Distribution and Characterization of Sulphur fractions in *Entisols*, *Inceptisols* and *Alfisols* Soil Orders of India

ABSTRACT

The present investigation was conducted to distribute and characterization of different Sulphur (S) fractions in selected soil orders of India. Soil samples were collected from cultivated fields in different states of India, covering West Bengal, Jharkhand, Bihar, Uttar Pradesh, Uttarakhand, and Himachal Pradesh. These states belong to the soil orders Entisols, Inceptisols, and Alfisols. A total of two hundred seventy composite soil samples were collected from ten locations of each order, representing three depths: 0-15 cm, 15-30 cm, and 30-45 cm, with thrice replication. After analyzing the various sulfur fractions, the results showed that there was no distinct distribution of sulfur reported in the various locations. In Entisols soil order, non-sulphate sulfur contributes highest fraction with a mean of 2744.99 mg kg^{-1} while lowest contribution was found in available sulfur with a mean of 25.24 mg kg^{-1} of total S followed by organic sulfur (112.54 mg kg^{-1}), adsorbed sulfur (97.79 mg kg^{-1}). A similar pattern was observed in Inceptisols and Alfisols soil orders. Available S was positive and significantly correlated with organic Sulphur in Entisol and Inceptisol while negative correlated with remaining fraction of S. Based on the sulfur availability index, the dominant fraction of sulfur in all three soil orders was non-sulfate sulfur.

Keywords: Soil orders, Sulphur fractions, Correlation, Sulphur

INTRODUCTION

Sulphur (S), recognized as fourth important essential plant nutrient followed by Nitrogen, Phosphorus and Potassium is gaining considerable importance in quality crop production in the context of Indian agriculture, particularly when there is more use of non-Sulphur containing fertilizers as well as less use of organic manures. In India, nearly 57 mha of arable land suffers from various degrees of Sulphur deficiency (Tripathy, 2003). The proportion of deficiencies of S and micronutrients in different areas such as different districts and states of a country is different due to differences in soils, climates, crops and crop management options (Shukla and Bahera, 2019). Sulfur is an essential element in the life processes of all living things, including microorganisms, higher plants, animals, and humans. It is an important part of the proteins needed to sustain life in all biological organisms. It plays an essential role in the formation of amino acids such as methionine (21 %), cystine (27 %) and cysteine (26 %), synthesis of proteins, chlorophyll, oil content of oil seeds and nutritive quality of forage crops. It is also involved in the formation of glucosides and glucosinolates (mustard oils); activation of enzymes and sulphydryl (-SH) linkages that are the source of pungency in onion, oils, *etc*. It is constituent of ferrodoxin-containing nitrogenase, hitch takes part in the biological nitrogen fixation (BNF) and other electron transfer reactions (Patra *et al.*, 2012).

Sulphur in soils is present in both inorganic and organic forms and the proportion of inorganic to organic sulphur varies widely depending upon the nature of soil, its depth and management factors to which the soil is subjected. Total soil sulphur, which comprises inorganic and organic binding forms, ranges between 250 and 2500 kg/ha in most top soils of arable land (Sharma, et al. 2014). The organic sulphur fraction governs the production of plant available SO_4^{-2}. Organic Sulphur composed of HI reducible S (represents 40-60% of total organic S, carbon bonded S (represent 10-12 % of total organic S) and residual S (represent 30-40 % of total organic S) (John et al., 2014). Inorganic S composed of water soluble and adsorbed SO_4^-, is generally believed to be the immediate source for plants. Generally, it accounts for less than 5% of total soil S. In soil solution, SO_4^- is present only in small quantities which varies continuously and its concentration at a particular time depends on the balance between plant uptake, fertilizer input, mineralization and immobilization. *Reduced inorganic* sulphides do not exist in well aerated soils. Forms of sulphur and their interrelationship with soil properties decide on the sulphur supplying power of soil, their influence on its release and dynamics in soil (Singh, 2015). Thus, the knowledge of different forms of sulphur is essential in improving the nutrition of crops. So far, inadequate information is available regarding the status of forms of S in selected soil orders of Indo-Gangetic plains of India. In view of this, the present study was undertaken to determine the sulphur fractions in some selected soils of India and to find out the relationship among S fractions.

Materials and methods:

Description of study area and sites

Two hundred seventy soil samples in three depths (0-15, 15-30 and 30-45 cm) collected from irrigated and non-irrigated fields of six districts covering Uttar Pradesh, Bihar, West Bengal (Entisol), six districts covering Uttar Pradesh, Bihar, Uttarakhand (Inceptisol) while six district covering Bihar, Jharkhand, Himachal Pradesh and West Bengal (Alfisol) were used for the study. Detailed description of soil samples has been presented in table 1.

