



E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; SP1: 435-440

Keveinituo Bier

Department of Agricultural
Chemistry and Soil Science,
School of Agricultural Sciences
and Rural Development,
Medziphema Campus, Nagaland
University, Nagaland, India

PK Singh

Department of Agricultural
Chemistry and Soil Science,
School of Agricultural Sciences
and Rural Development,
Medziphema Campus, Nagaland
University, Nagaland, India

Studies on sulphate releasing characteristics of acid soils under Jhum cultivation in Nagaland

Keveinituo Bier and PK Singh

Abstract

A research investigation was undertaken during 2014 in the Department of Agricultural Chemistry and Soil Science, NU:SASRD, Medziphema Campus to study the sulphate releasing characteristics of Acid soils under Jhum cultivation by repeated extractions with 0.15% CaCl₂, 0.016 M KCl and 0.016 M KH₂PO₄. The amount of SO₄²⁻-S extracted by all the three extractants was highest in the 1st extraction followed by gradual decrease till the 7th extraction after which no SO₄²⁻-S was detected. The amount of SO₄²⁻-S released was highest with KH₂PO₄ extractant ranging from 16.51 to 17.55% as compared to KCl (14.70 to 14.96%) and CaCl₂ (14.60 to 15.10%). The total CaCl₂ extracted SO₄²⁻-S was positively correlated with exchangeable Ca²⁺+Mg²⁺ (r= 0.604*). Total KCl extracted SO₄²⁻-S was positively correlated with EC (r= 0.702*) and negatively with soluble SO₄²⁻ (r= -0.727**). The total KH₂PO₄ extracted SO₄²⁻-S was positively correlated with exchangeable Ca²⁺+Mg²⁺ (r= 0.585*) and P (r= 0.694*). Higher amount of total SO₄²⁻ released by KH₂PO₄ can be attributed to the higher releasing power of phosphate than chloride. KH₂PO₄ was found to be a better extractant for SO₄²⁻ extraction than CaCl₂ and KCl under acidic range.

Keywords: Correlation, extractants, jhum, sulphate

Introduction

Sulphur is an essential secondary plant nutrient required by plants and animals in approximately the same amount as phosphorus and few years back it was a neglected element. However, recently sulphur is gaining importance for crop production in the balanced fertilization programme. Sulphur is an important factor in plant feeding as it is taken up by plants in sulphate (SO₄²⁻) form. It is one of the components of sulphur amino acids (cysteine and methionine) and plays an important role in the formation of proteins and is essential for the production of chlorophyll.

Sulphur deficiency has become widespread in most of the agricultural areas of the world over the past several decades, becoming a limiting factor to higher yields and fertilizer efficiency. The reasons behind the deficiency of sulphate in soils are not well defined. However, several studies on sulphate sorption/desorption in different soils revealed that several factors might be responsible for sulphur deficiency. The sulphur release and availability in the soils are governed by the key processes of Adsorption/desorption. The sulphate adsorption takes place below pH 6.5 in acid soils, Inceptisols (Dolui and Jana 1997), Alfisols and Vertisols (Patil *et al.* 1997) etc. Sulphate sorption by soils has been reported to be influenced mostly by pH, organic carbon, nature of clay, sulphate concentration and cations and anions (Patil *et al.* 1997).

Studies on S release characteristics are meagre, and no further work has been done in this field in Nagaland. Therefore, an attempt was made to investigate the "Sulphate releasing characteristics of soils under Jhum cultivation in acid soils of Nagaland" with the objective to determine the physico-chemical properties of soil and to determine the extractable sulphate in soil using KCl, KH₂PO₄ and CaCl₂.

Materials and Methods

The bulk surface soils (0-15cm) under Jhum cultivation were collected from twelve villages of three selected districts of Nagaland namely, Rusoma, Kohima, Meriema and Kidima under Kohima district; Kangching, Tamlu town, Tamlu and Namsang under Tuensang district; and Wansoi, Maksha, Panso and Keshai under Longleng district. Soil were crushed and passed through 2 mm sieve.

The soil pH was determined in 1:2 soil: water suspension using glass electrode pH meter (Richards, 1954). Electrical conductivity was determined in 1:2 soil: water suspension using Conductivity Bridge and expressed as dSm⁻¹ (Richards, 1954).

