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Soil Science

Forms of Sulphur and Evaluation to the Sulphur Test Methods for Moongbean in Some *terai* Soils of Eastern India

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Abstract

Surface soil samples of some *terai* soils of Eastern India were collected and analysed to evaluate different forms of sulphur status and soil test methods for predicting response of moong bean crop to sulphur application. The range of water soluble, sulphate, adsorbed, organic form and total sulphur were 6.91 to 26.23 (mean 16.69), 13.73 to 30.38 (mean 20.67), 3.19 to 42.91 (mean 18.37), 150.27 to 372.73 (mean 229.57) and 178.57 to 433.09 (mean 264.63) ppm, respectively. Soil pH, organic carbon, cation exchange capacity and total N content in soil were positively correlated to the all forms of sulphur. Although clay content was negatively correlated to water soluble and sulphate sulphur, but silt+clay content in soil was positively correlated to water soluble sulphur and negatively correlated to adsorbed sulphur content in these soils. Amongst the five chemical extractants employed, relative suitability of the extractants for predicting available sulphur status for these soils with reference to moong bean crop were in the order: Morgan > monocalcium phosphate 500ppm P > 0.15% $CaCl_2$ > 1 *N* NH_4OAc > 1% NaCl. Therefore, Morgan's extractant may be used as an index of available sulphur for moong bean (B1, Sonali) grown on acid soils of terai tract of Eastern India, the critical level being 18.0 mg kg^{-1}.

Highlights

- Organic form of sulphur is the most dominant form of sulphur in terai soils.
- Organic matter plays an important role in supplying available sulphur in the soil
- Morgan's extractant is most suitable for moong bean crop and critical limit is 18.0 mg kg^{-1} in *terai* soils of Eastern India.

Keywords: Sulphur forms, soil test methods, critical level, moongbean

Introduction

Sulphur is the fourth major plant nutrient element. It is essential for synthesis of amino acids like cystine, cysteine and methionine which are the basic structural units of protein molecules. It activates certain enzyme systems and is a component of some vitamins. It resembles N for many functions in plants and is synergistic to nitrogen fixation and nodule development in legumes. It is required by plants in amounts similar to phosphorus for cell wall formation, protein synthesis, enzyme reaction and energy transfer.

Terai soils of Eastern India, in general, are considered to be low in productivity and characterized as coarse textured, acidic in reaction with multinutrient deficiency problems. Besides micronutrient elements, emerging trend of sulphur response in some crops particularly in oilseeds and legumes has reportedly observed in various pockets of *terai* soils under humid sub-tropical setting. But sulphur availability and requirement to the plant etc. are very meager with reference to the *terai* soils and more so with those of humid sub-tropical region of Eastern India. A large number of chemical extractants have been evaluated for the extraction of available sulphur. It has been shown by many workers that for a given soil-crop situation, more than one extractant can be suitable but the critical limits used for categorizing soils into deficient, marginal and sufficient categories, will vary with the methods (Nayyar *et al.*, 1990, Palaskar and Ghosh, 1985). Even more with soils of a homogeneous group when extracted for sulphur by a given extractant, the estimates of its critical limit may differ in accordance with crops, seasons, water supply and also varieties. Available sulphur content in soils within the limit between 5 mg kg^{-1} and 30 mg kg^{-1} is generally considered to be the critical level depending upon the analytical methods, soils and crops (Tandon, 1991). A substantial volume of research work conducted so far in this direction has found to be confined mostly with four crops namely rice, groundnut, mustard and soybean and most so the information available in this concern are restricted to the soils of sub-humid to semi-arid regions. Results of these studies recorded that among extractants, the most commonly used is 0.15% $CaCl_2$, followed by phosphate solutions, heat-soluble sulphur, Morgan's extractant and NH_4OAc. However, no conclusive information about sulphur availability indices is found available for the *terai* soils under humid sub-tropical regions with high rainfall of Eastern India.