Table 1: Location of collected soil samples

S.N.	Village/Town	District	State	Order	Altitude (o)	Geog Location Latitude N Longitude E (o)	Cropping System
1.	Naini	Allahabad	U.P.	*Entisol*	98	N 25 57.041, E 81 56.274	Fallow-Wheat
2.	Gajia	Allahabad	U.P.	*Entisol*	98	N 25 57.658, E 81 54.721	Fallow-Wheat
3.	Badabaghara	Allahabad	U.P.	*Entisol*	97	N 25 56.210, E 81 55.156	Fallow-Wheat
4.	Rampur	Aurangabad	Bihar	*Entisol*	123	N 24 37.960, E 084 37.101	Rice-Lentil
5.	Katwa1	Burddhawan	W.B.	*Entisol*	21	N 23 41.120, E 088 08.013	Jute-Mustard
6.	Katwa2	Burddhawan	W.B.	*Entisol*	21	N 23 41.369, E 088 08.136	Jute-Mustard
7.	Bakul	Howrah	W.B.	*Entisol*	20	N 22 40.091, E 088 07.166	Rice-Rice
8.	Ramsevakpuram	Faizabad	U.P.	*Entisol*	93	N 26 80.074, E 82 20.175	Fallow-Wheat
9.	Sadyopuram	Faizabad	U.P.	*Entisol*	93	N 26 80.784, E 82 50.495	Maize-Bengal gram
10.	Tehatta	Nadia	W.B.	*Entisol*	14	N 23 45.856, E 088 32.276	Pea-Wheat
11.	Reewan	Hamirpur	U.P.	*Inceptisol*	125	N 25 35.605, E 080 04.889	Fallow-Bengal gram+ Mustard
12.	Gahabra	Hamirpur	U.P.	*Inceptisol*	128	N 25 35.996, E 080 03.007	Fallow-Mustard
13.	Mawai R	Mahoba	U.P.	*Inceptisol*	127	N 25 32.889, E 080 00.427	Til- Mustard
14.	Mawai K	Mahoba	U.P.	*Inceptisol*	160	N 25 31.597, E 080 01.797	Fallow-Pea
15.	Pura	Mahoba	U.P.	*Inceptisol*	136	N 25 32.504, E 079 59.596	Fallow-Wheat
16.	Daramnagar	Barabanki	U.P.	*Inceptisol*	120	N 26 54.074, E 081 12.065	Rice-Mustard
17.	Chhatouni	Gonda	U.P.	*Inceptisol*	95	N 26 59.111, E 081 50.466	Fallow-Chickpea
18.	Kasman	Aurangabad	Bihar	*Inceptisol*	97	N 24 46.464, E 084 39.328	Fallow-Potato
19.	Trimoorty	Dehradun	Uttarakhand	*Inceptisol*	435	N 30 17.198, E 78	Fallow-

						00.072	Wheat
20.	FRI	Dehradun	Uttarakhand	*Inceptisol*	435	N 30 17.542, E 78 00.017	Fallow-Wheat
21.	Korap	Gaya	Bihar	*Alfisol*	91	N 24 50.18, E 084 42.879	Rice-Wheat
22.	Dadar	Aurangabad	Bihar	*Alfisol*	83	N 24 56.350, E 084 39.027	Rice-Lentil
23.	Debatoli	Ranchi	Jharkhand	*Alfisol*	623	N 23 26.634, E 085 19.144	Soybean-Wheat
24.	Kanke	Ranchi	Jharkhand	*Alfisol*	623	N 23 26.017, E 085 19.754	Groundnut-Mustard
25.	Palampur	Kangra	H.P.	*Alfisol*	1272	N 31 26.068, E 76 50.110	Maize-Wheat
26.	Kangra	Kangra	H.P.	*Alfisol*	1245	N 31 26.417, E 76 50.542	Rice-Wheat
27.	Bheladanga	Burddhawan	W.B.	*Alfisol*	68	N 23 32.495, E 087 29.270	Rice-Rice
28.	Hijalgara	Burddhawan	W.B.	*Alfisol*	143	N 23 39.453, E 087 05.578	Brinjal-Potato
29.	Jhargram1	Medanipur	W.B.	*Alfisol*	70	N 22 27.966, E 087 00.909	Rice-Rice
30.	Jhargram2	Medanipur	W.B.	*Alfisol*	64	N 22 28.043, E 087 00.978	Mango Orchard