Correspondence**PK Singh**

Department of Agricultural
Chemistry and Soil Science,
School of Agricultural Sciences
and Rural Development,
Medziphema Campus, Nagaland
University, Nagaland, India

The sand, silt and clay fractions of soil samples were determined by the International Pipette method using 1N sodium hydroxide (NaOH) as a dispersing agent (Piper, 1966). The organic carbon of the soil sample was determined by rapid titration method advocated by Walkely and Black method and expressed in percentage as described by Jackson (1973). The cation exchange capacity (CEC) of the soil was determined by leaching the soil with neutral normal ammonium acetate solution (1 N NH₄OAc) at pH 7.0 (Chapman, 1965).

The available nitrogen was determined by using alkaline potassium permanganate method (Subbiah and Asija, 1956). The available phosphorous was determined by Bray and Kurtz No- 1 method (Bray and Kurtz, 1945) as described by Baruah and Barthakur (1997). The available potassium was determined flame photometrically after extracting the soil with neutral normal ammonium acetate (NH₄OAc) at pH 7.0 (Jackson, 1973). The available sulphur was extracted from the soil using 0.15% CaCl₂ as extractants in a ratio of 1:5 soil:extractant (Chesnin and Yien, 1950). The sulphur in the extract was determined by Turbidimetric method and the intensity of the turbidity formed was measured using UV spectrophotometer at a wavelength of 440 nm. The soluble and adsorbed sulphate S from the soil were extracted by 0.01M Ca(H₂PO₄)₂ and determined turbidimetrically by using spectrophotometer at wavelength 420µm (Chesnin and Yien, 1950). Exchangeable Ca and Mg were determined in 1N ammonium acetate extracts of soil by titration against EDTA (Black 1965).

Soil samples were added with solutions containing 200 µg SO₄²⁻-S mL⁻¹ in 1:2 soil: solution ratio for analysing the sulphate (SO₄²⁻) releasing power. The contents were shaken continuously for 2 hours in a reciprocating shaker and equilibrated at with intermittent shaking for 96 hours. The soil suspensions were then filtered and the soil were air-dried and ground to pass through 2 mm sieve. The SO₄²⁻ saturated soils, thus prepared were used for analysis (Das *et al.* 2008).

KCl extractable SO₄²⁻-S

Twenty-five ml of 0.016 M KCl was added to 2.5g SO₄²⁻ saturated soils samples and shaken continuously end-over-end for one hour and centrifuged. The supernatant was filtered using Whatman no. 42 filter paper. Concentration of SO₄²⁻-S in the extract was determined turbidimetrically (Chesnin and Yien 1950). The same soil was extracted repeatedly for ten times following the same steps (Das *et al.* 2008).

KH₂PO₄ extractable SO₄²⁻-S

Duplicate samples of 2.5g SO₄²⁻ saturated soils were extracted by 0.016 M KH₂PO₄ successively for ten times following the same procedure as adopted for extraction by 0.016 M KCl.

CaCl₂ extractable of SO₄²⁻-S

Duplicate samples of 2.5g of the SO₄²⁻ saturated soil were extracted with 0.15% CaCl₂. The SO₄²⁻ -S in soil extract was determined by turbidimetric method (Chesnin and Yien, 1950). The SO₄²⁻-S in the soil were extracted successively for ten times.

Results and Discussion

The investigation revealed that the soil pH ranges from strongly acidic to moderately acidic with high in organic carbon content in the soil. The available nitrogen content in the soil ranges from medium to high, available phosphorous was low while potassium was low to medium. The CEC varies from 6.20 to 19.80 cmol (p⁺) kg⁻¹ and the exchangeable Ca²⁺ + Mg²⁺ varies from 2.80 to 20.40 cmol (p⁺) kg⁻¹.

Sulphate releasing characteristics

SO₄²⁻-S released by 0.15% CaCl₂: The amount of SO₄²⁻-S extracted by 0.15% CaCl₂ was highest in the 1st extraction with a gradual decrease in the subsequent extraction till the 7th extraction after which no SO₄²⁻ was detected from the soil. Similar finding has been reported by Das *et al.* (2008). The average values of total SO₄²⁻-S extracted in soils were 29.2, 30.05 and 31.3 µg g⁻¹ for Kohima, Longleng and Tuensang district respectively. The highest amount of total SO₄²⁻-S extracted was 33.5 µg g⁻¹ in Panso under Tuensang district and the lowest was found in Rusoma with 27.6 µg g⁻¹ under Kohima district. The percentage of total SO₄²⁻-S released in soils using 0.15% CaCl₂ ranges from 13.80 to 16.75%. The percentage of SO₄²⁻-S retention in the form of adsorbed sulphate was highest in Rüsoma (86.22%) under Kohima district. Similar findings have been reported by Ghosh *et al.* (2012). This might be due to the fact that sulphate adsorption increases with decrease in pH (Xue *et al.* 1991). The total CaCl₂ SO₄²⁻-S was positively correlated with exchangeable Ca²⁺+Mg²⁺ (r= 0.604*) the amount of soluble SO₄²⁻ increases with increase in this constituent (Das *et al.* 2008).