Materials and Methods

Twenty one (21) soil samples of surface layers (0 – 0.15 m) collected in bulk from typical rice and mustard growing fields located at different soil series (Lotafela, Balorampur, Rajpur, Matiarkuthi under CoochBehar District and Berubari, Binnaguri under Jalpaiguri district of West Bengal, according to the Technical Bulletin, 89, NBSS & LUP, 2001) and some benchmark sites *viz*. Kharibari of Darjeeling district, Pundibari of CoochBehar district, Islampur of North Dinajpur district and Moinaguri as well as Dhupguri of Jalpaiguri district of West Bengal which together representing to the *terai* soils of West Bengal under humid sub-tropical region of Eastern India were used for different studies. After collection, samples were processed and analysed for determining important physico-chemical properties by standard methods and different forms of sulphur (S) like total sulphur (Tabatabai *et al.*, 1982), available sulphur /sulphate sulphur (Williams and Steinbergs, 1959), water soluble sulphur (Williams and Steinbergs, 1959), were extracted and sulphate in the extracts were determined by turbidimetric method (Chesnin and Yien, 1951). Adsorbed sulphur was calculated from the difference between phosphate extractable sulphur (Fox *et al.*, 1964) and $CaCl_2$ extractable sulphur and also organic sulphur was calculated by the difference between total sulphur and phosphate extractable sulphur (Freney *et al.* 1962).

Greenhouse experiment

A greenhouse experiment was conducted through these twenty one number of selected soils were used for moong bean (Var. B1, Sonali) as a test crop. For this experiment each soil weighing 3kg was filled in polythene pots sealed at the bottom. Sulphur was applied to each soil at four graded levels as per doses fixed for moong bean as a test crop including one treatment as the control where no sulphur was externally added. Each treatment pot was replicated thrice. All treatment chemicals were thoroughly mixed in the whole soil mass (bulk) before filling in the pots and it was followed in each soil. Required quantity of de-ionized water was added to each treatment pot to maintain optimum moisture condition suitable (40% WHC) for crop growth and pots were then allowed to stand four days to achieve the equilibrium condition. Sampling was made at 50% flowering stage. Above ground plant parts from each treatment pot were harvested by destructive sampling, washed first in running tap water followed by dilute 0.01 *N* HCl and finally with double distilled water and then dried (60^0C) in a hot-air oven. Plant biomass weight was recorded on oven-dry basis and then ground for chemical analysis. Sulphur in plant digest (using di-acid mixture:: 9:4) was estimated turbidimetrically.

Treatment details

Five different chemical extractants namely (i) 0.15% $CaCl_2$ solution (Williams and Steinbergs, 1959), (ii) 1.0% NaCl solution (Williams and Steinbergs, 1959), (iii) Morgan's solution (Chesnin and Yien, 1951) (iv) 1*N* NH_4OAc-HOAc

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solution (Hoeft *et al*., 1973) and (v) $Ca(H_2PO_4)_2$, 500 mg PL^{-1} solution (Fox *et al*., 1964), were tried to find out the most promising extractant for available S with moong bean as test crop.

For this study, sulphur was added at four (4) levels viz. 0, 30, 60, 90 kg ha^{-1} soil through ammonium per sulphate [$(NH_4)_2S_2O_8$], 39%S] as the source and each level was replicated thrice in a Completely Randomised Design (CRD). A basal dose of N, P_2O_5 and K_2O @ 25, 50 and 25 mg kg^{-1} respectively was applied in each soil. The amount of nitrogen added through ammonium per sulphate was balanced by urea. Basal dose of P_2O_5 and K_2O was given by reagent grade KH_2PO_4, sodium hexa-metaphosphate and KCl. Since most of the soils used in this study were very low in available (hot water-extractable) boron in all treatment pots including control, B was supplemented as basal dose @ 5 mg kg^{-1} soil through borax. All the fertilizers including B were applied by thorough mixing in the whole soil before filling in the pots. Seven healthy seeds of moong bean (Var. B1, Sonali) treated with rhizobium culture were sown in each pot and three plants were maintained after thinning. The crop was irrigated with de-ionised water as and when required to ensure the optimum moisture condition during entire growth period and harvested at 50 per cent flowering growth stage. Above ground plant parts were processed after harvesting for recording biomass weight on oven-dry basis and chemical analysis. This stage is designed for nutrient diagnosis and efficient nutrient management for economic optimum yield. Maximum yield amongst the three levels of sulphur *i.e.* 30 mg, 60 mg and 90 mg kg^{-1} was considered as an optimum yield for calculate on of Bray's per cent yield. The Bray's per cent yield was calculated according to the formula.

