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Sulphur coated urea improves morphological and yield characteristics of transplanted rice (*Oryza sativa* L.) through enhanced nitrogen uptake

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ABSTRACT

Imbalanced and non-judicious use of nitrogen in agriculture is one of the major factors responsible for ecological disturbance and threat to biodiversity. Among cultivated crops, nitrogen losses in rice are the highest that resulted in low nitrogen use efficiency. Urea coating with sulphur can deaccelerate nitrogen release and contribute to higher availability for plants. An experiment was conducted during two consecutive years 2016 and 2017 for the assessment of sulphur coating on urea in transplanted rice under varied nitrogen levels. There were two levels of urea source, U_1 = granular urea (U_G) and U_2 = sulphur coated urea (U_{SC}) and three levels of nitrogen rate were kept as, N_1 = 100% of the recommended nitrogen (160 kg ha^{-1}), N_2 = 75% of the recommended nitrogen (120 kg ha^{-1}) and N_3 = 50% of the recommended nitrogen (80 kg ha^{-1}). Results indicated that in both years highest kernel yield was recorded in U_{SC} as compared to U_G. Almost all morphological traits were influenced by nitrogen levels and urea sources. Chlorophyll *a* and *b* were also significantly higher in U_{SC} at 90 and 120 DAT (days after transplanting). Nitrogen contents in leaf and panicle were also increased when nitrogen was applied in form of U_{SC}. Leaf nitrogen contents were almost same at 90 and 120 DAT while panicle nitrogen contents increased significantly at 120 DAT under U_{SC}. It is concluded that urea coating with sulphur is more efficient than application of granular urea. To obtain higher yield in puddled rice, it is recommended that nitrogen must be applied at the rate of 160 kg ha^{-1} through coating of sulphur.
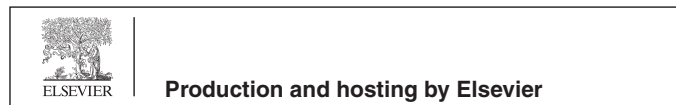
1. Introduction

Nitrogen application for agricultural purpose is one of the major activities that are responsible for disturbance of natural ecosystem and environmental problems at global level. Reactive nitrogen (Nr), that is lost from the agricultural fields, is the basis of various environmental and ecological disturbances. It is one of the major threats to biodiversity (Payne et al., 2017). It is evident from the last five decades that usage of nitrogen in agriculture has been rise at exponential rate (Lu and Tian, 2017). This terrific upsurge of nitrogen use is associated with increased nitrogen losses and reduced nitrogen use efficiency (NUE) that is only 20–35% in developing countries where major production of urea is consumed every year, main portion of the applied nitrogen 65–80% is lost to the environment (Naz and Sulaiman, 2016). Overdose of nitrogenous

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fertilizers is one of the foremost aspects that are responsible for N-losses (Ke et al., 2018; Raza et al., 2018).

Rice (*Oryza sativa* L.) is considered as one of the most important staple cereals, around half population of world is dependent upon rice for their daily food intake and calories. It is a source of persistence for the poorest people of the world, near about 750 million relays on it for their survival. Nitrogen is major nutrient that influence growth and development in rice production systems (Khan et al., 2012). Almost all forms of nitrogen are highly mobile in soil, unavailability of nitrogen at post-anthesis stage in rice results in reduced vegetative growth ultimately decreased translocation of assimilates from source to sinks (Ke et al., 2018).

Among cultivated crops, nitrogen losses in rice are highest followed by wheat and maize (Liu et al., 2016). The amount of nitrogen application is directly associated with nitrate (NO_3) concentration in water runoff (Woodley et al., 2018). It is reported that nitrogen losses in the form of run-off are more prominent in aerobic (direct seeded) rice (Zhang et al., 2018a; He et al., 2017). Volatilized nitrogen in the form of methane (CH_4) and ammonia (NH_3) from anaerobic (puddled) rice is the source of greenhouse gases (Sutton et al., 2011; Mekonnen and Hoekstra, 2015) and acid rain (Cameron et al., 2013). The misplaced nitrogen through leaching takes part in contamination of ground water (Su et al., 2018; Zhang et al., 2018b), water bodies, fresh lakes (Paerl et al., 2011), eutrophication and biodiversity disturbance (Robertson and Vitousek, 2009).