Physiochemical analysis of soils samples:

Soil samples were collected from three depths and taken into the laboratory for chemical and physical analysis. The bulk soil samples were air-dried, crushed with a wooden pestle and mortar and sieved to remove coarse (> 2 mm) fragments. The soil pH was measured on 1:2 soil: water suspension using pH meter and soluble salts were determined by measuring the electrical conductivity (EC) of 1:2 soil: water extract (Jackson 1973). Organic carbon content in soil was determined by Walkley and Black method (Walkley and Black 1934). The CEC was determined by 1N NH4OAc solution as described by Jackson (1973). Particle size distribution was determined by Bouyoucos hydrometer method (Bouyoucos 1962). Available nitrogen (N) was determined as per the method given by Subbiah and Asija (1956). Available P was determined by 0.5 M sodium bicarbonate by Olsen *et al*. (1954). Available potassium (K) was extracted with 1 N NH4OAc and then measured by flame photometer (Jackson 1973).

Determinations of Sulphur fractions:

Sulfur availability in the soil was determined using 0.15% $CaCl_2$, following the method outlined by Williams and Steinbergs (1959). The organic sulfur content in the soil was determined by oxidizing organic matter with hydrogen peroxide. This oxidation process converted organically bound sulfur into sulfate form, and the measurement was conducted in accordance with the procedure recommended by Evans and Rost (1945). To calculate adsorbed sulfur, the sulfur values extracted using 0.15% $CaCl_2$ were subtracted from those extracted using mono-calcium phosphate (MCP), as described by Fox *et al*. (1964).

Adsorbed Sulphur = [MCP extractable Sulphur - 0.15 % $CaCl_2$ extractable Sulphur].

Non-Sulphate Sulphur was calculated by subtracting the sum of organic Sulphur and Sulphate sulphur from the total sulphur (Fox *et al*. 1964).

Non-Sulphate Sulphur = [Total Sulphur - (Organic Sulphur + Sulphate Sulphur)].

Total Sulphur was determined following the method described by Arkley (1961). Sulphur Availability Index (SAI) was calculated by formula of Donahue *et al*. (1977).

SAI = (0.4 x $CaCl_2$ extractable SO_4 in mg kg^{-1} soil) + % organic matter

Statistical analysis

Using a PC with the help of Statistical Package for the Social Sciences (SPSS) software (SPSS 20), all measured variables were statistically analyzed following methods meant for Completely Randomized Design (CRD). Duncan's multiple range test (DMRT) at 5% was followed to compare the treatment means. Their mean effect means were further subjected to Post-Hoc tests like DMRT and LSD (Least Significant Difference) tests to identify the homogenous means at 5% level of significance.

Results and discussion:

Entisols soil order:

Available Sulphur and Organic Sulphur-The highest available and organic Sulphur (Table-2) in the *Entisol* soil order has been found to be 90.97 mg kg^{-1} and 372.79 mg kg^{-1} in Bakul district of West Bengal and the lowest available Sulphur (5.44mg kg^{-1}) has been found in the Katwa-2 village of Prayagraj district of Uttar Pradesh while organic Sulphur (7.85mg kg^{-1}) was found in Sadyopuram village of Ayodhya district of Uttar Pradesh. And the mean value of available Sulphur was recorded 25.24 mg kg^{-1}. Wide variation in the total S content in these soil orders may be due to greater heterogeneity in content of organic matter and parent material. Paramanik, *et al.* (2014) reported that the available sulphur content of the soils varied from different agro-climatic zones of India. Available sulphur is the form of sulphur that is taken up by plant roots. It is attributed to the more organic carbon content that is added to sulphate sulphur after microbial mineralization. According to the Pasricha and Sarkar (2009) organic sulphur may not be the dominant form in arid and semi-arid soils. In any case, the entire organic S fraction is not a uniform entity with similar activity or resistance to mineralization.

Adsorbed Sulphur –Adsorbed **S**ulphur content (mg kg^{-1}) in different locations ranged from 20.20 to 308.38 with an average of 97.79 ± 6.37 (Table-2). This could be due to enhanced displacement of adsorbed $SO4^{2-}$ by OH^{-} ions under high rainfall conditions with consequent leaching losses (Basumatari*et al*., 2010).