$$\text{Bray's per cent yield} = \frac{\text{Yield without sulphur}}{\text{Optimum yield with sulphur}} \times 100$$

For establishment of critical limit of available sulphur, the graphical, method of Cate and Nelson (1965) was used. The mean, correlation coefficients value and stepwise regression analyse were done following the procedures as described in Gomez and Gomez, (1983).

Results and Discussion

Physicochemical properties of experimental soils

Results of salient physicochemical properties of the soils used for greenhouse experiments with moong bean as the test crops have been presented in the Table 1. Results showed that the pH of these soils ranged from 4.11 to 7.13 (mean 5.54); organic carbon (OC) content varied from 0.64 to 2.24 with a mean value of 1.21 per cent. Cation Exchange Capacity (CEC) of the soil samples ranged from 7.70 to 18.46 (mean 12.73) cmol(+)kg^{-1}; clay content from 14.40 to 23.76 (mean 19.08) per cent, whereas silt+clay content in soils figured between 31.40 and 52.32 (mean 41.27) per cent . Respective content of CBD extractable Al & Fe ranged from 0.13 to 0.87 and 0.08 to 0.51 per cent and content of oxalate extractable Al & Fe in soils ranged between 0.12 to 0.76 and 0.05 to 0.45 per cent respectively.

Different forms of sulphur in experimental soils

Results presented in table 2 indicated that total sulphur status of soils varied widely between 178.57 and 433.09 with its mean of 264.63 mg kg^{-1} soil and the highest and lowest amount of total sulphur being 433.09 and 178.57 mg kg^{-1} in these soils. The organic sulphur status of experimental soils reported to vary within the range of 150.27 to 372.73 with its average of 229.57 mg kg^{-1} soil and it constituted 86.8 per cent of the total sulphur present in soils. Sulphate, adsorbed and water soluble forms of sulphur in soils ranged from 13.73 to 30.38, 3.19 to 42.91 and 6.91 to 26.23 mg kg^{-1} soil respectively. Similar trend of different forms of sulphur were also reported in Assam by Basumatary and Das (2012). These three forms of sulphur observed to have their mean contents very close to each other, being with respective magnitudes of 20.67, 18.73 and 16.70 mg kg^{-1} and contributing small fractions (6.3 to 7.8 %) of total sulphur content in soils. Relatively low concentration of these forms might be attributed to leaching loss of sulphate from soil layers due to high rainfall area. Similar observations have also been reported by Borkokoti and Das (2008) in some Entisols, Inceptisols and Alfisols of Assam. Heat soluble sulphur in these soils, which was actually the estimate of soluble sulphate along with some amounts from both adsorbed and organic sulphur fractions was found to occur in relatively higher amount than each of sulphate, adsorbed and soluble forms of sulphur in terms of its mean (47.85 mg kg^{-1}) as well as percentage share (18.1%) to the total sulphur content of soils considered under pot culture study. This result indicated that preponderance of various sulphur forms in these soils was in the order: total sulphur > organic sulphur> heat soluble sulphur> sulphate sulphur> adsorbed sulphur> water soluble sulphur. Similar phenomenon of sulphur fractions has also been reported

Table 1: Salient physicochemical properties of selected soils for greenhouse study