Controlled release urea (CRU) reduces nitrogen losses and improves NUE in paddy field thus contribute to yield enhancement (Li et al., 2018). Use of coated urea decreases nitrogen volatilization and runoff consequently improves rice yield and nitrogen recovery (Wang et al., 2016; Li et al., 2018). It is also predicted by growth models that controlled release of nitrogen in rice field can contribute to yield enhancement and reduces environmental contamination of nitrogen (Dubey and Mailapalli, 2018). Urea coating with micronutrients is associated with increased nitrogen use efficiency in cereals like maize (Affendi *et al.*, 2018). Deficiencies of micronutrients in cereals can be mitigated by their coating on fertilizer. This method is not only beneficial for the micronutrient application but also increases nitrogen use efficiency when coated on urea (Pooniya et al., 2018; Affendi et al., 2018). Use of sulphur coating on urea can help in slow release of nitrogen and contribute to improved nitrogen uses efficiency. Sulphur coated urea reduces nitrogen leaching in flooded rice and wheat (Ke et al., 2018; Shivay *et al.*, 2016; Khan et al., 2015). Sulphur coated urea is better than other polymer coated urea because later is associated with delayed growth and reduction in dry matter accumulation in direct seeded rice (Rose, 2016).

To avoid N-losses in puddled rice, controlled release of nitrogenous fertilizers can serve the purpose. The coating of urea with compatible compounds can be beneficial not only slow distributing of nitrogen but also enhancement of NUE in rice. Keeping these objectives in mind, two-year field research was designed to understand the efficacy of manually coated urea in puddled rice.

2. Materials and methods

2.1. Description of site

To investigate the interactive effect of granular and sulphur coated urea along with nitrogen levels for transplanted rice, a research trial was conducted at experimental farm of Department of Agronomy, Bahauddin Zakariya University Multan Pakistan during consecutive years, 2016 and 2017. The site where experiment was conducted is located at 71.5° N longitude, 30.2° E latitude and at 121 masl elevation. It is classified as arid zone by Köppen's

classification (hot desert climate) (Fig. 1). This site receives very low annual precipitation i.e., less than 150 mm per year, hence agriculture is totally dependent upon irrigation water. Before conducting trial, four soil samples were taken from the field at the depths of 0–15 and 16–30 cm each year. The soil samples were subjected to analysis for selected physical and chemical properties (Table 1).

2.2. Experimental details

Seeds of rice (*Oryza sativa* L.) *cv.* Super Basmati were taken from Rice Research Institute (RRI), Kala Shah Kaku Sheikhupura Pakistan. In both years, randomized complete block design (RCBD) with split-plot arrangement was used. There were two levels of urea sources, U_1 = granular urea (U_G) and U_2 = sulphur coated urea (U_{SC}) and three levels of nitrogen rates were kept as, N_1 = 100% recommended nitrogen (160 kg ha^{-1}), N_2 = 75% recommended nitrogen (120 kg ha^{-1}) and N3 = 50% recommended nitrogen (80 kg ha^{-1}). Urea sources and nitrogen rates were kept as main-plot and sub-plot factors, respectively.

2.3. Urea coating

Sulphur coated urea (Usc) was prepared by manual method using rotating drum (Shivay, *et al.*, 2015). Granular urea having measured amount 38 kg was taken in rotating drum. To adhere sulphur coating on urea, acacia gum was used (also known as gum Arabic). It considered as natural polymer and can be used for agricultural purposes (Patel and Goyal, 2015). Keeping the rate of 2 g acacia gum for 1 kg urea, 76 mL of acacia solution as prepared and sprinkled on urea in drum as suggested by Shivay *et al.* 2016 previously. Drum was rotated for 10 min then 2 kg sulphur powder (99%) was added into drum and again drum was rotated for further
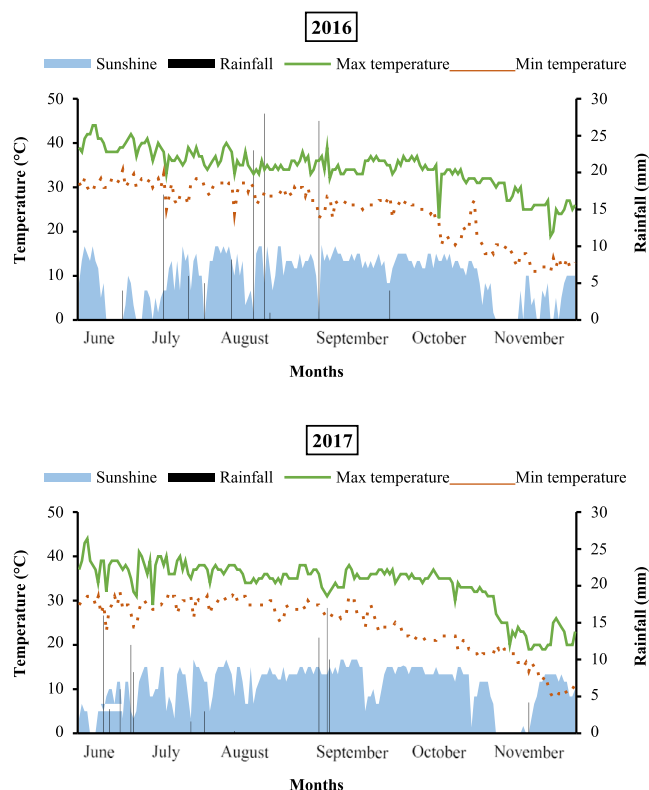

Fig. 1. Weather data exhibiting minimum and maximum temperature (°C), rainfall (mm) and sunshine (hour) during experimental period.