Non-Sulphate Sulphur and Total sulphur-The maximum non-sulphate sulphur and total sulphur was recorded (Table-2) in the Katwa-1 village with value 6447.09 mg kg^{-1} and 6830.72 mg kg^{-1}. And the minimum non-sulphate sulphur and total sulphur value (170.55 and 255.45 mg kg^{-1}) was recorded in the Rampur village of Ayodhya districts of Uttar Pradesh.These result find support from the observations made by Tripathi and Singh (1992) that the soil forming process in operation under low pH and high rainfall conditions continuously broken-down these Sulphur compounds in the surface horizons and leached them down to the underlying layers thereby increasing their content in the subsurface horizons but because this form of sulphur mostly are made up of insoluble sulphur compound, they remain occluded in or adsorbed on $CaCO_3$ of the soil (Evans and Rost, 1945).

Sulphur availability index (SAI)-The highest Sulphur availability index (Table-2) was found in the Bakul district of west Bengal (37.14 mgkg^{-1}) followed by Gajia village of Prayagraj district (22.03mg kg^{-1}) and lowest was recorded in Katwa-2 village of West Bengal (2.65 mg kg^{-1}).

Table-2 Location wise distribution of different pools of Sulphur in *Entisol* soil order.

Location	Available Sulphur	Organic Sulphur	Adsorbed-Sulphur	Non-Sulphate Sulphur	Total Sulphur	SAI
Katwa-2	5.44^{e}	171.41^{b}	107.12^{cd}	6569.67^{a}	6746.52^{a}	2.65^{e}
Katwa-1	5.59^{e}	178.04^{b}	135.86^{b}	6647.09^{a}	6830.72^{a}	2.97^{e}
Tehatta	6.00^{e}	135.64^{c}	97.82^{d}	5127.88^{b}	5269.52^{b}	3.62^{e}
Naini	9.04^{e}	75.03^{d}	308.38^{a}	4564.52^{b}	4648.59^{b}	4.67^{e}
Ramsevakpuram	10.02^{e}	11.42^{e}	29.17^{g}	646.23^{c}	667.67^{d}	5.20^{e}
Sadyopuram	17.55^{d}	7.85^{e}	51.69^{f}	1913.85^{c}	1947.12^{c}	8.14^{d}
Rampur	22.48^{d}	62.42^{d}	124.57^{bc}	170.55^{c}	255.45^{d}	10.22^{d}
Badabaghara	32.042^{c}	30.31^{e}	30.68^{g}	579.67^{c}	642.02^{d}	13.95^{c}
Gajia	53.21^{b}	80.45^{d}	20.20^{g}	564.49^{c}	698.16^{d}	22.03^{b}
Bakul	90.97^{a}	372.79^{a}	72.41^{e}	665.92^{c}	1129.68^{cd}	37.14^{a}
Mean	**25.24**	**112.54**	**97.79**	**2744.99**	**2883.55**	**11.06**

SEm(±)	2.07	9.28	6.37	396.07	393.59	0.86
CD (0.05)	5.82	26.12	17.94	1115.58	1108.62	2.42

Similar small letters within the same column denote homogenous means resulted by DMRT at 5% level of significance.

Correlation with Sulphur fraction in *Entisols* soil order-

The data present in Table-3 revealed that available Sulphur in the *Entisols* soil order had significant and positive correlation with organic sulphur (0.576), and Sulphur availability index (0.999). The organic sulphur had positive correlation with non-sulphate sulphur (0.214), total sulphur (0.257) and sulphur availability index (0.568). The adsorbed sulphur had significant positive correlation with non-sulphate sulphur (0.372) and Total sulphur (0.370). Non-sulphate sulphur had a highly positive correlation with total sulphur (0.999). This might be due to the fact that all these forms are, by and large, interchangeable; thereby, showing a positive relationship to each other (Das *et al*., 2012).

Table-3 Pearson Correlation Coefficient among different Sulphur fractions of *Entisol* soil Order.