Soil Serial No.	pH(1:2.5)	OC(%)	CEC[cmol(+)kg^{-1}]	Clay(%)	Silt+Clay(%)	Al_2O_3(%)	Fe_2O_3(%)	Ox-Al(%)	Ox-Fe(%)
Berubari-1	4.80	1.70	10.41	18.96	34.96	0.22	0.21	0.18	0.17
Berubari-2	5.05	1.62	18.46	23.40	31.40	0.13	0.18	0.12	0.13
Balorampur-1	5.58	1.03	14.66	17.04	51.04	0.43	0.25	0.23	0.24
Balorampur-2	5.08	0.92	11.77	16.96	38.96	0.13	0.21	0.16	0.11
Balorampur-3	6.07	1.23	14.74	23.76	43.76	0.13	0.09	0.19	0.24
Balorampur-4	6.85	1.62	18.46	22.40	47.40	0.51	0.51	0.49	0.45
Moinaguri	6.20	1.31	13.43	15.04	32.04	0.79	0.44	0.37	0.33
Dhupguri	5.82	0.92	13.04	20.76	41.76	0.22	0.12	0.38	0.15
Islampur	6.65	1.11	14.39	15.76	35.76	0.27	0.08	0.19	0.05
Kharibari	5.62	2.24	13.39	18.40	36.40	0.31	0.17	0.14	0.12
Lotafela-1	5.85	1.27	10.85	17.40	37.40	0.24	0.38	0.15	0.21
Lotafela-2	5.23	1.27	15.23	18.04	51.04	0.17	0.34	0.29	0.34
Lotafela-3	5.87	0.88	9.14	14.40	34.40	0.16	0.25	0.28	0.21
Lotafela-4	4.83	0.99	11.55	18.04	45.04	0.19	0.25	0.31	0.34
Matiarkuthi-1	4.62	0.64	7.70	21.40	32.40	0.45	0.28	0.31	0.21
Matiarkuthi-2	5.94	1.07	8.71	22.04	46.04	0.15	0.39	0.29	0.21
Pundibari-1	4.53	0.99	10.76	19.04	38.04	0.41	0.19	0.22	0.26
Pundibari-2	5.68	1.19	11.99	16.96	48.96	0.29	0.09	0.14	0.24
Pundibari-3	7.13	1.31	15.79	18.32	50.32	0.41	0.45	0.37	0.34
Rajpur-1	4.11	0.88	9.93	22.32	37.32	0.35	0.32	0.32	0.28
Rajpur-2	4.91	1.15	12.86	20.32	52.32	0.87	0.46	0.76	0.41
Mean	5.54	1.21	12.73	19.08	41.27	0.33	0.27	0.28	0.24
Range	4.11-7.13	0.64-2.24	7.70-18.46	14.40-23.76	31.40-52.32	0.13-0.87	0.08-0.51	0.12-0.76	0.05-0.45
SD	0.79	0.36	2.92	2.73	7.01	0.21	0.13	0.15	0.1

Ox-Al: Oxalate extractable Al, Ox-Fe: Oxalate extractable Fe

Table 2: Different forms of sulphur (mg kg^{-1}) in experimental soils

Soil Serial No.	Total S mg kg^{-1}	OrganicS mg kg^{-1}	SulphateS mg kg^{-1}	AdsorbedS mg kg^{-1}	Heat solubleS mg kg^{-1}	WatersolubleS mg kg^{-1}
Berubari-1	265.99	229.40	17.53	27.62	41.36	8.97
Berubari-2	296.14	257.10	16.41	31.34	33.88	7.70
Balorampur-1	258.62	229.76	21.59	8.36	39.60	20.50
Balorampur-2	277.09	249.93	15.75	13.16	41.80	14.00
Balorampur-3	328.41	297.10	18.67	13.50	50.60	17.81
Balorampur-4	397.14	328.11	30.38	42.81	83.16	26.22
Moinaguri	295.57	250.11	26.29	20.49	67.76	24.97
Dhupguri	285.3	250.03	21.61	18.67	61.52	16.60
Islampur	212.89	150.27	22.39	42.91	64.24	19.71
Kharibari	294.09	263.91	22.20	8.38	37.40	21.80
Lotafela-1	247.78	221.19	22.00	11.20	64.68	15.39
Lotafela-2	301.72	275.88	23.32	3.19	45.76	22.65
Lotafela-3	223.73	192.23	20.78	11.79	48.84	19.71
Lotafela-4	198.31	176.43	17.98	5.35	39.16	16.53
Matiarkuthi-1	178.57	151.60	19.67	19.01	39.60	7.96
Matiarkuthi-2	194.99	164.43	17.33	21.84	35.20	8.72
Pundibari-1	231.36	206.46	18.60	15.39	51.04	9.51
Pundibari-2	215.09	188.12	19.19	9.34	36.96	17.63
Pundibari-3	433.09	372.73	27.09	34.13	60.28	26.23
Rajpur-1	205.35	176.30	13.73	22.14	29.04	6.91
Rajpur-2	216.09	189.87	21.57	5.13	33.00	21.09
Range	178.57- 433.09	150.27-372.73	13.73-30.38	3.19- 42.91	29.04- 83.16	6.91-26.23
Mean	264.63	229.57(86.8)	20.67(7.8)	18.37(6.9)	47.85(18.1)	16.70(6.3)*
SD	65.4	58.17	3.96	11.71	14.16	6.34