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Table 1
Selected physio-chemical characteristics of experimental field soil during 2016 and 2017.

Soil characteristics	Unit	2016		2017	
		0–15 cm	16–30 cm	0–15 cm	16–30 cm
Physical properties					
Sand	%	26	24	29	27
Silt	%	51	57	50	56
Clay	%	23	19	21	17
Textural class	–	Silt loam	Silt loam	Silt loam	Silt loam
Chemical properties					
Soil EC (ECe)	dSm^{-1}	3.17	3.23	2.98	3.11
Soil pH (pHe)	1:1	8.4	8.6	8.3	8.4
Organic matter	%	0.59	0.43	0.57	0.46
Nitrogen (NO_3-N)	$mg\ kg^{-1}$	4.21	3.98	3.45	3.13
Phosphorus ($NaHCO_3$-P)	$mg\ kg^{-1}$	6	4	5	4
Potassium (NH_4OAc-K)	$mg\ kg^{-1}$	159	146	176	161

15 min. Urea was taken out of drum and spread out on plastic sheet under shade for 10 min and stored. This coated urea was consisted of 5% (w/w) sulphur.

2.4. Nursery raising

Nursery was raised keeping recommended seed rate of 18 kg ha^{-1}. On both years nursery was sown on 6th June 2016 and 5th June 2017. Seeds were soaked for 24 h in water than kept for 48 h in gunny sacks. After each of 6 h water was sprinkled on gunny sacks and seed was rotated to accelerate imbibition and germination. Nursery bed was prepared by making two cultivations followed by planking. Animal manure was also added and mixed with rotavator in nursery bed. Nursery field was irrigated and standing water was kept for 3 days. Afterwards nursery field was divided into plots of size 272.25 sq. ft (1 *marla*), in each *marla*, 500-gram seed was broadcasted. Fertilizer for nursery was applied at the rate of 100–60 kg ha^{-1} (N-P), for each *Marla*, 250-gram N and 150-gram P was broadcasted using urea and triple super phosphate as fertilizer material.

2.5. Nursery transplantation

Nursery was transplanted with seedling age of 30 days. On both years nursery was transplanted on 5th July 2016 and 4th July 2017. Two seedlings were transplanted per hill keeping the distance of hill × hill = 22.5 cm (9 in.).

2.6. Puddled field preparation

Animal manure was added and rotavator was drawn. Afterwards field was flooded, and cultivator was drawn three times in standing water followed by planking. Rotavator was also used in standing water. Field was divided into plots, the net plot size was 7 m × 3.4 m. Nitrogen was applied in three splits according to treatments using urea (46% N) while Phosphorus @ 85 kg ha^{-1} and Potassium @ 60 kg ha^{-1} were applied before transplanting using the sources of TSP (46% P) and SOP (50% K), respectively. For weed control in puddled field, Butachlor (60 EC) @ 800 mL acre^{-1} was applied.

3. Harvesting and measurements

3.1. Morphological traits

Crop was harvested on 6th November 2016 and 9th November 2017. At harvest maturity, data for morphological and yield related parameters like plant height (cm), total tillers (m^{-2}), productive tillers (m^{-2}), panicle length (cm), number of kernels panicle^{-1}, 1000-kernel weight (g), biological yield (kg ha^{-1}), kernel yield (kg ha^{-1}) and harvest index (%) were recorded.

3.2. Chlorophyll a, b and nitrogen determination

Samples of leaves and panicles were taken at 90 and 120 DAT (days after transplanting) for determination of chlorophyll *a*, *b* and nitrogen contents in leaf and panicle.

Chlorophyll *a* and b were quantified by acetone extraction method (Arnon, 1949). Fresh samples of leaves were taken from the field, immediately transferred to ice bucket for the transportation towards lab. Leaves sample of weight 0.2 g was taken, cut into tiny pieces, and extracted overnight in 80% acetone at 4 °C then it was centrifuged for 10 min at 8000 rpm. Readings were taken in spectrophotometer at 645 nm and 663 nm. Values were calculated by formula explained by Nagata and Yamashita (1992).

