrogen uptake in grain was calculated as: total N in grain (%) × grain yield (kg ha^{-1}), Sulfur uptake by grain as: total S in grain (%) × grain yield (kg ha^{-1}). Ammonium (NH_4^+) nitrogen content in soil was determined using 2 M KCl as extracting solution in a 1:5 (soil: water) ratio by steam distillation of ammonia (Bremner, 1965). The distillate was collected in saturated H_3BO_3 and titrated to pH 5.0 with dilute H_2SO_4. This method determined dissolved and adsorbed forms of NH_4^+ in soils. The sum determined by this method is referred to as Mineral-N (Keeney and Nelson, 1982). Plant height was measured using twenty primary tillers selected randomly from each plot from base to the tip of the panicle at maturity with a meter scale. Same plants were selected to count the number of tillers and panicles per plant. Panicle length was measured from base of the panicle to its tip.

Thousand kernels were counted manually from a random sample of kernels taken from each plot and weighed on digital balance to determine 1000-kernel weight in grams. Straw yield of each treatment was recorded with the help of a spring balance after proper drying in the field. The crop was threshed manually to determine grain yield. The grain yield was adjusted to 14% moisture content.

Statistical analysis

The data was analysed through complete randomized design, with three replications using analysis of variance (ANOVA). The treatment means were compared through LSD test at 5% probability level (Steel et al., 1997) using Statistical Analysis System software version 9.2.

Conclusions

The sulfur coated urea fertilizers, both polymer coated sulfur coated urea (PCSCU) and wax sulfur coated urea (WSCU) did not improve yield and N uptake by rice. N uptake were higher in rice receiving basal application of both sulfur coated urea.

Increase in S uptake by rice did not increase rice yield. All treatments with with sulfur coated urea except PSCU at 60kg/ha gave higher straw yield than the control.

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