SO₄²⁻-S released by 0.016 M KCl: The amount of SO₄²⁻-S extracted using 0.016 M KCl was highest in the 1st extraction with a slow decrease after the 2nd extraction till the 7th extraction after which no SO₄²⁻ was detected (Das *et al.* 2008). The average values of total SO₄²⁻-S extracted in soils by 0.016 M KCl were 29.8, 29.9 and 28.5 µg g⁻¹ for Kohima, Longleng and Tuensang district respectively. The total SO₄²⁻-S extracted in the soils by 0.016 M KCl was highest in Kohima, Kohima district with 31.5 µg g⁻¹ and the lowest was 26.1 µg g⁻¹ from Maksha, Tuensang district. The percentage of total SO₄²⁻-S released from the soils using 0.016 M KCl extractant ranges from 13.05 to 15.75%. The amount of total SO₄²⁻-S adsorbed was highest in Maksha, Tuensang district (86.95%). This may be due to the fact that SO₄ adsorption increased with decreasing pH (Xue *et al.* 1991). This can be attributed to the fact that the retention of sulphate was dependent mainly on FeO and AlO (Alves *et al.* 2004). Total KCl extracted SO₄²⁻-S was positively correlated with EC (r= 0.702*) and negatively with soluble SO₄²⁻ (r= -0.727**).

SO₄²⁻-S released using 0.016 M KH₂PO₄: The amount of SO₄²⁻-S extracted by 0.016 M KH₂PO₄ was highest in the 1st extraction with a slow decrease after the 2nd extraction. It slowly decreases till the 7th extraction thereafter no SO₄²⁻ was detected, similar findings has been reported by Das *et al.* (2008). The average values total SO₄²⁻-S extracted in soils by 0.016 M KH₂PO₄ were 33.03, 35.10 and 35.20 µg g⁻¹ for Kohima, Longleng and Tuensang district respectively. The total SO₄²⁻-S extracted in soils by 0.016 M KH₂PO₄ was highest in Namsang, Longleng district with 39.90 µg g⁻¹ and the lowest was 31.10 µg g⁻¹ from Kohima of Kohima district. The percentage of total SO₄²⁻-S released from the soils using 0.016 M KH₂PO₄ extractant ranges from 15.55 to 19.60%. The percentage of sulphate adsorbed was highest in Kohima (84.45%) and lowest in Namsang, Longleng district (80.20%). The higher percentage of sulphate released may be due to lesser amount of organic carbon and iron oxides (Patil *et al.* 1997). The total KH₂PO₄ extracted SO₄²⁻-S was found to be positively correlated with exchangeable Ca²⁺+Mg²⁺ (r= 0.585*) and P (r= 0.694*). Das *et al.* (2008) also reported positive correlation between total KH₂PO₄-SO₄²⁻ and exchangeable Ca²⁺+Mg²⁺ due to increase in the amount of adsorbed SO₄²⁻ with increase in this constituent. Schnabel *et*

al. (1991) also reported that sulphate retention decreases with addition of phosphate.

Comparison between SO_4^{2-} -S released by 0.15 % $CaCl_2$, 0.016 $MKCl$ and 0.016 MKH_2PO_4

The SO_4^{2-} -S released was highest in the 1st extraction followed by gradual decrease in the subsequent extractions by all the three extractants. Total KH_2PO_4 - SO_4^{2-} released was higher as compared to total $CaCl_2$ - SO_4^{2-} and KCl - SO_4^{2-} . Both soluble and adsorbed SO_4^{2-} in the soils was released when extracted with KH_2PO_4 while $CaCl_2$ and KCl released only soluble SO_4^{2-} . The higher amount of total SO_4^{2-} released by KH_2PO_4 can be attributed to the higher releasing power of phosphate than chloride.