Nitrogen contents in leaves and panicle were determined by H_2SO_4 digestion and distillation (Chapman and Parker, 1961). Samples (leaf and panicle) were oven dried, 0.5 g sample was taken in Kjeldahl digestion flask and 5 g digestion mixture K_2SO_4:Cu_2SO_4:$FeSO_4$ (10:0.5:1) was added, afterwards 10 mL concentrated H_2SO_4 (98%) was poured into flask. After an hour, digestion flask was placed on digester chamber. Temperature was raised slowly to 320 °C. When liquid attained transparent green colour, digestion was stopped, and sample was transferred to 100 mL volumetric flask and volume was made with deionized water. From this, 5 mL was taken, and distillation was performed against 40% NaOH using methyl red and bromocresol green (0.3%) as indicator. The quantity of acid utilized in titration was measured and readings were taken for quantification of nitrogen.

3.3. Statistical analysis

Recorded data were analysed statistically using two factors RCBD split-plot design through analytical software Statistix® 8.1 by ANOVA (analysis of variance) and LSD test at 5% probability (Steel et al., 1996). Year was not considered as factor variable. Standard error calculation and graphs making were done by MS-Excel® 2013.

4. Results and discussion

4.1. Morphological and yield characteristics

Results indicated that morphological and yield parameters were significantly influenced by source of urea and nitrogen levels. Data related to plant height was statistically significant during both

years. Maximum plant height was recorded in N_1 using U_{SC} as fertilizer material (121 cm) during both years (Table 2). Plant height at N_2 through U_{SC} was far better than U_G at N_1. Minimum plant height was measured at N_3 in U_G and U_{SC} with least value observed in 2017 at same nitrogen rate in U_G (83 cm).

Total tillers (m^{-2}) varied significantly in 2016 and 2017 among U (urea sources) and N (nitrogen rates), their interaction was also statistically significant during 2017 (Table 2). Maximum total tillers (m^{-2}) were recorded in 2016 (435) at N_1 using U_{SC} as fertilizer material, same case was recorded in 2017. Least total tillers were observed in N_3 through U_G in both years 369 and 367. Among nitrogen dose, N_1 gave maximum total tillers while least were recorded in N_3. During both years, U_{SC} was statistically better than U_G.

Productive tillers (m^{-2}) considered as one of the main yield determining parameters, more productive tiller m^{-2} contribute to kernel yield increment. U and N was significant during both years. Among nitrogen levels, maximum productive tillers were recorded in N_1, while U_{SC} performed better than U_G (Table 2). Lowest productive tillers were recorded in U_G 294 and 301 in 2016 and 2017, respectively. Highest productive tillers were observed in U_{SC} at the dose of N_1 378 and 368 during 2016 and 2017 accordingly, whereas N_2 applied in the form of U_{SC} gave better productive tillers than N_1 dose of UG.

For panicle length (cm), interaction of U (urea sources) and N (nitrogen rates) were non-significant both years. Panicle length was more influenced by dose of nitrogen rather than source of fertilizer used for nitrogen nutrient provision. During 2017, U was also non-significant while in 2016, it was also slightly affected panicle length (Table 3). Nitrogen rates significantly influenced length of panicle each year. Maximum panicle length was recorded in U_{SC} at N_1 (24 cm), at the same rate of nitrogen, U_G also gave almost identical value.

Number of kernels per panicle also yield determining trait, more kernels per panicle contribute to high yield. U, N, and their interaction was significant both years for kernel number per panicle. Maximum kernels per panicle were recorded in N_1 during 2017 at U_{SC} while in 2016, same value was shared by N_2 and N_1 (102). Least number of kernels per panicle were recorded in at N_3 with U_G. Among nitrogen doses, 100% and 75% recommended nitrogen gave almost same value (Table 3).

For 1000-kernel weight (g), interaction of U (urea sources) and N (nitrogen rates) was non-significant. Among N doses, 100% and 75% recommended nitrogen also shared same value for both urea sources that were also non-significant during 2017 (Table 3). Maximum kernel weight was recorded in N_1 using U_{SC} as fertilizer source (22 g), whereas minimum 1000-kernel weight was observed in N_3 at U_G.

Nitrogen levels significantly affected biological yield (kg ha^{-1}). During both years, maximum biological yield was recorded in N_1. Among sources of urea there was also significant difference, U_{SC} resulted in higher biological than U_G both years. Maximum biological yield was recorded in 100% and 75% recommended nitrogen during 2016 and 2017 at U_{SC} (8478 kg ha^{-1}). Biological yield was significantly higher at N_2 in U_{SC} than U_G even at N_1 (Table 4).

