



## **Status and Distribution of Sulphur in Acid Soils of Imphal East District, Manipur**

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### **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## **ABSTRACT**

A pot experiment was conducted with thirty soils of varying characteristics for selecting the most suitable chemical extractant for available sulphur. Rice variety CAU-R1(Tamphaphou) was grown in pots treated with and without sulphur for eight weeks. At harvest dry matter of rice was recorded. The average dry matter yield increased significantly @30 kg ha<sup>-1</sup> levels of S application. Sulphur in the soils was extracted with four different extractants. The extractable S of the soils varied considerably with the soils and the extractant used. In term of the efficiency of extraction, the extractants were in the order : 500 ppm Ca(H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub>.H<sub>2</sub>O > 0.5M NaHCO<sub>3</sub> > 0.5M NH<sub>4</sub>OAc > 0.15% CaCl<sub>2</sub>. Available sulphur extracted by 0.5M NH<sub>4</sub>OAc showed the highest correlation with Dry Matter Yield (0.510882\*\*), Total Plant Uptake (0.548974\*\*), Bray's % Yield (0.514887\*\*), Bray's % Uptake (0.70565\*\*). Therefore, 0.5M NH<sub>4</sub>OAc extractant was rated as most promising extractant for assessing S availability for rice in acid soils of Manipur. pH (-0.12481, -0.04153837, 0.15850443, -0.02106\*), EC (-0.2696\*, -0.08246, -0.21701\*, -0.28734\*), CEC (-0.27441\*, -0.24183\*, -0.18531, -0.28287\*), sand (-0.00152, -0.0166, -0.10168, 0.121165), silt (-0.00858, -0.15039, -0.10699, 0.030722), Ca<sup>2+</sup> (-0.1528, -0.1056, 0.007184, -0.09847) and Mg<sup>2+</sup> (-0.27248\*, -0.16614, -0.07896, -0.24056\*) had negative correlations with all extractants of S. The positive relationships of almost all extractants of sulphur with clay texture (0.040966, 0.20296\*, 0.306651\*\*, -0.0879), organic carbon (0.096396, 0.32224\*\*, 0.201351\*, -0.09377), nitrogen (0.036851, 0.203472\*, 0.24579\*, -0.06179), phosphorus (0.301882\*\*, 0.268273719\*, 0.322386047\*\*, 0.209681\*) and potassium (0.023932, -0.00667852, -0.04825616, 0.079524) were observed.

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## 1. INTRODUCTION

In India, according to the first estimates released by the agriculture and farmers welfare ministry, the kharif rice production is expected to reach a record level of 107.04 mt during 2021-2022, which is slightly higher than last year's figure of 104.41 mt [1]. Rice is the only major crop food that can be grown under a wide range of climatic and geographical conditions on five continents and occupies 11% of the world's cultivated area [2]. Role of sulphur in Indian agriculture is now gaining importance because of the recognition of its role in increasing crop production, not only of oil seeds, pulses and forages but also of many cereals [3]. Rice is the world's most important food crop and a primary source of food for more than half of the world's population. More than 90% of the world's rice is grown and consumed in Asia where 60% of the earth's people live. Rice accounts for 35 to 75% of the calories consumed by more than 3 billion Asians. It is planted to about 154 million hectares annually or on about 11% of the world's cultivated land [4]. Among the cereals, rice is an important food crop which ranks second after wheat in the world. Rice is the major staple food of 70% of the Indian population and being cultivated all over the country under varying agro-climatic regions. It occupies 44.6 million hectares which is 36.58% of the net cultivated area contributing 40% of country's food production [5]. In majority of Asian countries rice occupies one third or more of cultivated area [6]. Sulphur, one of the most important nutrient for all plants and animals, is considered as the fourth major nutrient after Nitrogen, Phosphorous and Potassium for agricultural crop production. Sulphur is a structural constituent of organic compounds, some of which are uniquely synthesized by plants, providing human and animals with essential amino acids (methionine, cystine and cysteine). It is involved in chlorophyll formation, activation of enzymes and is a part of vitamins, biotin and thiamin (B<sub>1</sub>) [7]. There are many other sulphur containing compounds in plants which are not essential, but may be involved in defense mechanisms against herbivores, pest and pathogens, or contribute to the special taste and odour of food plants. Sulphur improves oil and protein contents, flour quality for milling and baking, marketability of copra, quality of tobacco and nutritive value of forages Rahman et al., [8].