Sulphur Fractions	Available Sulphur	Organic Sulphur	Adsorbed Sulphur	Non sulphate Sulphur	Total-Sulphur	SAI
Available Sulphur	1					
Organic-Sulphur	0.576**	1				
Adsorbed-Sulphur	-0.330**	NS	1			
Non-sulphate Sulphur	-0.514**	0.214*	0.372**	1		
Total-Sulphur	-0.480**	0.257*	0.370**	0.999**	1	
SAI	0.999**	0.568**	-0.330**	-0.522**	-0.489**	1

* Significant at 5% level ** Significant at 1% level

Multiple regression of *Entisol* Soil Order:

Data presented in Table-4 revealed positive influence of organic sulphur and negative influence of total sulphur on $CaCl_2$extractable sulphur and this relationship could explain about 77 % of the variability. Water soluble sulphur was influenced positively by KH_2PO_4 extractable sulphur and negatively by organic sulphur and Monocalcium phosphate extractable sulphur and about 61 % of the variability in water soluble sulphur could be explained by this relationship. MCP extractable sulphur was influenced positively by $NaHCO_3$extractable sulphur and negatively by water soluble sulphur and about 34 % of the variability in Monocalcium phosphate extractable sulphur could be explained by this relationship. KH_2PO_4 extractable sulphur was influenced positively by water soluble and organic sulphur and about 56 % of the variability in KH_2PO_4extractable sulphur could be explained by this relationship. $NaHCO_3$ extractable sulphur was influenced positively by Monocalcium phosphate extractable S and negatively by Total sulphur and about 24 % of the variability in $NaHCO_3$extractable sulphur could be explained by this relationship. Organic sulphur was influenced positively by $CaCl_2$ extractable S, KH_2PO_4 extractable S and total sulphur and negatively by water soluble sulphur and about 82 % of the variability in organic sulphur could be explained by this relationship. Total sulphur was influenced positively by organic sulphur and negatively by $CaCl_2$ extractable and $NaHCO_3$extractable sulphur and about 71 % of the variability in total sulphur could be explained by this relationship.

Table-4 Multiple regression equation indicating relationship among different pools of sulphur in *Entisol*

S. No.	Regression equation	R^2	Adj. R^2
1	$CaCl_2$ = 0.170** (org S) - 0.006** (Total S)	0.77	0.76
2	WSS = - 0.057** (MCP S) + 0.125 (KH_2PO_4 S) - 0.116 ** (Org. S)	0.61	0.58
3	MCP S = - 2.250**(WSS) + 0.552** ($NaHCO_3$ S)	0.34	0.29
4	KH_2PO_4 S = 1.149 **(WSS) + 0.319** (organic S)	0.56	0.52
5	$NaHCO_3$ S = 0.168** (MCP S) -0.008** (Total S)	0.24	0.19
6	Organic S = 2.166** ($CaCl_2$ S) - 2.384** (WSS) + 0.719 **(KH_2PO_4 S) + 0.018** (Total S)	0.82	0.81
7	Total S = -95.589** ($CaCl_2$ S) -16.080**($NaHCO_3$ S) + 19.957 **(Organic S)	0.71	0.69

Inceptisols Soil Order:

Available and Organic Sulphur- The available and organic sulphur content (Table-5) varies among all the locations. The highestavailable sulphur and organic sulphur content was recorded in the Trimoorty village with value 86.89 mg kg^{-1} and 496.77 mg kg^{-1}. And the lowest values 3.60 and 22.75 mg $kg^{-1}$was recorded in the Reevan village of Madhya Pradesh. Their report is closely followed by Paramanik *et al.* (2014) with available and organic sulphur content.

Adsorbed Sulphur-The location exhibited different levels of adsorbed sulphur with Mawai-R village of Madhya Pradesh having the highest value 330.14mg kg^{-1} and Daramnagar village of Uttar Pradesh having the lowest value 32.79 mg kg^{-1}.

Non-sulphate and Total sulphur-The highest non-sulphate sulphur and total sulphur were recorded in the Daramnagar village of Ayodhya district of Uttar Pradesh with values 7548.03

and 7620.41 mg kg^{-1} respectively. The lowest values were found in the Kasman village of Himanchal Pradesh, with values 94.49 and 202.44 $mgkg^{-1}$ for non-sulphate and total sulphur respectively. Joshi *et al*. (1973) reported a higher range of total sulphur status was found in different parts of India.

Sulphur Availability Index (SAI)- The highest Sulphur availability index was recorded in the Trimoorty village with value 85.44 mg kg^{-1} and lowest was recorded with value 2.27 mg kg^{-1}.

Table-5 Location wise distribution of different pools of Sulphur in *Inceptisol* soil order.

