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Mineralization rate of sulphur in soils of new alluvial zone of West Bengal under regimes of moisture content

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Abstract
Sulphur (S) presents dominantly in organic form in soils and must undergo microbial mineralization prior to plant uptake. Thus, the potential of different soils to mineralize the native S varies differently and this is being influenced by the soil physical, chemical and biological environment. We aimed to evaluate the Sulphur mineralization potential of soils of new alluvial zone under regimes of moisture content. Therefore, an incubation study was conducted by taking soil samples from new alluvial zone and four moisture levels (field capacity, moist, submerged and alternate wetting and drying moisture content) were maintained for a period of 90 days. To study the S mineralization potential of soils or mineralization rate and influence of moisture content on such process, soil samples were drawn at 15, 30, 45, 60 and 90 days after incubation and analyzed for the increase or decrease amount of available sulphur (0.15% $CaCl_2$extractable S) in soils. So far, the physical attributes of soils of this zone are concerned, the sand content (g kg^{-1}) is 346 in this zone. The result also witnessed high amount of clay content in soils of new alluvial zone (344 g kg^{-1}). The total S content and the organic sulphur content in this zone are 722.1 µg g^{-1} and 691.8 µg g^{-1}. Low amount of inorganic S (30.3µg g^{-1}) was reported in this zone. For new alluvial zone the mineralization rate of sulphur followed reverse trend with periods of incubation; being highest at 15 DAI and followed the decreasing trend as 15 DAI< 30 DAI< 45 DAI< 60 DAI < 90 DAI irrespective of moisture regimes.

Keywords: Sulphur, mineralization, moisture regimes, new alluvial

Introduction

Sulphur is the thirteenth most abundant element in the earth crust with an estimated concentration of 0.06 - 0.10%. Sulphur is one of the important secondary plant nutrients and also considered as a synthesizer element. The importance of Sulphur in agriculture is obvious because of plants require Sulphur for synthesis of essential amino acids and proteins, certain enzymes and co- enzymes and also for activation of certain enzymes (Coleman, 1966) [5]. Organic fractions are the predominant form of Sulphur in soils. The transformation of organic form of Sulphur in soil to inorganic sulphate S (S mineralization) and the reverse process (S immobilization) wherein the incorporation of sulphate into soil organic compounds happens and plays vital roles in the cycling of S within the soil. Both S mineralization and immobilization are microbiologically mediated and are also influenced by concentration in organic matter, moisture, pH, presence of plants, time of cultivation, type of management and particularly the microbial diversity and enzymatic activity (Eriksen *et al.*,1998; Havlin *et al.* 2005; Schoenau & Malhi, 2008) [9, 10, 16]. The activity of the microbial population is affected by the prevailing soil physical and chemical conditions. The main controlling factors are the pH, moisture content and compaction of soil. It is essential to quantify the influence of pH and moisture regimes on net mineralization to improve our prediction of mineralization under field capacity, alternate wetting and drying, submerged and moist conditions. The need to distinguish between net and gross mineralization and immobilization rates over a period of time assumes greater significance in order to synchronize the availability of S with plant need (Deng and Dick, 1991) [7]. The present study was aimed to study the Sulphur mineralization rate of soil with varying soil reaction and also to study the effect of moisture regimes on such mineralization rate.

Materials and Methods

Soil samples were collected from new alluvial zone of west Bengal (Gayeshpur,Nadia) following standard protocols (Jackson,1973). Fresh soil samples were analyzed for soil microbial biomass content following the method of chloroform incubation (Vance *et al*, 1987a) [18]. The soil samples were processed in the laboratory for analysis of other soil properties. The pH of the soils was determined by glass electrode method in 1:2.5 soil: water suspension using Systronics pH meter following the method described by Jackson (1973). Electrical conductivity was determined by using conductivity meter in soil: water of 1:2 suspension. Oxidisable organic carbon content of the soils was determined by wet digestion method of Walkley and Black (1934). The particle size distribution was estimated by Bouyoucos hydrometer as outlined by Jackson (1973). The soil samples were analyzed for different fractions of Sulphur. The $CaCl_2$ extractable S was estimated using 0.15% $CaCl_2$ solution (soil: extractant::1:5); mono calcium phosphate extractable sulphur was estimated using 0.01 M $Ca(H_2PO_4)$. $2H_20$ solution (soil: extractant :: 1:5) and sodium bicarbonate extractable S was estimated using 0.5M $NaHCO_3$(pH 8.5) solution (soil : extract :: 1:4). The amount of S extracted by using all the three extractants was determined by turbidimetry method as outlined by Chesin and Yien (1951) [4]. Total Sulphur was estimated by wet acid digestion procedure as given by (Arkley, 1961) [1]. Mono calcium phosphate extractable S was considered as the inorganic S content of the experimental soils. Thus, organic S content was determined by the difference between total and inorganic S content of soils. Soil parameters viz. pH, electrical conductivity, organic carbon, microbial biomass carbon and percent sand, silt and clay content of the samples (initial as well as incubated soils at 45 and 90 days) were analyzed.