Maximum kernel yield (kg ha^{-1}) was recorded in U_{SC} during both years. Data was significant for nitrogen levels and urea sources each year while interaction among U (urea sources) and N (nitrogen rates) was non– significant both years (Table 4). Maximum kernel yield was observed at N_1 U_{SC} during 2016 (3646 kg ha^{-1}). Kernel yield of U_{SC} at all nitrogen levels were higher than U_G at its above level, kernel yield at N_3 in U_{SC} was better than N_2 in UG, same case was observed for N_2.

Harvest index (%) was also affected by urea sources and nitrogen rates. Data was significant for U and N both years, but their interaction was non-significant for harvest index during 2016. Maximum harvest index was recorded at N_1 using U_{SC} during 2016 (43%). Among nitrogen rates, maximum harvest index was observed at N_1 for U_{SC} and U_G during both years (Table 4).

4.2. Chlorophyll a, b and N-uptake

Data for chlorophyll *a* and *b* were significant for the effect of U and N at 90 DAT (days after transplanting), sources of urea and nitrogen levels affected chl a and b (Fig. 2). Maximum chl a and b was recorded in U_{SC} during 2017 at N_2, same results were observed in 2016. The interaction of U (urea sources) and N (nitrogen rates) was also significant both years at 90 DAT. Minimum chl-a was recorded in U_G during 2016 at N_3. At 120 DAT, the interaction of U and N was non-significant both years (Fig. 3).

Data regarding leaf nitrogen contents showed that the highest value was obtained in U_{SC} both years at 90 and 120 DAT. At 120

Table 2
Plant height (cm), total tillers (m^{-2}) and productive tillers (m^{-2}) as affected by different urea sources and nitrogen levels during 2016 and 2017.

Nitrogen levels	2016			2017		
	U_G	U_{SC}	Mean (N)	U_G	U_{SC}	Mean (N)
Plant height (cm)						
100 % recommended N (160 kg ha^{-1})	111.9 ± 0.93 bc	121.3 ± 0.92 a	116.6 A	106.1 ± 0.76c	121.2 ± 1.39 a	113.6 A
75 % recommended N (120 kg ha^{-1})	100.8 ± 0.80 d	115.2 ± 1.58b	108.3B	100.6 ± 1.30 d	116.4 ± 0.52b	108.5B
50 % recommended N (80 kg ha^{-1})	87.7 ± 1.23 e	111.1 ± 1.19c	99.4C	83.1 ± 1.18 e	108.3 ± 1.18c	95.7C
Mean (Urea)	100.1B	115.8 A		96.5B	115.3 A	
LSD value (p ≤ 0.05)	U = 4.76 **	N = 2.61 **	U × N = 3.70 **	U = 3.29 **	N = 2.64 **	U × N = 3.73 **
Total tillers (m^{-2})						
100 % recommended N (160 kg ha^{-1})	399.1 ± 7.76	435.2 ± 2.30	417.2 A	412.6 ± 5.78b	427.6 ± 2.40 a	420.1 A
75 % recommended N (120 kg ha^{-1})	389.2 ± 8.71	419.6 ± 1.76	404.3B	398.3 ± 1.76c	418.1 ± 1.73 ab	408.1B
50 % recommended N (80 kg ha^{-1})	369.6 ± 3.93	398.3 ± 2.02	384.8C	367.6 ± 5.36 d	400.3 ± 2.90c	384.7C
Mean (Urea)	385.8B	417.6 A		392.8B	415.3 A	
LSD value (p ≤ 0.05)	U = 21.05 *	N = 7.87 **	U × N = ns	U = 8.61 **	N = 7.52 **	U × N = 10.64 *
Productive tillers (m^{-2})						
100 % recommended N (160 kg ha^{-1})	339.1 ± 5.03c	378.3 ± 2.02 a	358.6 A	335.6 ± 3.48	368.3 ± 2.02	352.1 A
75 % recommended N (120 kg ha^{-1})	314.3 ± 2.33 e	361.4 ± 2.02b	337.8B	309.1 ± 1.52	344.6 ± 2.02	326.8B
50 % recommended N (80 kg ha^{-1})	294.3 ± 2.90f	325.3 ± 1.45 d	309.8C	301.6 ± 2.02	326.3 ± 3.84	314.1C
Mean (Urea)	315.8B	355.3 A		315.4B	346.4 A	
LSD value (p ≤ 0.05)	U = 6.32 **	N = 6.03 **	U × N = 8.53 *	U = 8.76 **	N = 6.62 **	U × N = ns

Means ± SE sharing unalike letters for main effects and interaction during each year differs significantly at p ≤ 0.05 (** = significant at p ≤ 0.01; * = significant at p ≤ 0.05; ns = non-significant; SE = standard error)

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Table 3
Panicle length (cm), kernel panicle^{-1} and 1000-kernel weight (g) as affected by different urea sources and nitrogen levels during 2016 and 2017.

