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Sulphur Status and Effect of Different Sources and Levels of Sulphur Application on Performance of Aerobic Rice (*Oryza sativa* L.)

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ABSTRACT

A survey was conducted to know the sulphur status in rice domains of Mandya district. Out of 119 soil samples collected from entire taluks of the district (4-5 samples for each hobli of all taluks), 92 samples (77.32 %) were sufficient and 27 samples (22.68 %) were deficient in sulphur content. Among the taluks, Mandya, Maddur, S.R. Patna and Pandavapura have a sufficient range of sulphur, whereas other taluks namely Malvalli, K.R. Pet and Nagamangala taluks have deficient sulphur status. Nagamangala taluk has the least sulphur status among taluks of Mandya district with all five hoblis showing deficiency range. To know the response of rice to different sources and levels of sulphur application, a field experiment was conducted during *kharif*, 2015 on sandy loam soil at the College of Agriculture, V.C. Farm, Mandya, University of Agriculture Sciences, Bangalore. The results revealed that application of RDF+FYM+26 kg sulphur ha^{-1} through ammonium sulphate recorded significantly higher grain and straw yield of 2716.45 kg ha^{-1} and 4240.49 kg ha^{-1}, respectively. Higher grain and straw yields were mainly attributed to growth parameters like higher plant height (85.87 cm), number of tillers (20.47) and number of leaves per hill (83.20) at harvest, and yield parameters *i.e.,* number of panicles per hill (15.93), length of panicle (20.03c m), number of grains per panicle (117.0), 1000 grain test weight (23.65g) and lower per cent chaffyness (6.33).

Keywords : Aerobic rice, Ammonium sulphate, Superphosphate, Elemental sulphur, Gypsum

RICE is a staple food for more than half of the world population and is generally grown by transplanting seedlings into a puddled soil in Asia. Transplanted puddled rice (TPR) is labor, water and energy intensive and is becoming less profitable as these resources are becoming increasingly scarce,especially water (Kumar and Ladha, 2011). Hence, shifting gradually from the traditional rice production system to growing rice aerobically especially in water scarce irrigated low lands can mitigate the occurrence of water-related problems. Aerobic rice system (ARS) is a new production system in which rice (*Oryza sativa* L.) is grown under unpuddled, unflooded, and unsaturated soil conditions as other upland crops (Prasad, 2011).

Paddy is one of the predominant crops in the southern dry zone (zone 6) of Karnataka and continuous paddy growing has shown evidence of soil nutrient depletion, imbalances and low nutrient use efficiency in the command area of the zone. This decline in soil fertility and productivity is attributed to the appearance of deficiencies of several plant nutrients including sulphur. Sulphur deficiency is wide spread now in India. Out of 142 million ha cultivated land in India, at least 57 m ha, that is about 40 per cent of the total, suffers from various degrees of S deficiency (Tripathi, 2003). Keeping this in view a survey was conducted to know the sulphur status in rice-growing regions of the Mandya district. Sulphur deficiency reduces crop yield and quality of the produce (Zuzhang *et al*., 2010).

In sulphur deficient soil, the application of high rates of other nutrients (N, P and K) may not result in increased yields, due to imbalances in the N/S and P/S ratios in the plants. In addition, an adequate and balanced supply of nutrients favors the proper development of crops, with a positive impact on the yield (Fageria *et al*., 2011). The application of sulphur increases growth and yields in rice (Singh *et al.,* 2012 and Jena and Kabi, 2012).Therefore, an attempt was made to study the response of aerobic rice to sources and levels of sulphur application for achieving maximum production.

Material and Methods

Soil samples were collected from 0-15 cm depth in the paddy growing regions of Mandya district. The samples were collected randomly hobli wise (4-5 samples/hobli) and brought to the laboratory, shade dried and processed. These processed soil samples were analyzed for available sulphur content by using 0.15 per cent $CaCl_2$ extraction by turbidimetry method.

A field experiment was carried out at the College of Agriculture, V.C. Farm, Mandya during *kharif* 2015. The soil was sandy loam in texture with neutral reaction (pH 7.4), electrical conductivity was 0.14 dSm^{-1} and organic carbon content was medium (7.5 g kg^{-1}). The soil was medium in available nitrogen (439 kg ha^{-1}), phosphorus (53.86 kg ha^{-1}) and exchangeable potassium (176.4 kg ha^{-1}), with low available sulphur (5.21 mg kg^{-1}).