## 2. MATERIALS AND METHODS

Thirty bulk surface soil samples (0-15 cm depth) of varying soil characteristics were collected from three different blocks (Porompat, Sawombung and Keirao – bitra ) of Imphal East district of Manipur. Soils were air-dried, ground and passed through a 2 mm sieve. Processed soil samples were analyzed for some important physico-chemical properties following the standard procedures [9] and reported in Table 1 and 2. Sulphate-S in soil was extracted by using four different extractants viz., 500ppm Ca (H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub>.H<sub>2</sub>O (Ensminger,1954), 0.5M NH<sub>4</sub>OAc [10], 0.15% CaCl<sub>2</sub> (Williams and Steinbergs,1959) and 0.5M NaHCO<sub>3</sub> (Victor and Nearpass,1960). The soil samples were shaken for half an hour with a soil to solution ratio of 1:5 and extractable S was determined turbidimetrically (Chesnin and Yien,1951). During the period of experimentation, the mean minimum and maximum temperature recorded during the cropping season was 21.5 and 29.8°C, respectively. The average relative humidity in the morning hours was 89.66 per cent and in the evening it was 67.96 per cent. The average bright sunshine hour was 4.1 respectively during the period of investigation.

To understand the usefulness of the extractants, a pot culture experiment was conducted with each soil. Four kg of air-dried processed soils were taken in black polythene-lined earthen pots. There were five sulphur treatments viz., 0, 10, 20, 30 and 40 Kg S ha<sup>-1</sup> and gypsum was used as a source of sulphur. Each of the treatments was replicated thrice in a two factorial completely randomized design to give a total of 450 pots. A basal dose of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O @ 60:40:30 Kg ha<sup>-1</sup> were applied in the form of Urea, Single Super Phosphate (SSP) and Muriate of Potash (MOP) to each pot to support the normal plant growth. All pots were kept submerged with distilled water to a depth of 5cm. Weeds were removed as they appeared. The plants were grown for eight weeks with a protection from insects and diseases. Plants were uprooted carefully at ground level followed by washing with distilled water and drying in a hot air oven at 60°C for 48 hours and dry matter yield was recorded. Later, the dried plant samples were ground and sieved through 2 mm sieve and kept for analyzing plant nutrient content. The simple correlation co-efficients between the amount of S extracted by different

extractants were worked out to find out the suitability of various extractants. Accordingly the Bray's % yield (known as relative yield) was calculated from the following relationship.

$$\frac{\text{Bray's \% Yield}}{\frac{\text{Yield without sulphur (Control)}}{\text{Maximum Yield in fertilizer treated pots}}} \times 100 =$$

varied from 4.59 – 5.43 with a mean value of 5.03 .The EC content of the soils varied from 0.05 – 0.29 d Sm<sup>-1</sup> with a mean value of 0.13 d Sm<sup>-1</sup>.The organic carbon content of the soil ranging from 10.5 – 27.0 g kg<sup>-1</sup> with a mean value of 17.2 g kg<sup>-1</sup>.CEC of the soils ranged from 10.28 – 20.10 Cmol (p+) kg<sup>-1</sup> with a mean value of 15.07 C mol (p+) kg<sup>-1</sup>.The available N,P and K ranged from 214.21 – 489.85 Kg ha<sup>-1</sup> , 17.28 – 57.62 Kg ha<sup>-1</sup> and 145.89 – 369.47 Kg ha<sup>-1</sup> with a mean values of 330.22 Kg ha<sup>-1</sup> ,28.80 Kg ha<sup>-1</sup> and 266.08 Kg ha<sup>-1</sup> , respectively. The variation in soil texture may be ascribed to difference in parent material and influence of pedogenesis [11]. The acidic nature of Manipur soils may be due to the high organic matter content [12]. The probable reason for low electrical conductivity

### 3. RESULTS AND DISCUSSION

#### 3.1 Soil Properties

The physical and chemical characteristics of bulk soil samples are presented in Table 1.The sand, silt and clay fractions varied from 8.20 - 34.70% ,6.10 - 32.50% and 36.40 – 80.92%. Majority of the soils were clay in texture. The pH of the soils