Locations	Available Sulphur	Organic sulphur	Adsorbed sulphur	Non-Sulphate sulpur	Total sulphur	SAI
Reewan	3.60^{c}	22.75^{f}	164.67^{bc}	5685.54^{b}	5711.90^{b}	2.27^{d}
Daramnagar	4.69^{c}	67.69^{cd}	202.79^{bc}	7548.03^{a}	7620.41^{a}	3.07^{d}
Pura	4.83^{c}	25.99^{ef}	121.21^{cd}	1104.052^{f}	1134.88^{ef}	3.11^{d}
Mawai R	5.73^{c}	$50.48d^{ef}$	330.14^{a}	864.17^{f}	920.38^{ef}	3.28^{d}
Gahabra	6.16^{c}	$58.79c^{de}$	48.99^{d}	2756.95^{d}	2821.87^{c}	3.74^{d}
Mawai K	10.53^{c}	26.93^{ef}	246.0^{ab}	1213.50^{ef}	1250.97^{def}	5.37^{d}
Kasman	21.20^{b}	86.75^{c}	66.60^{d}	94.49^{f}	202.44^{f}	9.26^{c}
Chhatouni	26.67^{b}	37.59^{def}	32.79^{d}	2456.45^{de}	2520.72^{cd}	11.79^{c}
FRI	68.61^{b}	203.03^{b}	56.70^{d}	1323.33^{ef}	1594.97^{cde}	29.63^{b}
Trimoorty	86.89^{a}	496.77^{a}	61.90^{d}	4036.94^{c}	4740.60^{b}	85.44^{a}
Mean	**35.90**	**107.67**	**133.19**	**2708.35**	**2851.92**	**15.70**
SEm (±)	3.22	11.13	32.32	434.09	433.63	1.32
CD (0.05)	9.07	31.36	91.05	1222.69	1221.40	3.71

Similar small letters within the same column denote homogenous means resulted by DMRT at 5% level of significance.

Correlation with Sulphur fraction in *inceptisols* soil order-

The data presented in the Table-6 showed that the *inceptisols* soil order, available sulphur had positive correction with organic sulphur (0.956) and SAI (0.97). The organic sulphur had positive correlation with total sulphur (0.194) and SAI (0.959). And non-sulphate sulphur with total sulphur, (0.997). Adsorbed and total sulphur had nonsignificant correlation with all fractions of sulphur same result was examined by Tripathi and Singh (1992).

Table-6 Pearson Correlation Coefficient among different sulphur fractions of *Inceptisol* Order

Sulphur fractions	Available sulphur	Organic sulphur	Adsorbed sulphur	Non sulphate suphur	Total-sulphur	SAI
Available sulphur	1					

Organic sulphur	0.956**	1				
Adsorbed-Sulphur	-0.285**	-0.262*	1			
Non-sulphate sulphur	NS	NS	NS	1		
Total-Sulphur	NS	0.194	NS	0.997**	1	
SAI	0.970**	0.959**	-0.287**	NS	NS	1

* Significant at 5% level ** Significant at 1% level

Multiple Regression of *Inceptisols* Soil Order

Data presented in Table-7 revealed positive influence of KH_2PO_4 extractable S and organic sulphur on $CaCl_2$extractable sulphur and about 94% of the variability in $CaCl_2$extractable sulphur could be explained by this relationship. KH_2PO_4extractable sulphur was influenced positively by $CaCl_2$extractable sulphur and negatively by organic sulphur and about 58 % of the variability in KH_2PO_4extractable sulphur could be explained by this relationship. $NaHCO_3$extractable sulphur was influenced positively by organic sulphur and negatively by total sulphur and about 58 % of the variability in $NaHCO_3$ extractable sulphur could be explained by this relationship. Organic sulphur was influenced positively by $CaCl_2$ extractable sulphur and total sulphur and negatively by KH_2PO_4 and $NaHCO_3$ extractable sulphur and about 94 % of the variability in organic sulphur could be explained by this relationship. Total sulphur was influenced positively by $NaHCO_3$ extractable sulphur and organic sulphur and negatively by $CaCl_2$ extractable sulphur and about 40 % of the variability in total sulphur could be explained by this relationship.

Table-7 Multiple regression equation indicating relationship among different pools of sulphur in *Inceptisol*

S. No.	Regression equation	R^2	Adj. R^2
1	$CaCl_2$ S = 0.388** (KH_2PO_4 S) + 0.375** (org S)	0.94	0.94
2	KH_2PO_4S = 0.794** ($CaCl_2$ S) - 0.203 **(organic S)	0.58	0.55
3	$NaHCO_3$ S = 0.617**(org S) + 0.015** (Total S)	0.58	0.55
4	Organic S = 2.24**($CaCl_2$ S) - 0.589**(KH_2PO_4 S) - 0.268**($NaHCO_3$ S) +0.007**(Total S)	0.94	0.94
5	Total S = -33.367*($CaCl_2$ S) + 22.388**($NaHCO_3$ S) + 22.217**(organic S)	0.40	0.36

*Significant at 5 % level and **Significant at 1 % level,
S = sulphur, WSS = water soluble sulphur, NSS = non-sulphate sulphur

Alfisols soil order-

Available Sulphur-The data presented in Table-8 showed that the highest available sulfur was recorded in Alfisols soils order from Heijalgara village with a value of 25.13 mg kg^{-1}. The minimum value was found in Jhalgram-1 village, with a value of 19.95 mg kg^{-1}. The average value of all these locations was recorded as 13.95 ± 2.44 mg kg^{-1}.