The experiment was laid out in Randomized Complete Block Design (RCBD) with twelve treatments and three replications. The treatment combinations consisting of five sources of sulphur fertilizers (*viz.,* Gypsum, Ammonium Sulphate, Elemental Sulphur, 20:20:0:13 and SSP) and two levels of sulphur (13 and 26 kg Sulphur) ha^{-1} from each source along with one absolute control and recommended dose of fertilizers. Here 13 and 26 kg S ha^{-1} was fixed mainly because the complex used in the experiment was 20:20:0:13 and based on 5 kg S $acre^{-1}$ as standard was fixed. The recommended quantity of FYM at the rate of 10 t ha^{-1} was applied and mixed into the soil two weeks before sowing. As per the treatments, fifty per cent of nitrogen and the entire quantity of phosphorus, potassium and sulphur were supplied at the time of sowing as a basal dose to each plot and the remaining fifty per cent of nitrogen was applied as top-dressing at 30 days after sowing. The contribution of N and P from applied S sources *viz.,* Ammonium sulphate and SSP was made good by reducing the quantity of fertilizer nutrient in respective treatment. Good quality seeds of the cultivar (Rashi) were sown manually at the rate of one seed per hill with a spacing of 25 cm × 25 cm as inter and intra row spacing. Irrigation was given as per requirement. Usually, every four to five days once irrigation was given based on the moisture prevailing in the field as per the recommendation for aerobic rice to keep optimum moisture. Three hand weedings were done to keep the plots free from weeds at 30, 45 and 60 DAS.

Results and Discussion

The mean available sulphur status of rice grown regions of the Mandya district is given in Tables 1 and 2. As per the sulphur content, the data was categorized into two groups: one is taluk with high sulphur status and the other one taluk with low sulphur status according to hobli wise.

As per the statistical analysis, in Mandya taluk sulphur concentration was significantly highest in Mandya hobli with an average mean concentration of 18.87 ppm followed by Duddha (17.16 ppm). The lowest (13.74 ppm) sulphur status was observed in Kothattihobli. In Maddur taluk, a high sulphur concentration of 15.89 ppm was in Chikkarasikere hobli followed by Koppa (15.48 ppm). The lowest (13.43 ppm) sulphur status was observed in Athagurhobli. In Malvalli taluk sulphur concentration was significantly highest in B.G. Pura hobli with an average mean concentration of 15.76 ppm followed by Halagur (15.27 ppm). The lowest of 11.72 ppm of sulphur status was observed in Kirugavaluhobli. In S.R. Patna taluk sulphur concentration of 20.22 ppm was in Arkerehobli followed by S.R. Patna (19.22 ppm). The lowest (13.63 ppm) sulphur status was observed in Belgolahobli. In Pandavapura taluk sulphur status was significantly highest in Melkote hobli with a concentration of 15.97 ppm followed by Chinnakurli (15.02 ppm). The lowest of 13.76 ppm of sulphur status was observed in Pandavapura hobli. In K.R.Pet taluk sulphur status was highest in Akki Hebbal hobli with a concentration of 22.41 ppm followed by the K.R. Pet (14.51 ppm). The lowest of 12.15 ppm of sulphur status was observed in Bukinakere hobli. In Nagamangala taluk sulphur status was significantly highest in Bellur hobli with a concentration of 14.48 ppm followed by