* Figures in parentheses indicate percent contribution to total sulphur in respective cases

Table 3: Amount of sulphur (mg kg^{-1}) extracted by various extractants from experimental soils

Soil Serial No.	0.15% $CaCl_2$ mg kg^{-1}	1% NaCl mg kg^{-1}	Morgan mg kg^{-1}	1 *N* NH_4OAc mg kg^{-1}	$Ca(H_2PO_4)_2$- 500 mg PL^{-1} mg kg^{-1}
Berubari-1	17.53	23.39	24.94	21.30	36.59
Berubari-2	16.41	26.90	20.91	19.09	39.04
Balorampur-1	21.59	23.21	24.09	17.88	28.86
Balorampur-2	15.75	22.16	16.37	12.06	27.16
Balorampur-3	18.67	23.91	21.82	18.69	31.31
Balorampur-4	30.38	40.79	40.46	27.33	69.03
Moinaguri	26.29	27.96	19.54	22.31	45.46
Dhupguri	21.61	33.58	18.18	23.52	35.27
Islampur	22.39	40.09	24.86	20.70	62.62
Kharibari	22.20	23.74	26.59	16.28	30.18
Lotafela-1	22.00	29.19	28.24	19.39	26.59
Lotafela-2	23.32	25.50	36.53	26.32	25.84
Lotafela-3	20.78	33.94	25.91	21.28	31.50
Lotafela-4	17.98	14.42	21.31	18.35	21.88
Matiarkuthi-1	19.67	25.14	23.18	17.88	26.97
Matiarkuthi-2	17.33	21.45	24.55	14.06	30.56
Pundibari-1	18.60	19.34	21.36	13.47	24.90
Pundibari-2	19.19	20.40	23.64	15.27	26.97
Pundibari-3	27.09	27.61	38.64	24.72	60.36
Rajpur-1	13.73	16.64	15.91	12.66	29.05
Rajpur-2	21.57	20.05	24.43	20.30	26.22
Range	13.73-30.38	14.42- 40.79	15.91- 40.44	12.06-27.33	21.88- 69.03
Mean	20.67(7.8)*	25.69(9.7)	24.83(9.4)	19.18(7.2)	35.06(13.3)
SD	3.96	6.88	6.58	4.3	13.29

* Figures in parentheses indicate percent contribution to total sulphur.

Table 4: Relationship of sulphur soil test values extracted by chemical reagents with different sulphur forms in experimental soils

Chemicals	TotalS	OrganicS	SulphateS	AdsorbedS	HeatsolubleS	WatersolubleS
0.15% $CaCl_2$	0.63**	0.56**	1.00	0.29	0.78**	0.85**
1% NaCl	0.40	0.28	0.64**	0.61**	0.78**	0.44*
Morgan	0.60**	0.56**	0.75**	0.27	0.47*	0.59**
1 *N* NH_4OAc	0.59**	0.54*	0.78**	0.31	0.64**	0.64**
$Ca(H_2PO_4)_{2}$-500 mg PL^{-1}	0.62**	0.46*	0.66**	0.88**	0.71**	0.47*

* and ** : refer to significant level at 0.05 and 0.01 respectively.

by Patel *et al.* (2011) and Basumatary and Das (2012). The dominance of heat soluble sulphur over sulphate and adsorbed sulphur may be ascribed to the solubilization of easily decomposable portion of sulphur from soil organic fraction as well as clay particles on wet and dry heating of soil during extraction. Heating of soil may liberate greater amount of SO_4^{-2}- S covalently bonded to organic matter (Basumatary and Das, 2012) and thus, contributing as constituent into the heat soluble form.