**Table 1. Particle size distribution of the soils of Imphal east district covering all blocks**

Soils	Latitude	Longitude	SAND	SILT	CLAY	TEXTURE
Koirengei	24°49'23.58N	93°54'05.33E	27	13.2	59.8	Clay
Thongju	24°45'43.30N	93°57'07.90E	19	16.8	64.2	Clay
Luwangsangbam	24°53'30.31N	93°54'49.67E	24.9	13.5	61.6	Clay
Mongjam	24°53'35.77N	93°56'17.93E	23.1	19	57.9	Clay
Nilakuthi	24°53'14.30N	93°54'26.24E	22.8	16.7	60.5	Clay
Khongman	24°48'50.85N	93°58'22.55E	25.6	20.1	54.3	Clay
Top dusara	24°48'59.88N	93°58'41.91E	29.4	23.6	47	Clay
Chingangbam leikai	24°47'45.59N	93°58'00.29E	30.2	10.8	59	Clay
Uchkeekon	24°45'43.26N	93°57'07.84E	30.5	15.6	53.9	Clay
kabosiphai	24°50'31.91N	93°58'56.37E	28.1	14	57.9	Clay
Pourabi	24°46'32.03N	93°58'12.84E	24.8	22.5	52.7	Clay
Pangei	24°52'21.79N	94°00'46.18E	29.8	32.5	37.7	Clay
Taorem	24°52'59.27N	94°01'22.55E	20.6	22.4	57	Clay
Heirok	24°53'26.62N	94°01'49.36E	19.7	18.5	61.8	Clay
Keibi heikak mapal	24°53'54.55N	94°02'07.22E	8.2	31.8	60	Clay
Taretkhul	24°54'36.09N	94°02'18.43E	34.7	10.9	54.4	Clay
Keibi leishangkhong	24°55'22.26N	94°02'35.61E	17.1	13.2	69.7	Clay
Sekta	24°54'28.61N	94°03'02.84E	27.2	15.3	57.5	Clay
Pungdongbam	24°53'19.91N	94°02'19.19E	17.6	13.1	69.3	Clay
Khongbal tangkhul	24°52'12.10N	94,01,37.60E	28.2	20.67	51.13	Clay
Bamon kampu	24°45'18.60N	93°58'49.17E	23	14.6	62.4	Clay
Keirao - Langdum	24°43'58.17N	94°00'18.52E	34	29.6	36.4	Clay
Khanarok	24°42'48.36N	94°01'45.22E	24.3	9	66.7	Clay
Huikap	24°44'02.61N	94°02'12.27E	28.2	7.2	64.6	Clay
Andro	24°44'28.50N	94°02'31.68E	29.34	19.75	50.91	Clay
Angtha	24°41'50.95N	94°01'29.87E	33.7	23	43.3	C.L
Kaina	24°41'28.07N	94°01'44.65E	12.98	6.1	80.92	Clay
Kamu yaithibi	24°41'05.11N	94°02'15.13E	25.5	21.1	53.4	Clay
Uchekon khunou	24°46'12.70N	93°58'09.00E	32.4	18.6	49	Clay
Kalika	24°47'09.92N	93°58'10.16E	27.3	24.1	48.6	Clay
Mean			25.60	18.21	56.78	
Range			8.20-34.70	6.10-32.50	36.40-80.92	