TABLE 1

Paddy growing areas in Mandya with high-S status

Taluks	Hoblis	Mean sulphur (ppm)	± Sd
Mandya	Mandya	18.87	5.484
	Duddha	17.16	5.627
	Basaralu	14.54	4.555
	Keregodu	14.44	2.573
	Kothatti	13.74	1.093
		15.75	**4.272**
Maddur	Maddur	13.57	1.338
	Koppa	15.48	1.442
	Athagur	13.43	1.908
	Chikkarasikere	15.89	4.800
		14.60	**2.722**
Malvalli	Malvalli	12.41	1.434
	Halagur	15.27	1.245
	Kirugavalu	11.72	0.615
	B.GPura	15.76	6.489
		13.71	**3.529**
S.R.Patna	S.R.Patna	19.22	3.852
	K.Shettihalli	15.23	0.416
	Arkere	20.22	6.256
	Belgola	13.63	1.947
		17.07	**4.420**
Pandavapura	Pandavapura	13.76	1.489
	Chinnakurali	15.02	4.164
	Melkotae	15.97	0.794
		14.73	**2.554**
K.R.Pet	Bukinakere	12.15	-
	Akkihebbal	22.41	3.594
	K.R.Pet	14.51	2.917
	Seelanare	14.22	0.634
		15.82	**4.888**
Nagamangala	Nagamangala	11.53	1.082
	Bindiganavile	12.29	0.000
	Bellur	14.48	0.622
	Devalapura	12.15	-
		12.74	**1.491**

TABLE 2

Paddy growing areas in Mandya with low-S status

Taluks	Hoblis	Mean sulphur (ppm)	± Sd
Malvalli	Halgur	9.11	0.863
	Kirugavalu	7.03	0.368
	B.GPura	7.63	0.000
		7.92	**1.158**
K.R.Pet	Bukinakere	8.85	0.240
	K.R.Pet	8.33	0.000
	Kikkeri	6.72	1.655
		7.97	**1.190**
Nagamangala	Nagamangala	8.24	0.368
	Bindiganavile	6.94	0.240
	Bellur	9.03	0.983
	Deevalapura	8.76	0.368
	Honakere	8.85	0.240
		8.36	**0.965**

Bindiganavile (12.29 ppm). The lowest (11.53 ppm) sulphur status was observed in Nagamangala hobli.

Taluk-wise hoblis deficient in available sulphur concentration are presented in Table 2. As per the statistical analysis, in Malvalli taluk the sulphur concentration was significantly more deficit in Halgur hobli with a concentration of 9.11 ppm was, followed by B.G. Pura (7.63 ppm). The lowest of 7.03 ppm of deficit sulphur concentration was observed in Kirugavalu hobli. In K.R. Pet taluk the sulphur concentration significantly more deficit in Bukanakere hobli with a concentration of 8.85 ppm, followed by K.R. Pet (8.33 ppm). The lowest of 6.72 ppm of deficit sulphur status was observed in Kikkeri hobli. In Nagamangala taluk sulphur concentration significantly more deficit in Bellur hobli with a concentration of 9.03 ppm followed by Honakere (8.85 ppm). The lowest of 6.94 ppm of deficit sulphur concentration was observed in Bindiganavile hobli.

Taluk wise sufficient in available sulphur concentration are presented in Table 1. As per the statistical analysis in the Mandya district sulphur concentration was significantly highest in S.R. Patna taluka with an average mean concentration of 17.07 ppm followed by K.R. Pet (15.82 ppm). The lowest of 12.74 ppm of sulphur status was observed in Nagamangala taluk. As per the statistical analysis, the overall per cent of the highest sulphur concentration was observed in S.R. Patna taluk.

Taluks, deficient in available sulphur concentration are presented in Table 2. As per statistical analysis in Mandya district, the sulphur concentration was significantly more deficit in Malvalli taluk with a concentration of 7.92 ppm followed by K.R. Pet (7.97 ppm). 8.36 ppm of sulphur status was observed in Nagamangala taluk. As per the statistical analysis, the overall per cent of lowest sulphur status was observed in Malvalli taluk.

In the field experiment sulphur application at different levels through different sources significantly influenced the growth and yield parameters of aerobic rice. The growth parameters of aerobic rice *viz.,* plant height (cm), number of tillers per hill, number of leaves per hill, as influenced by different sources and levels of sulphur at different growth stages are presented in Table 3.

Plant Height

The plant height (cm) of aerobic rice was significantly influenced by various levels and sources of sulphur application at all the growth stages and the same is presented in Table 3. At 30, 60, 90 DAS and harvest, significantly higher plant height (27.13 cm, 59.73 cm, 77.93 and 85.87 cm, respectively) was observed with RDF + 26 kg sulphur per hectare through ammonium sulphate (T_6 treatment). Significantly lowest plant height was observed in absolute control (21.33 cm, 46.40 cm,67.07 and 74.13 cm, respectively).