Incubation studies

All the samples were subjected to incubation studies up to 90 days under four different moisture regimes (field capacity, moist, submerged, alternate wetting and drying) and samples were taken at 15, 30-, 45-, 60- and 90-days interval for determining the amount of available S. The samples were incubated at 30^0C. For maintaining field capacity conditions of the soils, each soil was moistened to 50-60% of its water holding capacity (WHC) using a fine spray of de-ionized distilled water. So as to maintain moist condition, the samples were moistened to 70 to 80% of its water holding capacity (WHC). For maintaining submerged condition 5 cm of surface water was maintained during the entire period of incubation. The alternate wetting and drying condition were maintained by adding water at 5 days interval throughout the incubation studies.

Statistical Analysis

Statistical analysis was performed by the windows-based SPSS programme (version 10.0, SPSS, 1966, Chicago, IL). The SPSS procedure used for analysis of variance to determine the statistical significance of treatment effects. Duncan’s multiple range test was used to compare treatment means. Multiple correlations were developed to evaluate the relationship among the response variables. The 5% probability level is regarded as statistically significant.

Results and Discussion

Changes in properties of soils of new alluvial zone during incubation periods

The soil properties varied significantly among the various moisture regimes imposed during the period of incubation study in soils of new alluvial zone. The soil pH increased slightly at 45 DAI (day after incubation) in all four moisture regimes with exception to submerged moisture regime where the pH values decrease from its initial value at 90 DAI (Table1). There was a gradual decrease in soil pH values under submerged condition. The electrical conductivity of soils in all four moisture regimes increased continually at both 45 and 90 DAI with exception to submerged condition which witnessed a lower value at 90 DAI. This suggested that the electrical conductance of a soil under submergence lowered with period of submergence due to unique behavior of soils having differential submerged chemistry. The OC content decreased at 45 DAI and then increased at 90 DAI. So far, the MBC (microbial biomass carbon) soil is concerned; its values decreased continually both at 45 and 90 DAI than its initial values in all four moisture regimes with an exception to submerged condition these findings are in line with the reports of Masunga *et al.*, (2016) [12].

Mineralization rate of Sulphur in soils with varying moisture regimes during incubation

Sulphur mainly presents in organic and inorganic forms in soils; the former being contributing a lion share of total S. Plants usually uptake S in inorganic sulphate form which occurs in readily available form, adsorbed or in occluded form and its amount is very less compared to organic S. Thus, the organic S must undergo the process of mineralization prior to its uptake by plants. Mineralization of soil organic S has been shown to contribute substantially to plant S uptake and leaching (Eriksen *et al*., 1995) [8]. It has been suggested that mineralization of soil organic S involves two distinctive pathways: the biochemical pathway via the hydrolysis of organic ester S by exo-enzymes and the biological pathway involving the release of S from organic materials due to the oxidation of C by soil organisms (McGill and Cole, 1981) [13]. In contrast, microbes assimilate the inorganic sulphate in soil prior to further transformation into soil organic matter through the process of immobilization (Saggar *et al*., 1981) [15]. Because the availability of C substrates largely controls microbial growth in soil, it is also the key factor governing S immobilization. Factors that change C cycling in soil, such as different land uses and fertilization practices are expected to influence S turnover. Under S limiting conditions, however, S availability can also influence C cycling (Chapman, 1997) [3]. However, the process of mineralization and immobilization of S depend upon the mineralization-immobilization turnover (MIT) of substrates besides soil properties