Relationship among different forms of sulphur with important physicochemical characteristics of soils

In order to evaluate the influence of important soil characteristic upon different forms of sulphur content of soils, simple correlation (r) values between forms of sulphur and soil properties were worked out. The total sulphur in the soils was significantly and positively correlated with pH (r = 0.61**), organic C (r = 0.50*), CEC (r = 0.74**) and total N (r = 0.0.54*). Organic carbon, total N and CEC content of soil influences the total sulphur. The results

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are in agreement with the findings of several workers (Kour and Jalali, 2008; Basumatary and Das, 2012; Ghosh *et. al.*, 2012). A significant and positive correlation was found with pH (r = 0.0.52*), CEC (r = 0.71**) and total N (r = 0.55**) to organic sulphur content. The variation in the organic sulphur content was largely due to wide variability in the organic matter status of experimental soils as evidenced by positive and significant correlation (r = 0.50*) between these two parameters. These observations were substantiated by the significant positive correlation of organic S with organic carbon and clay. These observations corroborate the finding of Das *et al.* (2011). Since most of the soil sulphur is an integral part of soil organic matter, this relationship was anticipated. Adsorbed sulphur content wide variation in results might be due to the differential amount of clay content in the soils leading to absorb varying amount of sulphur. Most of the soils under study primarily contained with water soluble sulphate, but also had significant amount of adsorbed sulphate which are considered to be available to plant. This might be expected due to presence of Fe and Al oxides in surface soils (Singh *et al.*, 2006). Adsorbed sulphur was positively correlated with pH (r = 0.46*). It was also positively correlated to clay content of the soils but maintained negative correlation with silt+clay content soil. Positively and significant correlations of sulphate and water soluble forms of sulphur with pH (r = 0.75**, r = 0.71**), CEC (r = 0.51*, r = 0.84*) and total N (r = 0.45*, r = 0.44*) content of the soil were recorded. These were also negatively correlated with clay content (r = -0.24, r = -0.43) of the soil and positively correlated to organic carbon (r = 0.31, r = 0.29) and silt+clay content (r = 0.29, r = 46*) respectively, but the water soluble sulphur was significantly correlated which suggested that organic carbon and silt content of the soil might have played an important role to supply the readily available sulphur to plant. Similar findings were also reported by several workers (Ghosh *et al.*, 2012, Ogeh *et. al.*, 2012).

Predictability of available sulphur in soils for moong bean

The quantity of sulphur extracted by five selected chemical reagents namely 1 *N* NH_4OAc, 0.15% $CaCl_2$, 1% NaCl, Morgan's reagent and $Ca(H_2PO_4)_2$, 500 mg P L^{-1} solution have presented in table 3. A perusal of the data indicated that extent of variation in extractable sulphur by these five extractants ranged from 12.06 to 27.33, 13.73 to 30.38, 14.42 to 40.79, 15.91 to 40.44 and 21.88 to 69.03 mg kg^{-1} soil respectively. The overall mean extractable sulphur concentration in soils, however, shown to vary between 19.18 and 35.06 mg kg^{-1} soil. Further that ability to extract sulphur from the available pool by the extractants when compared among themselves, it was observed to be lowest in case of NH_4OAc as against the highest for $Ca(H_2PO_4)_2$, 500 mg P L^{-1} extractant. Moreover, NH_4OAc and 0.15% $CaCl_2$ extractants in one hand while the other two extractants namely Morgan's and 1% NaCl as the other were shown to be in close proximity with each other in terms of sulphur extractability, the respective mean values of which in a pair ranged from 19.18 to 20.67 and 24.83 to 25.69 mg kg^{-1} soil respectively. However, $Ca(H_2PO_4)_2$, 500 mg P L^{-1} solution resulted to give much higher extractable sulphur content for all soil samples tested with a mean of 35.06 mg kg^{-1} which was about 1.5 to 2.0 times more than the amount extracted by the former four extractants. A close examination into the pattern of sulphur release from the soils revealed that the extractants used under this study had the abilities to release an overall amount of 7only 7.2 to 13.3 per cent of the total sulphur in soils, the minimum being with NH_4OAc and maximum with $Ca(H_2PO_4)_2$, 500 mg PL^{-1} extractant.