Table 1: Sand, silt and clay percentage, pH, organic carbon (OC), electrical conductivity (EC), cation exchange capacity (CEC), available N, P and K and exchangeable Ca²⁺+Mg²⁺, soluble and adsorbed SO₄²⁻-S of soils

Soil Sample	Sand (%)	Silt (%)	Clay (%)	Textural class	pH	Organic carbon (%)	EC (dSm ⁻¹)	CEC (cmol (p ⁺) kg ⁻¹)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)	Exchangeable Ca ²⁺ + Mg ²⁺ (cmol(p ⁺)kg ⁻¹)	Soluble SO ₄ ²⁻ -S (μg g ⁻¹)	Adsorbed SO ₄ ²⁻ -S (μg g ⁻¹)
Kohima District														
Rusoma	52.00	16.80	31.20	scl	5.10	2.40	0.19	12.60	612.46	8.30	156.60	5.60	1.00	2.50
Kohima	51.80	19.20	29.00	scl	5.21	1.73	0.20	19.40	515.01	5.58	78.40	6.40	1.50	2.75
Meriema	46.60	15.40	38.00	sc	5.65	2.55	0.21	19.80	651.94	5.59	167.20	6.00	1.25	2.50
Kidima	48.20	14.20	37.6	sc	5.40	1.45	0.16	14.00	498.86	8.06	184.80	15.00	1.50	3.25
Longleng District														
Kangching	46.00	14.80	39.20	sc	5.90	1.26	0.11	6.20	514.76	6.27	110.20	3.60	1.63	2.13
Tamlu Town	53.40	12.00	34.60	scl	5.40	0.96	0.23	10.20	476.02	7.62	134.40	2.80	1.13	2.75
Tamlu	54.00	15.40	30.20	scl	5.50	1.13	0.24	8.40	502.30	6.70	84.00	5.80	1.88	2.63
Namsang	53.80	11.80	34.40	scl	5.70	1.28	0.18	6.20	576.67	8.06	134.40	9.00	1.63	4.00
Tuensang District														
Wansoi	49.20	13.20	37.60	sc	5.90	1.35	0.12	9.60	562.64	6.50	179.20	7.00	1.88	7.75
Maksha	46.00	21.00	33.00	scl	5.70	2.19	0.11	10.20	627.55	8.10	173.60	8.00	3.50	2.25
Panso	59.40	11.20	29.40	scl	5.60	2.36	0.29	7.60	677.55	8.40	89.60	20.40	2.00	1.63
Keshai	54.20	12.40	33.40	scl	5.50	1.91	0.12	13.00	594.66	7.17	123.20	5.20	2.25	2.25

Note: sc indicates sandy clay
scl indicates sandy clay loam

Table 2: SO₄²⁻-S releasing pattern (μg g⁻¹) by 0.15% CaCl₂ at different extractions of soils

Soil sample	SO ₄ ²⁻ -S in extractions (μg g ⁻¹)												SO ₄ ²⁻ -S released (%)	SO ₄ ²⁻ -S adsorbed (%)
	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th	Total			
Kohima District														
Rusoma	6.60	4.50	4.00	3.80	3.50	3.00	2.20	ND	ND	ND	27.60	13.80	86.20	
Kohima	6.60	5.20	4.50	4.00	3.80	3.20	2.40	-	-	-	29.70	14.85	85.15	
Meriema	8.30	4.70	4.40	3.80	3.60	3.40	2.10	-	-	-	30.30	15.15	84.85	
Kidima	7.10	5.00	4.30	3.70	3.00	2.80	2.20	-	-	-	29.20	14.60	85.40	
Longleng District														
Kangching	7.30	5.20	4.70	4.00	3.70	2.20	2.10	ND	ND	ND	29.20	14.60	85.40	
Tamlu Town	8.00	5.20	4.70	3.70	3.20	2.80	2.20	-	-	-	29.80	14.90	85.10	
Tamlu	7.80	5.80	4.90	4.20	3.50	2.40	2.30	-	-	-	30.80	15.40	84.60	
Namsang	8.20	5.60	4.60	4.00	3.20	2.50	2.20	-	-	-	30.40	15.20	84.80	
Tuensang District														
Wansoi	8.40	5.40	4.40	4.00	3.80	2.50	2.20	ND	ND	ND	30.70	15.35	84.65	
Maksha	8.80	5.80	4.90	3.80	3.00	2.80	2.20	-	-	-	31.30	15.65	84.35	
Panso	10.80	5.70	4.80	4.20	3.40	2.40	2.10	-	-	-	33.50	16.75	83.25	
Keshai	8.50	5.30	4.60	3.50	3.00	2.50	2.10	-	-	-	29.50	14.75	85.25	