Table 2. Physico – chemical properties of the soils

Soils	pH	EC (d Sm <sup>-1</sup> )	OC (g kg <sup>-1</sup> )	CEC Cmol(p+)kg <sup>-1</sup>	N (Kg ha <sup>-1</sup> )	P (Kgha <sup>-1</sup> )	K (Kgha <sup>-1</sup> )	Ca <sup>2+</sup> Cmol(p+)kg <sup>-1</sup>	Mg <sup>2+</sup> Cmol(p+)kg <sup>-1</sup>
Koirengei	4.86	0.11	13.7	15.71	250.75	21.47	145.89	1.15	0.65
Thongju	5.12	0.20	17.4	17.68	421.76	33.54	336.41	0.64	0.44
Luwangsangbam	4.79	0.12	27.0	14.54	230.70	27.63	201.13	1.45	0.92
Mongjam	5.38	0.21	18.6	17.72	291.41	35.68	253.84	1.32	0.76
Nilakuthi	5.20	0.17	17.1	10.28	318.52	39.41	210.64	1.27	0.74
Khongman	5.11	0.25	26.1	11.39	439.05	17.28	345.82	1.32	0.82
Top dusara	4.81	0.09	16.3	13.81	271.95	22.19	279.88	0.72	0.61
Chingangbam leikai	5.01	0.10	11.5	20.10	400.41	27.11	253.71	0.91	0.62
Uchkeckon	4.83	0.13	12.4	16.84	335.16	35.02	316.36	1.17	0.89
kabosiphai	4.59	0.21	22.0	16.57	277.18	25.20	265.82	1.41	0.85
Pourabi	4.88	0.14	12.2	15.09	214.21	20.46	302.04	1.67	0.76
Pangei	5.24	0.29	10.6	13.28	300.94	18.44	241.74	1.79	0.66
Taorem	4.98	0.18	17.2	18.61	489.22	21.59	210.63	1.61	0.91
Heirok	4.76	0.11	10.5	14.19	295.96	24.17	264.42	1.31	0.81
Keibi heikak mapal	5.31	0.11	16.8	11.78	358.28	29.93	212.18	0.94	1.03
Taretkhul	4.82	0.05	19.4	19.74	301.05	17.96	319.32	1.72	0.82
Keibi leishangkhong	5.33	0.12	15.3	15.94	315.72	39.82	369.47	0.78	0.84
Sekta	4.93	0.08	20.4	12.05	395.14	24.56	164.64	1.34	0.61
Pungdongbam	5.43	0.13	21.0	18.53	326.58	33.59	233.18	1.95	0.74
Khongbal tangkhul	5.29	0.15	19.8	12.02	489.85	29.38	218.34	1.92	0.63
Bamon kampu	5.31	0.08	18.9	12.71	268.33	22.34	315.38	0.90	0.75
Keirao - Langdum	4.79	0.09	16.2	15.38	338.67	32.41	268.72	1.55	0.58
Khanarok	4.87	0.12	20.7	19.23	330.84	23.48	281.04	0.99	0.74
Huikap	5.26	0.21	15.4	15.03	394.15	32.84	300.23	1.86	0.79
Andro	4.91	0.07	14.4	12.61	282.39	57.62	269.48	1.41	0.94
Angtha	5.15	0.17	18.1	10.95	250.68	28.31	336.82	1.23	0.86
Kaina	4.96	0.13	11.9	13.64	318.50	30.14	289.63	0.79	0.55
Kamu yaithibi	4.98	0.12	14.8	16.90	334.61	28.74	245.18	1.86	0.77

<b>Soils</b>	<b>pH</b>	<b>EC (d Sm<sup>-1</sup>)</b>	<b>OC (g kg<sup>-1</sup>)</b>	<b>CEC Cmol(p+)kg<sup>-1</sup></b>	<b>N (Kg ha<sup>-1</sup>)</b>	<b>P (Kgha<sup>-1</sup>)</b>	<b>K (Kgha<sup>-1</sup>)</b>	<b>Ca<sup>2+</sup> Cmol(p+)kg<sup>-1</sup></b>	<b>Mg<sup>2+</sup> Cmol(p+)kg<sup>-1</sup></b>
Uchekon khunou	5.27	0.07	22.4	14.53	332.43	36.45	216.21	1.13	0.61
Kalika	4.99	0.16	19.8	15.53	332.21	20.83	314.26	1.19	0.91
Mean	5.03	0.13	17.2	15.07	330.22	28.58	266.08	1.31	0.75
Range	4.59-5.43	0.05-0.29	10.5-27.0	10.28-20.10	214.21-489.85	17.28-57.62	145.89-369.47	0.64-1.95	0.44-1.03

may be attributed to the fact that the climate of the study area is sub-tropical due to which soluble salts rise up by capillary action [11]. The wide variation of organic carbon content may be due to various locations, altitude of the state, previous soil management. The increase in organic carbon content in soil with application of N, P, K and S had also been reported by Vandana et al., [13]. The build up of organic carbon in sulphur applied plots might have increased the CEC of soil [14]. The variation of available nitrogen content in the soil may be due to different amounts of organic carbon present in soils which release variable amount of inorganic nitrogen into the soil on mineralization. The increase in soil P content with increasing sulphur fertilizer levels [15] and Ahmad et al., [16]. This could be attributed to the increase in root activity, plant root excrete organic acids and chelating organic compounds in rhizosphere which form multiple complex compounds with Calcium, magnesium and iron and thereby increase phosphorus availability in soil. The variation in K might be due to variation in the nature and quantity of adsorbed K resulting in K surplus in soil solution. Higher value of surface layer indicate a greater K release into solution, which result in a larger pool of labile K. The soil was low in exchangeable base which is due to the higher rainfall and season variation normally observed in the area leading to intense leaching of bases and accumulation of exchangeable acidity in these soils.