Organic Sulphur-Similarly, the highest organic sulfur was found in Alfisols soils order from Heijalgara village, with a value of 277.19 mg kg^{-1}. The lowest value was observed in Kangra village, with a value of 51.77 mg kg^{-1}. The average value of all these locations was recorded as 114.52 ± 10.48 mg kg^{-1}.

Adsorbed sulphur-The highest adsorbed sulfate sulfur was recorded in Alfisols soils order from Palampur village, with a value of 346.45 $mgkg^{-1}$. The lowest value was found in Bheladanga village, with a value of 37.61 mg kg^{-1}. The average value of all these locations was recorded as 154.16 ± 21.61 mg kg^{-1}.

Non-sulfate sulfur and total sulfur-The maximum values of non-sulfate sulfur and total sulfur were found in Dadar, with values of 3524.08 and 3690.77 mg kg^{-1}, respectively. The minimum values (128.06 and 378.9 mg kg^{-1}) were recorded in Bheladanga village. The average values of non-sulfate sulfur and total sulfur were recorded as 998.66 ± 171.01 and 1127.13 ± 170.04 mg kg^{-1}, respectively.

Sulphur Availability Index (SAI)-The highest sulphur availability index was recorded in the Hijalgara village of West-Bengal with a value 11.67 mg kg^{-1}, and minimum was found in the Jhargram-1 village of West-Bengal with a value 2.88 mg kg^{-1}.The SAI approach has been tested in many soils of India and is reported to be equal or better than the critical level in assessing the status of Sulphur same report was proposed by Gowrishankar *et al.* (1998) and Chattopadhyay S *et al*. (2006).

Table-8 Location wise distribution of different pools of sulphur in *Alfiisol* soil order.

Locations	Available Sulphur	Organic sulphur	Adsorbed sulphur	Non-Sulphate sulpur	Total sulphur	SAI
Jhargram 1	6.11^{e}	114.23^{d}	81.70^{cd}	349.77^{d}	470.12^{d}	2.88^{e}
Bheladanga	$7.32d^{e}$	242.98^{b}	37.61^{d}	128.60^{d}	378.9^{d}	3.23^{e}
Jhargram 2	8.26^{cde}	111.69^{d}	42.70^{cd}	616.80^{d}	736.75^{d}	3.82^{e}
Kangra	9.89^{cde}	51.77^{f}	232.60^{b}	193.93^{d}	255.60^{d}	$5.32d^{e}$
Palampur	11.83^{cde}	78.27^{ef}	346.45^{a}	1668.45^{c}	1758.56^{c}	6.89^{cd}
Kanke	14.02^{bcd}	16.63^{g}	60.01^{cd}	532.85^{d}	563.5d	7.22^{bcd}
Korap	15.60^{bc}	85.19^{de}	219.60^{b}	188.47^{d}	289.26d	7.30^{bcd}

Dadar	19.93[ab]	146.75[c]	108.34[c]	3524.08[a]	3690.77[a]	9.18[abc]
Debatoli	21.37[ab]	20.45[g]	335.27[a]	570.51[d]	612.34[d]	10.09[ab]
Hijalgara	25.13[a]	277.19[a]	77.24[cd]	2213.15[b]	2515.47[b]	11.67[a]
Mean	**13.95**	**114.52**	**154.16**	**998.66**	**1127.13**	**6.76**
SEm(±)	2.44	10.48	21.61	171.01	170.04	1.01
CD (0.05)	6.88	29.51	60.87	481.67	478.94	2.86

Similar small letters within the same column denote homogenous means resulted by DMRT at 5% level of significance.