Nitrogen levels	2016			2017		
	U_G	U_{SC}	Mean (N)	U_G	U_{SC}	Mean (N)
Panicle length (cm)						
100 % recommended N (160 kg ha^{-1})	21.9 ± 0.28	23.4 ± 0.49	22.7 A	23.7 ± 0.40	24.1 ± 0.17	23.9 A
75 % recommended N (120 kg ha^{-1})	20.3 ± 0.31	22.1 ± 0.20	21.2B	21.5 ± 0.40	23.3 ± 0.27	22.4B
50 % recommended N (80 kg ha^{-1})	19.7 ± 0.20	20.8 ± 0.40	20.2B	19.9 ± 0.39	21.1 ± 0.25	20.5C
Mean (Urea)	20.6B	22.1 A		21.7	22.8	
LSD value (p ≤ 0.05)	U = 0.47 **	N = 0.92 **	U × N = ns	U = ns	N = 0.80 **	U × N = ns
No. of kernels panicle^{-1}						
100 % recommended N (160 kg ha^{-1})	95.1 ± 1.73b	102.3 ± 1.76 a	98.6 A	8.6 ± 2.33 a	102.3 ± 2.02 a	100.5 A
75 % recommended N (120 kg ha^{-1})	85.3 ± 2.02c	102.1 ± 1.15 a	93.6B	83.1 ± 2.08c	91.3 ± 0.57b	87.1B
50 % recommended N (80 kg ha^{-1})	71.0 ± 1.15 d	93.3 ± 0.88b	82.1C	73.3 ± 1.15 d	82.6 ± 1.20c	77.8C
Mean (Urea)	83.7B	99.2 A		84.8B	92.1 A	
LSD value (p ≤ 0.05)	U = 3.73 **	N = 2.04 **	U × N = 2.89 **	U = 1.26 **	N = 4.30 **	U × N = 6.09 *
1000-kernel weight (g)						
100 % recommended N (160 kg ha^{-1})	18.1 ± 0.33 cd	19.8 ± 0.26 a	18.9 A	18.13 ± 0.42	22.6 ± 3.60	20.3 A
75 % recommended N (120 kg ha^{-1})	17.7 ± 0.26 d	18.7 ± 0.37 bc	18.2B	17.57 ± 0.55	18.9 ± 0.78	18.2 AB
50 % recommended N (80 kg ha^{-1})	15.9 ± 0.26 e	19.1 ± 0.20 ab	17.4C	15.93 ± 0.39	18.1 ± 0.41	17.1B
Mean (Urea)	17.2B	19.1 A		17.2	19.8	
LSD value (p ≤ 0.05)	U = 0.38 **	N = 0.69 **	U × N = 0.98 *	U = ns	N = 3.10 *	U × N = ns

Means ± SE sharing unalike letters for main effects and interaction during each year differs significantly at p ≤ 0.05 (** = significant at p ≤ 0.01; *= significant at p ≤ 0.05; ns = non-significant; SE = standard error)

Table 4
Biological yield (kg ha^{-1}), kernel yield (kg ha^{-1}) and harvest index (%) as affected by different urea sources and nitrogen levels during 2016 and 2017.

Nitrogen levels	2016			2017		
	U_G	U_{SC}	Mean (N)	U_G	U_{SC}	Mean (N)
Biological yield (kg ha^{-1})						
100 % recommended N (160 kg ha^{-1})	7572.6 ± 152	8478.3 ± 67	8025.5 A	7826.6 ± 244 bc	8447.1 ± 68 a	8136.8 A
75 % recommended N (120 kg ha^{-1})	7212.6 ± 173	8126.1 ± 86	7669.3B	7337.1 ± 64 d	8323.3 ± 58 ab	7830.1 A
50 % recommended N (80 kg ha^{-1})	6763.1 ± 94	7430.1 ± 135	7096.5C	6822.6 ± 113 e	7816.6 ± 86 cd	7319.6B
Mean (Urea)	7182.7B	8011.4 A		7328.7B	8195.6 A	
LSD value (p ≤ 0.05)	U = 189.21 **	N = 189.10 **	U × N = ns	U = 401.16 **	N = 322.56 **	U × N = 456.1 *
Kernel yield (kg ha^{-1})						
100 % recommended N (160 kg ha^{-1})	2969.3 ± 78	3646.6 ± 114	3308.1 A	2843.3 ± 38	3575.1 ± 68	3209.1 A
75 % recommended N (120 kg ha^{-1})	2696.6 ± 30	3360.1 ± 53	3028.3B	2477.6 ± 48	3271.1 ± 51	2874.3B
50 % recommended N (80 kg ha^{-1})	2196.6 ± 111	2693.1 ± 19	2444.8C	1985.3 ± 19	2771.3 ± 55	2378.3C
Mean (Urea)	2620.8B	3233.2 A		2435.4B	3205.7 A	
LSD value (p ≤ 0.05)	U = 324.39 **	N = 164.75 **	U × N = ns	U = 231.12 **	N = 79.49 **	U × N = ns
Harvest index (%)						
100 % recommended N (160 kg ha^{-1})	39.1 ± 0.35	43.3 ± 1.69	41.1 A	36.4 ± 1.52 bc	42.3 ± 1.02 a	39.3 A
75 % recommended N (120 kg ha^{-1})	37.4 ± 0.65	41.3 ± 0.37	39.4 A	33.7 ± 0.85c	39.3 ± 0.89b	36.5B
50 % recommended N (80 kg ha^{-1})	32.4 ± 1.68	36.2 ± 0.67	34.3B	29.1 ± 0.64 d	35.4 ± 0.81c	32.2C
Mean (Urea)	36.3B	40.2 A		33.1B	39.1 A	
LSD value (p ≤ 0.05)	U = 3.60 *	N = 2.76 **	U × N = ns	U = 4.59 *	N = 2.07 **	U × N = 2.93 *