### 3.2 Extractable Sulphur

The variations in extractable soil S content by various extractants were due to differences in their nature and strength for extraction of soil S from various soil S pool. 500 ppm monocalcium phosphate ( $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ ) extractable sulphur in these soils ranged from 10.12 ppm to 80.34 ppm. The mean value of 500 ppm monocalcium phosphate ( $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ ) was 44.33 ppm. Among the extractants, phosphate containing extractants such as  $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$  extracted more S than others. The higher extractability could be attributed to the powerful replacing capacity of phosphate ions for sulphate. This revealed that the phosphate containing solution extracted more amount of S possibly because adsorbed sulphate also get extracted from the soils. This is in conformity with the findings reported by Pandey and Girish [17] and Singh et al. [18]. 0.5M  $\text{NH}_4\text{OAc}$  (Ammonium acetate) extractable sulphur was between 7.81 ppm to 70.16 ppm with a mean value of 34.82

ppm. Acetate extractants like  $\text{NH}_4\text{OAc}$  reagent probably extracted some amount of organic S in addition to soluble sulphate fraction. Soluble sulphates and adsorbed sulphates were extracted by acetate, phosphate and bicarbonate solutions. Chloride solutions did not extract an appreciable quantity of adsorbed sulphates. Hence, S extracted with acetate extractants was relatively higher than those extracted with chloride salt. Similar findings were also reported by Kumar et al., [19]; Ensminger and Freney, [20]. The 0.15% Calcium Chloride [0.15%  $\text{CaCl}_2$ ] extractable sulphur was varied from 5.64 ppm to 35.52 ppm with a mean value of 18.66 ppm. This extractant has been shown to extract mainly water-soluble inorganic sulphate and little or no organic and adsorbed S. Similar finding by Williams and Steinbergs, (1959). Extractant like 0.15%  $\text{CaCl}_2$  extract only the soluble sulphate [21] but cannot displace adsorbed sulphate [22] because the chloride ion may be a poor competitor for adsorption site. Hence, the amount of extracted -S was found to be low. Similar findings were also reported by [18]. The 0.5M Sodium bicarbonate (0.5M  $\text{NaHCO}_3$ ) extractable sulphur was varied from 17.23 ppm to 69.31 ppm with a mean value of 41.16 ppm. A number of field and glasshouse experiments have shown that  $\text{NaHCO}_3$  - extractable soil S represents not only immediately plant -available soil S i.e., readily soluble and adsorbed soil S but also potentially mineralisable soil organic S [23]. Although the ability of phosphate and bicarbonate extractants to displace adsorbed sulfate suggests that they might be better extractants for studying mineralized sulfate, particularly for soils with a high sulfate adsorption capacity [24]. Kilmer and Nearing, [23] also reported that a 0.5 M sodium bicarbonate extracts a fraction of the organic S present in soils in addition to soluble sulphates and adsorbed sulphates.

### 3.3 Correlations Relationship between Different Extractants of Sulphur and Physico – Chemical Properties of Soil

The results on the relationship between different extractants of sulphur with different soil properties are expressed in the forms of their coefficient of correlation value (r) for the collected soil samples. The data on correlation co-efficient between physico- chemical properties and extractant of sulphur are presented in Table (4) pH and electrical conductivity had negative correlations with all extractants of S. This might be due to the presence of  $\text{H}^+$  and  $\text{OH}^-$  ions on the