Number of Tillers per Hill

The results on the number of tillers per hill of aerobic rice, as influenced by different sources and levels of sulphur at different growth stages are presented in Table 3. The number of tillers per hill varied significantly by different sources and levels of sulphur at all growth stages. At 30, 60, 90 DAS and at harvest, a significantly higher number of tillers (12, 15.8, 19.07 and 20.46 hill^{-1}, respectively) were observed with RDF + 26 kg sulphur per hectare through ammonium sulphate (T_6 treatment). Significantly lower numbers of tillers (7.13, 11.33, 14.73 and 17 tillers hill^{-1}) were observed under absolute control.

Number of Leaves per Hill

The data on a number of leaves hill^{-1} recorded at 30, 60, 90 DAS and at harvest as influenced by the application of different levels and sources of sulphur are presented in Table 3. The effect of different levels and sources of sulphur on the number of leaves per hill in aerobic rice crops was significant. At 30 and 60 DAS significantly the lower number of leaves hill^{-1} (27.27 and 40.37, respectively) was recorded in T_1 treatment (absolute control) and a significantly higher number of leaves hill^{-1} (49 and 65.07, respectively) was recorded in T_6 treatment.

Similarly, at 90 DAS and harvest, T_6 treatment (RDF + 26 kg sulphur per hectare through ammonium sulphate) registered a significantly higher number of leaves hill^{-1} (79.47 and 83.20, respectively) and it is at par with T_5 treatment (77.33 and 81.27, respectively) as compared to absolute control (59.67 and 66.93, respectively).

The plant height, the number of leaves per plant and the number of tillers per plant increased due to the application of S through different sources and levels of sulphur. In the effect among sources of sulphur, ammonium sulphate followed by elemental sulphur had a significant influence and was relatively better than other sources. With regard to levels, the highest growth parameters were recorded with the highest level of sulphur application @ 26 kg ha^{-1}. The two levels of S application varied significantly in their effect on growth components of aerobic rice.

The highest plant height, number of tillers per plant and number of leaves per plant was observed in T_6 treatment (RDF + FYM + 26 kg S per hectare through ammonium sulphate) at all the growth stages of plant 30, 60, 90 DAS and at harvest (Table 3). This could be attributed to the availability of nutrients in the root

TABLE 3

Effect of different sources and levels of sulphur on plant height, number of tillers and number of leaves per hill of aerobic rice

Treatments	Plant height (Cm)				No of tillers per hill				Number of leaves per hill			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T_1 - Absolute control	21.33	46.40	67.07	74.13	7.13	11.33	14.73	17.00	27.27	40.37	59.67	66.93
T_2 - RDF+FYM	21.87	46.40	67.47	75.07	9.87	11.93	15.00	17.13	28.87	41.87	64.00	70.27
T_3 - T_2+13 kg S ha^{-1} (Gypsum)	22.07	48.27	68.93	76.20	8.47	12.53	16.00	17.20	33.40	43.40	61.53	70.47
T_4 - T_2+26 kg S ha^{-1} (Gypsum)	23.47	51.13	69.67	81.67	7.67	13.67	17.30	17.67	35.67	55.67	64.47	72.53
T_5 - T_2+13 kg S ha^{-1} (Ammonium sulphate)	25.87	57.60	75.13	82.93	12.00	13.63	17.40	17.67	45.07	62.07	77.33	81.27
T_6 - T_2+26 kg S ha^{-1} (Ammonium sulphate)	27.13	59.73	77.93	85.87	10.07	15.80	19.07	20.47	49.00	65.07	79.47	83.20
T_7 - T_2+13 kg S ha^{-1} (Elemental sulphur)	21.80	49.07	68.20	77.93	8.40	12.20	16.20	17.53	30.30	43.67	64.33	71.47
T_8 - T_2+26 kg S ha^{-1} (Elementalsulphur)	23.00	50.87	74.07	78.87	8.00	12.67	16.43	17.60	31.00	49.60	67.47	73.33
T_9 - T_2+13 kg S ha^{-1} (20:20:0:13)	21.93	47.33	67.67	75.67	7.87	12.27	15.93	16.87	31.60	50.00	70.27	77.87
T_{10} - T_2+26 kg S ha^{-1} (20:20:0:13)	22.60	47.80	70.20	80.13	7.67	12.87	16.93	17.33	33.20	55.00	71.73	77.00
T_{11} - T_2+13 kg S (SSP)	22.27	49.00	68.27	77.47	10.40	12.40	16.13	17.20	32.93	59.33	70.27	74.89
T_{12} - T_2+26 kg S (SSP)	23.93	51.13	70.87	80.93	8.93	13.87	17.40	17.73	41.80	60.20	72.67	79.47
SEm±	0.89	2.30	2.17	2.34	0.49	0.41	0.52	0.54	1.07	2.18	2.17	2.31
CD (p=0.05)	2.64	6.82	6.43	6.94	1.45	1.21	1.55	1.61	3.16	6.49	6.45	6.85