Means ± SE sharing unalike letters for main effects and interaction during each year differs significantly at p ≤ 0.05 (** = significant at p ≤ 0.01; *= significant at p ≤ 0.05; ns = non-significant; SE = standard error)
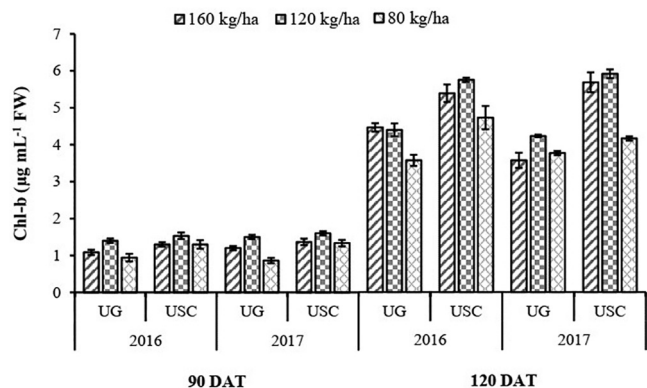

Fig. 2. Chlorophyll-b (µg mL^{-1} FW) as affected by urea sources and levels of nitrogen at 90 and 120 DAT during 2016 and 2017.
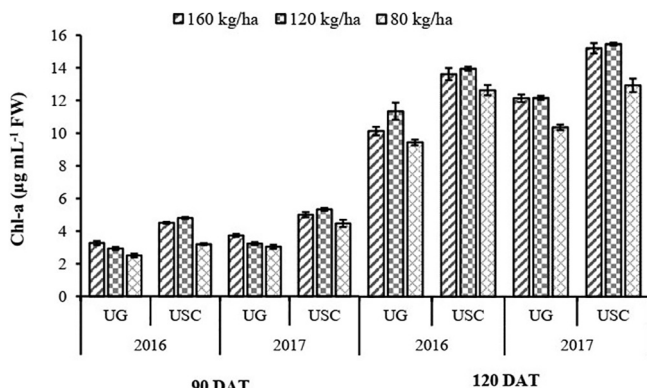

Fig. 3. Chlorophyll-a (µg mL^{-1} FW) as affected by urea sources and levels of nitrogen at 90 and 120 DAT during 2016 and 2017.

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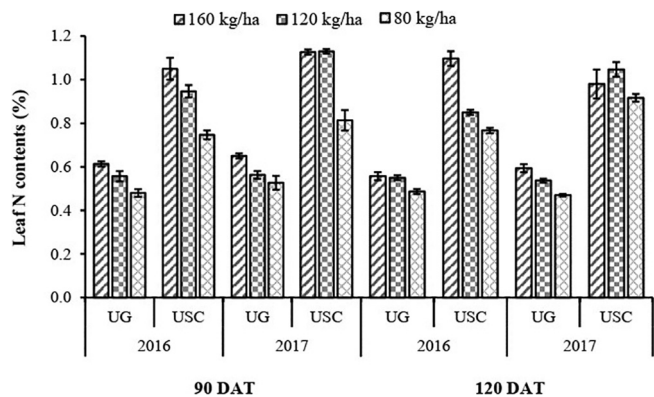Journal of King Saud University – Science 34 (2022) 101664