**Table 3. Amount of sulphate - sulphur of soils extracted by different extractants (PPM)**

Soils	Latitude	Longitude	500 ppm $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	0.5M $\text{NH}_4\text{OAc}$	0.15% $\text{CaCl}_2$	0.5M $\text{NaHCO}_3$
Koirengei	24'49'23.58N	93'54'05.33E	22.51	20.48	18.63	21.4
Thongju	24'45'43.30N	93'57'07.90E	42.51	45.62	16.38	39.52
Luwangsangbam	24'53'30.31N	93'54'49.67E	35.11	48.73	28.16	30.07
Mongjam	24'53'35.77N	93'56'17.93E	50.15	40.56	12.57	45.13
Nilakuthi	24'53'14.30N	93'54'26.24E	45.49	34.52	34.5	40.52
Khongman	24'48'50.85N	93'58'22.55E	55.29	55.82	9.34	50.24
Top dusara	24'48'59.88N	93'58'41.91E	70.52	47.84	23.39	65.58
Chingangbam leikai	24'47'45.59N	93'58'00.29E	40.63	35.15	6.06	36.49
Uchkeckon	24'45'43.26N	93'57'07.84E	58.47	29.81	10.54	60.54
kabosiphai	24'50'31.91N	93'58'56.37E	39.17	36.52	18.01	30.13
Pourabi	24'46'32.03N	93'58'12.84E	49.26	41.19	13.9	65.51
Pangei	24'52'21.79N	94'00'46.18E	23.86	7.81	10.05	22.86
Taorem	24'52'59.27N	94'01'22.55E	10.12	10.11	7.12	17.23
Heirok	24'53'26.62N	94'01'49.36E	48.15	35.71	25.18	47.34
Keibi heikak mapal	24'53'54.55N	94'02'07.22E	39.53	30.45	10.41	38.51
Taretkhul	24'54'36.09N	94'02'18.43E	24.87	20.32	26.67	24.85
Keibi leishangkhang	24'55'22.26N	94'02'35.61E	46.19	35.11	29.13	45.19
Sekta	24'54'28.61N	94'03'02.84E	80.34	70.16	23.86	69.31
Pungdongbam	24'53'19.91N	94'02'19.19E	38.65	24.47	9.01	27.64
Khongbal tangkhul	24'52'12.10N	94,01,37.60E	57.13	36.58	19.76	56.1
Bamon kampu	24'45'18.60N	93'58'49.17E	43.56	25.68	5.64	43.51
Keirao - Langdum	24'43'58.17N	94'00'18.52E	50.28	39.76	22.12	49.27
Khanarok	24'42'48.36N	94'01'45.22E	53.52	32.79	27.19	37.39
Huikap	24'44'02.61N	94'02'12.27E	47.85	66.68	35.52	32.83
Andro	24'44'28.50N	94'02'31.68E	54.35	45.63	19.85	48.33
Angtha	24'41'50.95N	94'01'29.87E	27.42	17.42	20.14	26.41
Kaina	24'41'28.07N	94'01'44.65E	39.11	24.98	22.68	35.09
Kamu yaithibi	24'41'05.11N	94'02'15.13E	50.68	15.61	16.85	56.45
Uchekon khunou	24'46'12.70N	93'58'09.00E	54.25	47.82	26.85	44.27
Kalika	24'47'09.92N	93'58'10.16E	31.17	21.34	10.48	27.13
Mean			44.33	34.82	18.66	41.16
Range			10.12 – 80.34	7.81 – 70.16	5.64- 35.52	17.23 – 69.31

Notes:  $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$  = Monocalcium Phosphate (MCP),  $\text{NH}_4\text{OAc}$  = Ammonium acetate, 0.15%  $\text{CaCl}_2$  = Calcium chloride,  $\text{NaHCO}_3$  = Sodium bicarbonate

**Table 4. Correlation co-efficient (R) between soil properties and different extractants of sulphur**

Extractants	500 ppm MCP	0.5M NH <sub>4</sub> OAc	0.15% CaCl <sub>2</sub>	0.5M NaHCO <sub>3</sub>
Sand	-0.00152	-0.0166	-0.10168	0.121165
Silt	-0.00858	-0.15039	-0.10699	0.030722
Clay	0.040966	0.20296*	0.306651**	-0.0879
pH	-0.12481	-0.04153837	-0.15850443	-0.02106*
EC	-0.2696*	-0.08246	-0.21701*	-0.28734*
OC	0.096396	0.32224**	0.201351*	-0.09377
CEC	-0.27441*	-0.24183*	-0.18531	-0.28287*
N	0.036851	0.203472*	0.24579*	-0.06179
P	0.301882**	0.268273719*	0.322386047**	0.209681*
K	0.023932	-0.00667852	-0.04825616	0.079524
Ca <sup>2+</sup>	-0.1528	-0.1056	0.007184	-0.09847
Mg <sup>2+</sup>	-0.27248*	-0.16614	-0.07896	-0.24056*