zone of plants, where plants were able to utilize maximum nutrients. The superiority of ammonium sulphate over other sources of sulphur is mainly due to the agronomic efficiency of the fertilizer. The research findings also proved that combined application of nitrogen with sulphur source in chemically bound form proved better compared to the individual application of nitrogen and sulphur to the soil. Results of Fageria *et al.* (2011) also reported that ammonium sulphate is the most efficient source of fertilizer for paddy, which outperformed in all growth attributing characters of paddy by producing about two per cent higher plant height, four per cent higher shoot dry weight compared to urea as a source of N. Further they reported that in upland rice maximum plant height was achieved at 260 mg N kg^{-1} ammonium sulphate. Ahmed *et al.* (1989) also reported similar findings that sulphur fertilization to rice on clay loam soils produced a significantly higher number of tillers per plot.

Yield and Yield Components of Aerobic Rice

The data on yield components *viz.*, a number of panicles per hill, length of the panicle, the total number of grains per panicle, thousand-grain weight, per cent chaffyness, straw yield and grain yield of aerobic rice as influenced by different levels and sources of sulphur application are presented in Table 4.

Significantly greater number of panicles (15.93 $hill^{-1}$) was recorded in T_6 treatment (RDF + 26 kg sulphur per hectare through ammonium sulphate), followed by T_5 and T_{12} treatments (15.47 and 15.20 $hill^{-1}$, respectively). However, a lower number of panicles per hill was recorded in T_1 treatment, absolute

TABLE 4

Effect of different sources and levels of sulphur on yield parameters and yield of aerobic rice

Treatments	No of panicles /hill	Length of the panicle (cm)	No of grains / Panicle	Test Weight (g)	% Chaffyness	Straw Yield (kg ha^{-1})	Grain Yield (kg ha^{-1})
T_1 - Absolute control	12.33	17.23	76.53	20.05	11.67	3037	1999
T_2 - RDF+FYM	13.07	17.41	83.00	20.66	10	3116	2087
T_3 - T_2+13 kg S ha^{-1} (Gypsum)	13.93	18.02	83.53	20.84	7.67	3182	2116
T_4 - T_2+26 kg S ha^{-1} (Gypsum)	15.00	19.37	86.40	21.46	6.67	3294	2214
T_5 - T_2+13 kg S ha^{-1} (Ammonium sulphate)	15.47	18.48	107.80	22.80	7.00	3826	2564
T_6 - T_2+26 kg S ha^{-1} (Ammonium sulphate)	15.93	20.03	117.00	23.65	6.33	4240	2717
T_7 - T_2+13 kg S ha^{-1} (Elemental sulphur)	14.60	17.63	89.07	20.71	7.33	3721	2209
T_8 - T_2+26 kg S ha^{-1} (Elementalsulphur)	15.07	17.79	98.33	21.54	6.67	3774	2302
T_9 - T_2+13 kg S ha^{-1} (20:20:0:13)	13.53	18.02	83.73	21.01	8.33	3121	2286
T_{10} - T_2+26 kg S ha^{-1} (20:20:0:13)	14.53	18.16	92.33	21.25	8.0	3639	2428
T_{11} - T_2+13 kg S (SSP)	14.27	18.47	91.20	21.77	7.0	3734	2337
T_{12} - T_2+26 kg S (SSP)	15.20	19.50	100.60	22.31	8.33	3899	2440
SEm±	0.61	0.57	2.71	0.64	_	243.14	123.40
CD (p=0.05)	1.82	1.71	8.05	1.91	_	722.07	366.49