Fig. 4. Leaf nitrogen contents (%) as affected by urea sources and levels of nitrogen at 90 and 120 DAT during 2016 and 2017.
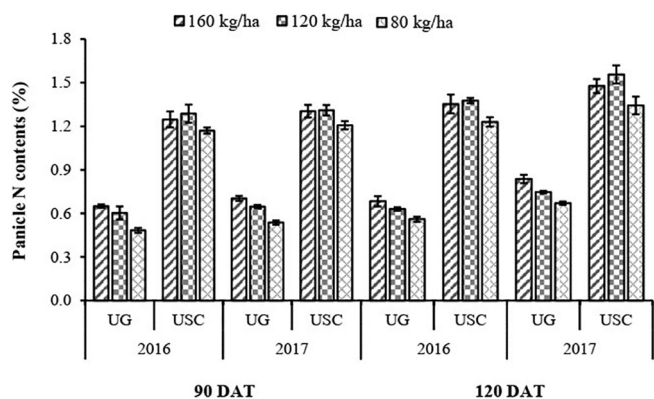

Fig. 5. Panicle nitrogen contents (%) as affected by urea sources and levels of nitrogen at 90 and 120 DAT during 2016 and 2017.

DAT, a slight increase in leaves were observed (Fig. 4). At N_1, maximum nitrogen uptake was recorded. Panicle nitrogen contents increased in 120 DAT as compared to 90 DAT. Highest nitrogen uptake was recorded in U_{SC} both years, but under same urea source, variations were recorded among different nitrogen rates (Fig. 5). Highest nitrogen contents in panicle were recorded in U_{SC} at N_2. Overall, in U_G the value that obtained at N_1 was comparable to U_{SC} at N_1.

5. Discussion

Nitrogenous fertilizers have become integral part of agricultural productions as it is engaged in numerous physiological processes of crops. Addition of N-fertilizers enhance crop yield, but at the same time, it is responsible for disturbance in natural ecosystem and reduction in NUE due to excessive loss. Among cultivated crops, rice has the highest nitrogen losses through water runoff and volatilization. Efficient agronomic practices can not only lessen these N-losses but also will be economical in enhancing yield. Urea coating is environment friendly and cost-effective method. Deficiency of micronutrients like sulphur can also be mitigated by their coating on core fertilizers.

Yield traits were boosted considerably at N_1, since higher nitrogen rate can accelerate higher N-availability therefore resulted in dry matter accumulation and contributed to increase in kernel yield (Kumar et al., 2010; Ke et al., 2018), regardless of U_G where results were slightly varied from N_1 to N_2. It may be since application of high dose of nitrogen in rice in the form of granular urea accelerates nitrogen losses (Shivay et al., 2015; Shivay et al.,

2016), so reduction in N-dose directly abridged rice yield. Nitrogen losses in rice are the highest (Liu et al., 2016), on the other hand, maximum 1000-kernel weight, kernel yield, biological yield and harvest index were observed in U_{SC}. Coating of urea reduces nitrogen losses (Wang et al., 2016; Li et al., 2018) thus improves plant availability of nitrogen. Higher uptake of nitrogen resulted in increased panicle length, numbers of grains per panicle and grain weight. Sulphur coated urea (U_{SC}) performed better than granular urea (U_G) in obtaining higher chlorophyll a and b. The stability in chlorophyll contents directly contributed to dry matter portioning. Increased uptake of nitrogen was recorded in leaf and panicle at both 90 and 120 DAT under U_{SC} that were in accordance with the results of Khan et al., (2015) who quantified that sulphur coated urea improves nitrogen uptake and dry matter production. Urea coating with nutrients also reduces their deficiencies and contribute to yield enhancement in cereals (Affendi et al., 2018). In transplanted rice, use of U_{SC} contributes to increased kernel yield (Ke et al., 2018). Urea is highly volatile compound, so excessive nitrogen is lost to the environment that becomes unavailable for plants. The major contribution of coated urea in enhancing NUE is slow releasing of nitrogen from fertilizers (Li et al., 2018). Accessibility of more N to plants improved nitrogen recovery, chlorophyll, and total dry matter (Wang et al., 2016). Sulphur has key role in physiological processes of plants such as formation of chlorophyll that helps in producing carbohydrates, fats, oils, and other compounds. Urea coated with sulphur enhanced its availability and played its part in dry matter assimilation. It also reduced N-release from urea thus contributed to N-accessibility for enhanced duration (Rose, 2016). Urea coated with sulphur reduces N-leaching (Ke et al., 2018; Shivay et al., 2016a,b).

6. Conclusion

From the above discussion of two years experiment, it is concluded that coating of urea with sulphur is more effective in all respects than granular urea. Urea coated with sulphur helps in slow release of nitrogen, therefore it reduces nitrogen losses increases nitrogen availability and uptake. It is recommended that nitrogen must be applied at the rate of 160 kg ha^{-1} through sulphur coating to obtain higher yield of aromatic transplanted rice.

Declaration of Competing Interest

On behalf of all authors, the corresponding author state that there is no conflict of interest.

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