In soil of new alluvial zone, the lowest value of available Sulphur (20.6 $\mu g\ g^{-1}$) content was observed in the initial soil (0 day), and the maximum content was recorded with alternate wetting and drying moisture regime (39.7 $\mu g\ g^{-1}$) 90 DAI. It was quite obvious that after different days of incubation the difference in the stratum of soil moisture contents impart significant difference in the quantity of Sulphur available (Table 2) for soil biota and crops grown on it. Interestingly, there was a peak in the content of available Sulphur at15th DAI (Day after incubation) over 0 day of incubation while no significant change was observed at subsequent days of incubation (Fig 1). The highest content of available Sulphur at 15 DAI & 30DAI was observed under submerged condition, whereas the same witnessed higher amounts in alternate wetting-drying moisture regime at succeeding days of sampling. The field capacity and moist moisture regime maintained less fluctuation in the content of available Sulphur and that under submerged and alternate wetting drying were quite high. The quantum of available Sulphur gradually decreasing from 15th days of incubation under submergence, consequently more and more amount of Sulphur was available in the soils under alternate wetting and drying moisture regime. Gradual suppression in availability of Sulphur under submerged condition hints the fact that due to anaerobiosis, the biodegradability of the soil organic S was in the decreasing trend. This could be obvious because of less availability of soil microbiota for biochemical degradation. The mineralization rate of Sulphur followed reverse trend with periods of incubation; being highest at 15 DAI and followed the decreasing trend as 15 DAI< 30 DAI< 45 DAI< 60 DAI < 90 DAI irrespective of moisture regimes (Table. 3). It was quite acceptable that with days of incubation, the microbial activity falls and the more resistant organic sources act as the substrate as initially the easily degradable organics are used up by soil biota.

Table 1: Initial soil properties of new alluvial zone and their changes in 45 and 90thday of incubation under regimes of moisture content

Sampling sites	Moisture regimes	pH			Electrical Conductivity(µS)			Soil organic Carbon (g kg -1)			Microbial biomass carbon (µg g-1)			Sand	Silt	Clay	Textural class
		0 D	45 D	90 D	0 D	45 D	90 D	0 D	45 D	90 D	0 D	45 D	90 D	(G kg-1)			
New alluvial zone (Gayeshpur, Nadia)	FC	6.36^{Ab}	6.65aA	5.48cC	92.5aC	131.0aB	174.5aA	7.42aA	4.50cB	7.15cA	171.8aA	104.2bB	63.7bC	346b	310a	344b	Clay loam
	Moist	6.36Ab	6.37aA	6.31aA	92.5aC	112.5bcB	166.5aA	7.42aA	5.06bcC	7.14cB	171.8aA	103.4bB	55.0bC				
	Sub	6.36Ab	5.76bB	5.75bB	92.5aC	116.0bB	80.0bC	7.42aA	6.97aB	9.14aA	171.8aA	268.4aA	234.4aB				
	AWD	6.36Ab	6.78aA	6.46aA	92.5aC	108.0Cb	162.5aA	7.42aA	5.52bB	8.17bA	171.8aA	107.6bB	56.3bC				

FC- Field Capacity, Sub - Submerged, AWD - Alternate wetting and Drying

Table 2: Sulphur fractions in soils of new alluvial zone and the changes in amount of available Sulphur during the period of incubation under regimes of moisture content

Sampling sites	Moisture regimes	Available Sulphur (µg g-1)						Sulphur fractions (µg g-1)					
		0 D	15 D	30 D	45 D	60 D	90 D	Total Sulphur	Organic Sulphur	Inorganic Sulphur	Available Sulphur	NaHCO3 Sulphur	Adsorb Sulphur
Newalluvial zone (Gayeshpur, Nadia)	FC	20.6aE	23.8dB	26.2cBC	25.4cC	26.6cB	28.5cA	722.1c	691.8c	30.3c	20.6b	53.0c	9.7b
	Moist	20.6aE	25.8cA	24.8cAB	23.8dB	24.8dAB	24.3dB						
	Sub	20.6aE	36.0aA	34.0aB	31.2bC	29.5bC	30.5bC						
	AWD	20.6aE	31.7bD	31.7bD	34.1aC	35.3aB	39.7aA						