In terms of mean values of extractable sulphur obtained from soils by extraction with different chemical procedures, the extractability followed the order as: $Ca(H_2PO_4)_2$, 500 mg PL^{-1}–extractable S > 1% NaCl-extractable S > Morgan's-extractable S > 0.15% $CaCl_2$-extractable S > 1 *N* NH_4OAc-extractable S. This differential behaviour of several extractants were mainly due to their selectivity in solubilizing specific fractions of sulphur to different extent in soils with varying physicochemical properties. Substantial amount of sulphur extracted from soils by $Ca(H_2PO_4)_2$, 500 mg PL^{-1} reagent may be explained due to the dissolution of organically bound SO_4^{-2} - S (most dominant form) as well as soluble SO_4^{-2} - S and that adsorbed on inorganic colloids accelerated by the presence of $H_2PO_4^-$ ion under acidic soil environments leading to their collective contribution into the amount of sulphur extracted by this method.

Availability in relation to forms of sulphur in soil

In order to evaluate degree of selectivity to specific forms of sulphur by different chemical reagents employed for sulphur extraction from soils, correlation coefficients (r) between sulphur test values and estimate of its different forms were worked out and presented in table 4. Results showed that soil test values by all five extractants had significant correlations with total sulphur content in soils

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as expected. However, among the extractants used, only $Ca(H_2PO_4)_2$ 500 mg PL^{-1} was found to record significant correlations with all labile sulphur pools viz. organic S (r = 0.46*), sulphate S (r = 0.66**), adsorbed S (r = 0.0.88**), heat soluble S (r = 0.71**) and water soluble S (r = 0.47*) suggesting that other than the soluble part, the extractant had the ability to dissolute sulphur from various reactive forms occurring in soil. Further that $H_2PO_4^{-1}$, being relatively stronger than Cl^{-1} and CH_3COO^- ions, caused to better displace SO_4^{-2} under acidic soil conditions from organically and inorganically bound and also from exchangeable SO_4^{-2} ion which together resulted to release more sulphur into the solution phase than others. Sulphur test values by 0.15% $CaCl_2$, Morgan's and NH_4OAc extractants showed significant correlations with most of sulphur forms, but $CaCl_2$ appeared more suitable over the former two because of its stronger association (r-values) with different sulphur forms as compared to Morgan's and NH_4OAc extractants. On the other, relatively higher sulphur extractability as well as stronger correlations with sulphur forms over NH_4OAc may be attributed to higher acidic strength of Morgan's extractant. 1% NaCl although extracted equivalent amount of sulphur from these soils to that obtained by Morgan's reagent and that too showed significant correlations with majority of sulphur forms; but the nature and degree of its association with several sulphur forms when compared with others, 1% NaCl extractant appeared to rank at the bottom out of five extractants tried to assess the sulphur availability under this study.