\*\*Correlation co-efficients (r) is Significant at 1% (0.01) level

\* Correlation co-efficients (r) is Significant at 5% (0.05) level

**Table 5. Linear regression (R<sup>2</sup>) Between soil properties and different extractants of sulphur**

Extractants	500 ppm MCP	0.5M NH <sub>4</sub> OAc	0.15% CaCl <sub>2</sub>	0.5M NaHCO <sub>3</sub>
Sand	0.00000231	0.000276	0.010338	0.014681
Silt	0.0000735	0.022616	0.011448	0.000944
Clay	0.001678	0.041193	0.094035	0.007726
pH	0.015578	0.001725436	0.025123653	0.000444
EC	0.072686	0.006799	0.047094	0.082567
OC	0.009292	0.103838	0.040542	0.008792
CEC	0.075303	0.058483	0.034339	0.080013
N	0.001358	0.041401	0.060413	0.003818
P	0.091133	0.071970788	0.103932763	0.043966
K	0.000573	0.0000446	0.002328657	0.006324
Ca <sup>2+</sup>	0.023347	0.011152	0.0000516	0.009697
Mg <sup>2+</sup>	0.074246	0.027601	0.006235	0.05787

**Table 6. Correlation co-efficients (R) between different extractants of sulphur**

Extractants	500 ppm MCP	0.5M NH <sub>4</sub> OAc	0.15% CaCl <sub>2</sub>	0.5M NaHCO <sub>3</sub>
500 ppm MCP	1			
0.5M NH <sub>4</sub> OAc	0.72513**	1		
0.15% CaCl <sub>2</sub>	0.256174*	0.417542**	1	
0.5M NaHCO <sub>3</sub>	0.89886**	0.538815**	0.084796	1

Note:

\*\*Correlation co-efficients (r) is Significant at 1% (0.01) level

\* Correlation co-efficients (r) is Significant at 5% (0.05) level

**Table 7. Correlation co-efficients (R) Between sulphur extractants with DMP (control), total uptake (control), bray's % yield and bray's % uptake**

Extractants	DMP (g pot <sup>-1</sup> )	Uptake(mg pot <sup>-1</sup> )	Bray's % yield	Bray's % uptake
500 ppm MCP	0.410696**	0.401707**	0.42593**	0.521069**
0.5M NH <sub>4</sub> OAc	0.510882**	0.548974**	0.514887**	0.70565**
0.15% CaCl <sub>2</sub>	0.308673**	0.230554*	0.414401**	0.386195**
0.5M NaHCO <sub>3</sub>	0.273913*	0.286575*	0.2718*	0.354376**



**Table 8. Linear regression ( $R^2$ ) between sulphur extractants with DMP (control), total uptake (control), bray's % yield and bray's % uptake**

Extractants	DMP(g pot <sup>-1</sup> )	Uptake (mg pot <sup>-1</sup> )	Bray's % yield	Bray's % uptake
500 ppm MCP	0.168671	0.161369	0.181417	0.271513*
0.5 M NH <sub>4</sub> OAc	0.261*	0.301372**	0.265109*	0.497941**
0.15% CaCl <sub>2</sub>	0.095279	0.053155	0.171728	0.149147
05M NaHCO <sub>3</sub>	0.075028	0.082125	0.073875	0.125582

\*\* Linear regression ( $r^2$ ) is Significant at 1% (0.01) level

\* Linear regression ( $r^2$ ) is Significant at 5% (0.05)level

soil-exchange complex where sulfate ions attracted to H<sup>+</sup> ions. The statistical minus symbol (-) entailed that when 500 ppm MCP, 0.5 M NH<sub>4</sub>OAc, 0.15% CaCl<sub>2</sub> and 0.5 M NaHCO<sub>3</sub> contents increased in soils there was reduced in pH and Vice -Versa. A similar negative relationship with pH and electrical conductivity (EC) was reported by Sharma and Gangwar, [25] where SO<sub>4</sub><sup>2-</sup> ions are attracted to H<sup>+</sup> ions and formation of insoluble compounds of S with Fe and Al oxides [26]. Electrical conductivity showed no significant relation with all other extractants of sulphur. The positive relationships of almost all extractants of sulphur with organic carbon were observed. The observed significant positive correlation with all extractants of sulphur with organic carbon suggests that the sulphur supplying power of these soils having largely dependent upon these parameters [27]. Simultaneous increase in the status of organic sulphur with increase in organic carbon content may be due to organic matter which is a source of the nutrients especially N, P and S. Similar results were obtained by Jat and Yadav, [28]. Organic carbon and available N, P, K content were positively correlated with the different extractants of sulphur because organic matter could be a good reservoir or source of sulphur. All the extractants of S gave significant positive correlation with OC, indicating sulphur as the integral part of soil organic matter and all the extractants of sulphur was positively and significantly correlated with each other suggesting a dynamic equilibrium among them. Similar was observed by [29]. Maintaining the trend of soil Ph, CEC also showed negative correlation with all the S extractants. Sand content of soil was negatively correlated with all the S extractants. This indicates that the sand particles are attributed to less organic carbon accumulation and high leaching. The correlations of silt content with different S extractants were found to be mostly negative whereas strong found to be positive correlations were recorded between clay content and S extractants. This might be due to appreciable quantity of sulphur is