Correlation with Sulphur fraction in *Alfisols* soil order-

In the table-9 that the Alfisols soil order had positive correlation with non-sulphate (0.425), total sulphur (0.426) and SAI (0.980). The organic sulphur has been positively correlated with non-sulphate (0.283) and total sulphur (0.352). Non-sulphate sulphur has been highly correlated with total sulphur (0.997) and SAI (0.515). Total sulphur had positively correlated with SAI (0.514). The significant and positive correlations of total sulphur with organic carbon, silt and clay have also been reported by Aggarwal and Nayyar (1998) and Trivedi *et al.* (1998). Adsorbed sulphur has been non-significant correlated with the all fraction of sulphur.

Table -9 Pearson Correlation Coefficient among different sulphur fractions of *Alfisol* Order.

Sulphur Fractions	**Available Sulphur**	**Organic Sulphur**	**Adsorbed Sulphur**	**Non sulphate Sulphur**	**Total-Sulphur**	**SAI**
Available sulphur	1					
Organic sulphur	NS	1				
Adsorbed-Sulphur	NS	-0.389**	1			
Non-sulphate sulphur	0.425**	0.283**	NS	1		
Total-Sulphur	0.426**	0.352**	NS	0.997**	1	
SAI	0.980**	NS	NS	0.515**	0.514**	1

* Significant at 5% level ** Significant at 1% level

Multiple Regression of *Alfisols* Soil Order-

Data presented in Table-10 revealed positive influence of water soluble, MCP extractable and organic sulphur on $CaCl_2$extractable sulphur and about 39 % of the variability in $CaCl_2$ extractable sulphur could be explained by this relationship. Water soluble sulphur was influenced positively by $NaHCO_3$ and $CaCl_2$extractable sulphur and negatively by MCP extractable sulphur and about 59 % of the variability in water soluble sulphur could be explained by this relationship. MCP extractable sulphur was influenced positively by $CaCl_2$ extractable S, $NaHCO_3$ extractable S and KH_2PO_4extractable sulphur and negatively by MCP extractable S and organic sulphur and about 39 % of the variability in MCP extractable sulphur could be explained by this relationship.KH_2PO_4 extractable sulphur was influenced positively by MCP extractable sulphur and about 12 % of the variability in KH_2PO_4extractable sulphur could be explained by this relationship.$NaHCO_3$extractable sulphur was influenced positively by water soluble sulphur, MCP extractable S and total sulphur and negatively by organic sulphur and about 65% of the variability in $NaHCO_3$ extractable sulphur could be explained by this relationship. Organic sulphur was influenced positively by total sulphur and negatively by total sulphur $NaHCO_3$ extractable S and MCP extractable sulphur and about 46 % of the variability in organic sulphur could be explained by this relationship. Total sulphur was influenced positively by $CaCl_2$ extractable S, $NaHCO_3$ extractable Sand organic sulphur and about 36 % of the variability in total sulphur could be explained by this relationship.

Table 10 Multiple regression equations indicating relationship among different pools of sulphur in *Alfisol*

S. No.	Regression equation	R^2	Adj.R^2
1	$CaCl_2$ S = 0.234**(WSS) + 0.023**(MCP) + 0.003 (Total S)	0.39	0.34
2	WSS = 0.533** ($CaCl_2$S) - 0.44**(MCP) + 0.604**($NaHCO_3$ S)	0.59	0.56
3	MCP S = 4.224**($CaCl_2$ S) - 3.638** (MCP S) + 1.181* (KH_2PO_4 S) + 3.456**($NaHCO_3$) - 0.371* (org. S)	0.39	0.34
4	KH_2PO_4 S = 0.52* (MCP S)	0.12	0.06
5	$NaHCO_3$ S = 0.669** (WSS) + 0.047** (MCP S) - 0.55**(Org. S) + 0.003* (Total S)	0.65	0.63
6	Organic S = -0.163* (MCP S) -1.799** ($NaHCO_3$ S) + 0.023 (Total S)	0.46	0.42
7	Total S = 55.972** ($CaCl_2$ S) +21.068* ($NaHCO_3$S) + 4.668** (Org. S)	0.36	0.31

Conclusion:

Study was concluded that the content of organic and inorganic Sulphur fractions varied in different soil orders based on their parent material, organic matter and soil properties of Indo-Gangetic plains of India. Among the sulphur fractions, non sulphate Sulphur was dominant in all the selected soil orders followed by organic sulfur, adsorbed sulfur and available sulphur. Inceptisols soil witnessed higher content of extractable available S fractions compared to Entisols and Alfisols soils. Available S was positive and significant correlated with organic Sulphur in Entisol and Inceptisol while negative correlated with remaining fraction of S. Based on the sulfur availability index, the dominant fraction of sulfur in all three soil orders was non-sulfate sulfur.

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