Note: ND indicates not detected

Table 3: SO₄²⁻-S releasing pattern ($\mu\text{g g}^{-1}$) by 0.016 M KCl at different extractions of soils

Soil sample	SO ₄ ²⁻ -S in extractions ($\mu\text{g g}^{-1}$)											SO ₄ ²⁻ -S released (%)	SO ₄ ²⁻ -S adsorbed (%)	
	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th	Total			
<i>Kohima District</i>														
Rusoma	9.00	6.10	4.90	4.00	3.20	2.20	2.10	ND	ND	ND	31.50	15.75	84.25	
Kohima	8.60	5.40	4.30	4.00	3.40	2.40	2.20	-	-	-	30.30	15.15	84.85	
Meriema	7.10	5.50	4.80	3.30	2.80	2.60	2.20	-	-	-	28.30	14.15	85.85	
Kidima	8.80	4.50	4.00	3.80	3.10	2.80	2.20	-	-	-	29.20	14.60	85.40	
<i>Longleng District</i>														
Kangching	7.00	5.80	4.70	3.80	2.80	2.40	2.10	ND	ND	ND	28.60	14.30	85.70	
Tamlu Town	8.90	5.10	4.80	4.00	3.20	2.60	2.20	-	-	-	30.80	15.40	84.60	
Tamlu	8.00	5.70	4.90	3.70	3.00	2.80	2.10	-	-	-	30.20	15.10	84.90	
Namsang	7.60	5.50	4.50	4.00	3.50	2.80	2.20	-	-	-	30.10	15.05	84.95	
<i>Tuensang District</i>														
Wansoi	8.00	5.80	4.80	3.70	2.70	2.30	2.10	ND	ND	ND	29.40	14.70	85.30	
Maksha	7.00	5.10	4.20	2.80	2.60	2.20	2.20	-	-	-	26.10	13.05	86.95	
Panso	9.00	6.60	4.60	3.80	2.80	2.10	2.10	-	-	-	31.00	15.50	84.50	
Keshai	8.00	5.30	4.10	3.30	2.30	2.30	2.20	-	-	-	27.50	13.75	86.25	

Note: ND indicates not detected

Table 4: SO₄²⁻-S releasing pattern ($\mu\text{g g}^{-1}$) by 0.016 M KH₂PO₄ at different extractions of soils

Soil sample	SO ₄ ²⁻ -S in extractions ($\mu\text{g g}^{-1}$)											SO ₄ ²⁻ -S released (%)	SO ₄ ²⁻ -S adsorbed (%)	
	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th	Total			
<i>Kohima District</i>														
Rusoma	8.80	6.70	4.90	4.20	3.00	2.50	2.10	ND	ND	ND	32.20	16.10	83.90	
Kohima	9.70	5.90	4.60	3.80	3.20	2.30	2.20	-	-	-	31.10	15.55	84.45	
Meriema	11.00	6.60	4.50	3.80	3.20	2.20	2.20	-	-	-	33.50	16.75	83.25	
Kidima	10.30	6.90	5.20	4.60	3.80	2.40	2.10	-	-	-	35.30	17.65	82.35	
<i>Longleng District</i>														
Kangching	9.60	6.50	4.30	3.60	3.20	2.40	2.20	ND	ND	ND	31.80	15.90	84.10	
Tamlu Town	11.70	7.10	4.50	3.80	3.00	2.40	2.10	-	-	-	34.60	17.30	82.70	
Tamlu	12.30	6.40	4.80	3.50	2.80	2.40	2.20	-	-	-	34.40	17.20	82.80	
Namsang	14.70	8.20	6.10	4.00	2.40	2.10	2.10	-	-	-	39.60	19.80	80.20	
<i>Tuensang District</i>														
Wansoi	9.80	7.90	4.80	4.00	3.50	2.70	2.10	ND	ND	ND	34.80	17.40	82.60	
Maksha	12.90	6.60	4.50	3.60	2.80	2.20	2.10	-	-	-	34.70	17.35	82.65	
Panso	14.80	6.80	4.80	3.80	3.30	2.10	2.10	-	-	-	37.70	18.85	81.15	
Keshai	10.40	6.50	5.10	4.00	3.20	2.20	2.20	-	-	-	33.60	16.80	83.20	

Note: ND indicates not detected

Table 5: Correlation coefficient between total $\text{CaCl}_2\text{SO}_4^{2-}\text{-S}$, $\text{KCl}_2\text{SO}_4^{2-}\text{-S}$, $\text{KH}_2\text{PO}_4\text{SO}_4^{2-}\text{-S}$ and different soil properties of Acid soils under Jhum cultivation