Suitability of extractant for moong bean crop

Of five extractants used, monocalcium phosphate 500 mg PL^{-1} extractant recorded highest significant correlation with dry matter yield and sulphur uptake value under control treatment (Table 5). This reagent was found to be equally effective to extract sulphur from soils both under native soil status as well as high sulphur containing soils *i.e.* it can suitably be used for determining the available sulphur status for soils having wide range of sulphur content. Next to monocalcium phosphate at 500 mg PL^{-1}, Morgan's extractant was identified to be the next in terms of its relationship with dry matter weight, sulphur uptake and sulphur content both at control and higher levels of sulphur treatments. However 0.15% $CaCl_2$ was assumed to have intermediate merit for its use in the assessment of sulphur availability status. Similar with 0.15% $CaCl_2$, NH_4OAc and 1%NaCl have shown their ability to extract sulphur from soils with its relatively high content. Apart from their significant correlations with plant parameters based on consideration of some practical aspects including the cost factors, experimental simplicity, time & labour consumption, ease of availability etc, Morgan's extractant may be proposed as the superior most for routine soil analysis purpose, although monocalcium phosphate at 500 mg PL^{-1} would provides better relationships and efficacy with plant parameters studied. Relative suitability of the extractants for assessing the sulphur status for moong bean under the present soil conditions can be rated as Morgan > monocalcium phosphate 500 mg PL^{-1} > 0.15% $CaCl_2$ > NH_4OAc > 1% NaCl.

Table 5: Co-efficient of correlations (r-value) of extractable forms of sulphur with plant parameters of moong bean crop

Extractant	Dry matter				S-uptake				S-concentration			
	S_0	S_1	S_2	S_3	S_0	S_1	S_2	S_3	S_0	S_1	S_2	S_3
$Ca(H_2PO_4)_2$ 500 mg PL^{-1}	0.66**	0.77**	0.64**	0.44*	0.77**	0.83**	0.72**	0.70**	0.39	0.49*	0.65**	0.48*
Morgan	0.53*	0.62**	0.50*	0.03	0.71**	0.62**	0.60**	0.35	0.52*	0.36	0.73**	0.44*
0.15% $CaCl_2$	0.31	0.60**	0.54*	0.15	0.50*	0.69**	0.64**	0.49*	0.45*	0.51*	0.71**	0.50*
1% NaCl	0.22	0.55*	0.47*	0.29	0.49*	0.76**	0.43	0.64**	0.65**	0.67**	0.60**	0.60**
1 *N* NH_4OAc	0.30	0.61**	0.66**	0.09	0.46*	0.62**	0.58**	0.27	0.40	0.40	0.48*	0.24

* and ** : refer to significant level at 0.05 and 0.01 respectively.
[S_0 = Control, S_1 = 30 kg S ha^{-1}, S_2 = 60 kg S ha^{-1}, S_3 = 90 kg S ha^{-1}]

Scatter diagram by graphical method of Cate and Nelson (1965) showing relationship between Bray's per cent yield and Morgan's extractable sulphur in soil (Fig. 1) indicated 18.0 mg S kg^{-1} in soil as a critical limit of sulphur below which moongbean (Var. B1, Sonali) may respond to sulphur application. Singh *et al.* (2004) reported that Morgan's reagent may be used as predictor of available sulphur for rapeseed grown on acid soils of Manipur, the critical level being 40.0 mg kg^{-1}.

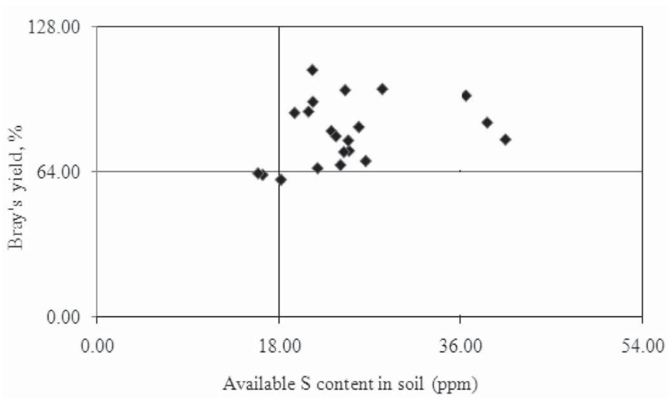

Fig. 1: Scatter diagram showing relationship between Bray' per cent yield and available concentration in soil

From this study, it is suggested that organic matter plays an important role in supplying available sulphur in the soil which implies that increase of organic pool in soil would help for better crop nutrition. A single extractant would not be suitable for predicting the available sulphur status for all crops. Morgan's extractant is the most suitable extractant for moong bean crop in *terai* soils of under humid sub-tropical region of Eastern India.

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