control (12.33 hill^{-1}). Application of RDF + 26 kg sulphur per hectare (T_6 treatment) registered significantly higher panicle length (20.03 cm), followed by T_{12} and T_4 treatments (19.50 and 19.37 cm, respectively). Treatment T_1 (absolute control) recorded the lowest panicle length of 17.23 cm. Different levels and sources of sulphur had a significant effect on the number of grains per panicle of aerobic rice. The significantly higher number of grains per panicle (117) was recorded in T_6treatment followed by T_5 and T_{12} treatments which were on par with each other. However, the lowest number of grains per panicle was observed in absolute control T_1 (76.53).

Different levels and sources of sulphur exerted a significant influence on thousand-grain weight (g) in aerobic rice. The highest thousand-grain weight (23.65 g) was recorded in T_6 treatment and was at par with T_5 and T_{12} treatments (22.80 and 22.31 g respectively). However, the lowest thousand-grain weight (20.05 g) was noticed in absolute control. Numerically lowest chaffy grain percentage (6.33) was recorded in T_6 treatment (RDF + 26 kg sulphur per hectare through ammonium sulphate) and the highest chaffy grain per cent was noticed under absolute control (11.67).

Grain and Straw Yield

The grain and straw yield of aerobic rice as influenced by different levels and sources of sulphur is presented in Table 4. A significantly higher straw yield (4240 kg ha^{-1}) was recorded with T_6treatment followed by T_{12} and T_5 treatments (3899 and 3826 kg ha^{-1}, respectively). The absolute control recorded the lowest straw yield of 3037 kg ha^{-1}. Grain yield of aerobic rice varied significantly with different levels and sources of sulphur treatments. RDF + 26 kg sulphur per hectare through ammonium sulphate recorded significantly higher grain yield (2717.85 kg ha^{-1}) and was on par with T_5, T_{10} and T_{12} treatments. However, the lowest grain yield was recorded under absolute control (1999 kg ha^{-1}).

The growth and yield of aerobic rice differed significantly by the application of suplur and further increased with increased doses. In the effect among sources of sulphur, Ammonium Sulphate followed by elemental Sulphur had a significant influence and relatively better than other sources, which indicated the better utilization of all nutrients due to ammonium sulphate application and hence moregrains. Further, the lowest percent chaffyness was also observed under ammonium sulphate treatment and these are confirmed with the results of Fageria *et al.* (2011), which reported that ammonium sulphate accounted for 70 per cent variability in panicle number, produced 12 per cent lower spikelet sterility and highest 1000 grain test weight of 22.7 g over other treatments and also concluded that ammonium sulphate was superior fertilizer for panicle production. The increased number of panicles per hill, panicle length, and higher test weight in treatment T_6 have contributed to significantly higher yield, which in turn increased growth parameters in this treatment.

As per the statistical analysis, among the 119 soil samples analysed for available sulphur content of paddy growing areas of Mandya district ninetytwo (77.32 %) samples were found sufficient and twenty seven (22.68 %) samples were deficit. In different taluks of Mandya district, four taluks *i.e.,* Mandya, Maddur, S.R. Patna and Pandavapura have recorded a sufficient range of sulphur status, whereas in other taluks namely Malvalli, K.R. Pet and Nagamangala taluks with deficient sulphur status were observed. Nagamangala taluk has the least sulphur status among all the taluks of Mandya district with all the five hoblis showing deficiency range of sulphur status. Overall the Mandya district has a good amount of sulphur content in paddy growning soil sand the high status of sulphur in these soils may be due to the application of sulfur-containing fertilizers and because of application of $ZnSO_4$ to soil and low sulphur use efficiency because of continuous paddy cultivation in most of the taluks of Mandya district. This has resulted in a buildup of sulphur in these soils.

Based on the present findings, it is concluded that irrespective of the sources, the increase in S levels (13 to 26 kg/ha) resulted in significant improvement in growth and yield attributes. The sulphur application

@ 26 kg/ha applied through ammonium sulphate improved growth and yield attributes and hence grain yield of aerobic rice. Among different sources of sulphur ammonium sulphate performed better.

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