Soil properties	$\text{CaCl}_2\text{SO}_4^{2-}\text{-S}$	$\text{KCl}_2\text{SO}_4^{2-}\text{-S}$	$\text{KH}_2\text{PO}_4\text{SO}_4^{2-}\text{-S}$
Clay (%)	-0.271	-0.398	-0.027
pH	0.451	-0.485	0.326
Organic carbon (%)	0.140	-0.187	-0.124
EC (dSm^{-1})	0.407	0.702*	0.278
CEC ($\text{cmol (p}^+)\text{ kg}^{-1}$)	-0.306	-0.111	-0.524
Available N (kg ha^{-1})	0.428	-0.206	0.263
Available P (kg ha^{-1})	0.134	0.202	0.397
Available K (kg ha^{-1})	-0.262	-0.379	0.105
Exchangeable $\text{Ca}^{2+} + \text{Mg}^{2+}$ (me^{-1})	0.604*	0.169	0.585*
Soluble $\text{SO}_4^{2-}\text{-S}$ ($\mu\text{g g}^{-1}$)	0.500	-0.727**	0.188
Adsorbed $\text{SO}_4^{2-}\text{-S}$ ($\mu\text{g g}^{-1}$)	-0.014	0.061	0.184

Note: *, ** indicates significant at 5% and 1% level of significance respectively

Conclusion

The investigation revealed that sulphate adsorption is high in acid soils under Jhum cultivation. KH_2PO_4 was found to be a better extractant for SO_4^{2-} sulphur than CaCl_2 and KCl under acidic range. Since no studies has been conducted regarding sulphate releasing characteristics in Nagaland conditions earlier, therefore further investigation is required to give confirmation to the present findings.

References

- Alves ME, Lavorenti A. Sulphate adsorption and its relationships with properties of representative soils of the Sao Paulo State, Brazil. *Geoderma*. 2004; 118:89-99.
- Baruah TC, Barthakur HP. *A Textbook of Soil Analysis*, Vikas Publishing House Private Limited, New Delhi, 1997.
- Black CA. *Methods of Soil Analysis*. American Society of Agronomy, Inc, Publisher, Madison, Wisconsin, USA, 1965, 171-175.
- Bray RH, Kurtz LT. Determination of total organic and available forms of phosphorus in soils. *Soil Science*. 1945; 59:39-45.
- Chapman HD. CEC by ammonium saturation. *American Journal of Agronomy*. 1965; 9:891-901.
- Chesnin L, Yien CH. Turbimetric determination of available sulphates. *Soil Science Society of America Proceedings*. 1950; 28:149-151.
- Das PK, Sahu SK, Sahoo GC. Sulphate release characteristics of some Alfisols of Orissa. *Journal of the Indian Society of Soil Science*. 2008; 56:59-63.
- Dolui AK, Nandi S. Adsorption and desorption of sulphate in some soils of West Bengal. *Proceedings of Indian National Science*. 1989, 483-488.
- Ghosh GK, Das NR. Sulphate sorption-desorption characteristics of lateritic soils of West Bengal, India. *International Journal of Plant, Animal and Environmental Sciences*. 2012; 2(1):167-176.
- Jackson ML. *Soil Chemical Analysis*, Prentice Hall of India Private Limited., New Delhi, 1973.
- Patil SG, Veeramallappa P, Hebbara M. Sulphate retention as influenced by pH and soil constituents in some major soil groups of Karnataka. *Journal of the Indian Society of Soil Science*. 1997; 45:48-53.
- Piper CS. *Soil and Plant Analysis*. Hans Publishers, Bombay, 1966.
- Richards LA. *Diagnosis and improvement of saline and alkali soils*. Agricultural Handbook No. 60, USDA, Washington, 1954.
- Schnabel RR, Potter RM. Kinetics of sulphate retention on soils as affected by solution pH and concentration. *Soil Science Society of America Journal*. 1991; 55:693-698.
- Subbiah BV, Asiji AL. A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, 1965; 25:259-260.
- Walkey A, Black IA. An examination of the Degtjareff method for determining soil organic carbon matter and a proposed modification of chronic acid titration method. *Soil Science*. 1934; 37:29-38.
- Xue DS, Harrison RB. Sulphate, aluminium, iron and pH relationships in four Pacific-Northwest forest subsoil horizon. *Soil Science Society of America Journal*. 1991; 55:837-840.