adsorbed on finer fraction of soil and its availability is increase with increase in fineness of particles. The association of clay minerals with organic matter and sulphate and non-sulphate bearing minerals might be responsible for such relationship, as reported by Kher and Singh, [30] and Patel et al., [31]. Thus, indicating that these soil properties played a major role in availability of sulphur content. The availability of phosphorus also increase with increase in organic carbon due to the formation of phosphorus humic complex which are easily assimilated by plants, anion replacement of phosphate by humation and coating of sesquioxide by particles of humus to form a protective cover and thus reduced the phosphate fixing capacity of the soils. The similar findings were also reported by Akbari et al., [32].

### 3.4 Response of Sulphur to Rice Plant

The dry matter yield of rice variety CAU-R1 (Tampaphou) was affected by the application of sulphur regardless of the initial sulphur status in the soils. The results indicated that the dry matter yield of rice was greatly influenced by different levels of sulphur concentration. Dry matter accumulation/assimilation are the important growth and development phenomenon which provide platform for realization of economic produce for any crop [33]. With the progression of stage dry matter accumulation was increased, it was not like the LAI which was decreased after panicle initiation stage. Sulphur had significant effects on dry matter assimilation during all the phenological stages [34,35]. Application of sulphur at 30 kg prove superior or at par with corresponding lower and higher dose, similar types of results were also noticed by Charati and Malakouti, [36]. Higher straw yield due to S may be attributed to increase in growth and yield characters of rice and to be stimulating effect of applied S in the Synthesis of chloroplast protein resulting in greater photosynthetic efficiency, which in turn increased the yield [37].

It is evident from the Table (4) that sulphur uptake by rice CAU-R1 Tamphaphou was highest with sulphur applied at the rate of 30 kg S ha<sup>-1</sup> (26.36 g pot<sup>-1</sup>) which was significantly superior over control (12.14 g pot<sup>-1</sup>). Significant increase in S uptake within S levels could be due to increased availability of S in the soil from applied with concomitant increase in dry matter yield. The increasing dosage of sulphur @ 30 kg S ha<sup>-1</sup> increases the metabolism and nutrient uptake of the plants which leads to increased uptake of sulphur from soil by the plants.

### 3.5 Suitability of the Sulphur Extractants

Data revealed that all the extractants for available S showed significant positive correlation with biological attributes such as Bray's % yield and Bray's % uptake. Thus, it appeared that all these four extractants were suitable for estimation of available S for rice plant but with varying degree. However, among the extractants, available S extracted by 0.5M NH<sub>4</sub>OAc gave the highest correlation with DMP, Total Uptake, Bray's % yield and Bray's % uptake. Similar finding was reported by Huda et al., [38].

## 4. CONCLUSION

Perusal of the data indicated that the abundance of various extractants of sulphur in these soils was in the order of 500 ppm Ca(H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub>·H<sub>2</sub>O > 0.5M NaHCO<sub>3</sub> > 0.5M NH<sub>4</sub>OAc > 0.15% CaCl<sub>2</sub> and their availability was influenced by various soils properties. The results indicated that different extractants of sulphur in these soils follow each other and are inter-related within them. All the extractants for available S showed significant positive correlation with biological attributes such as DMP, Total uptake, Bray's % yield and Bray's % uptake. Among the extractants, 0.5M NH<sub>4</sub>OAc was found to be the best extractant for assessing the available soil S. pH, EC, CEC, Sand, Silt, Ca<sup>2+</sup> and Mg<sup>2+</sup> had a negative correlations with all extractants of S. The positive relationships of almost all extractants of sulphur with Clay texture, organic carbon, nitrogen, phosphorus and potassium were observed.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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