FC- Field Capacity, Sub - Submerged, AWD - Alternate wetting and Drying

Table 3: Native Sulphur mineralized (µg g-1) in soils of Coastal saline and Terai region with various moisture regimes over different days of incubation

Sampling sites	Moisture regimes	Native Sulphur mineralized (µg g-1) in soils				
		15 Days	30 Days	45 Days	60 Days	90 Days
New alluvial zone (Gayeshpur, Nadia)	FC	3.2	5.6	4.8	6.0	7.9
	Moist	5.2	4.2	3.2	4.2	3.7
	Sub	15.4	13.4	10.6	8.9	9.9
	AWD	11.1	11.1	13.5	14.7	19.1
	Mean	8.7	8.6	8.0	8.4	10.2
	Range	3.2-15.4	4.2-13.4	3.2-13.5	4.2-14.7	3.7-19.1

FC- Field Capacity, Sub - Submerged, AWD - Alternate wetting and Drying

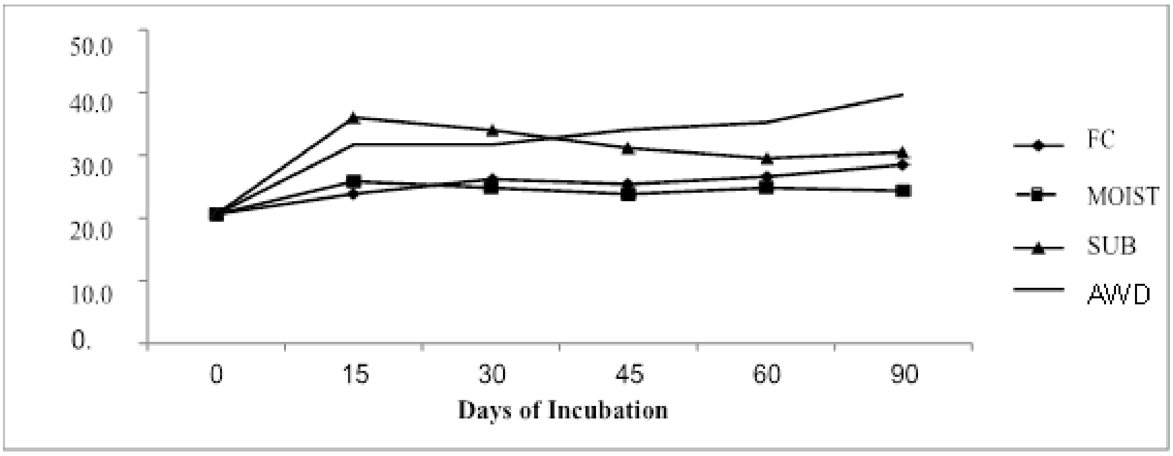

Fig 1: Changes in available Sulphur content of soils of new alluvial zone with days of incubation

Effect of various moisture regimes on Sulphur mineralization rate in soils of New Alluvial Zone of West Bengal

Incubation of all the selected soils under four different moisture regimes for 15, 30, 45, 60 and 90 days period resulted in mineralization of native organic S. Mineralization of native organicS was then determined as the increase in 0.15 per cent $CaCl_2$ extractable S in all the soils. The rate of mineralization during the successive incubation periods (0-15, 15-30, 30-45, 45-60 and 60-90 days) was then calculated using Janzen and Bettany equation (1987) [11].

K = (1-(1-m/mo) 1/3) z Do/2t

Where,
K = Mineralization rate (μg S cm-2d-1)
m = Amount of mineralized Sulphur μg (calculated as an increase in 0.15 per cent $CaCl_2$ extractable S concentration)
mo = Amount of Sulphur at the beginning of each incubation period μg (calculated as the 0.15 per cent $CaCl_2$ extractable S concentration).
z = Density of S (2.07 x 106μg cm-3)
Do = Particle diameter at the beginning of each incubation period (0.075cm by assuming spherical particles)
t = Time of each incubation period in days

The net mineralization rate was determined to calculate the rate of native S mineralized and it ranged from 0.40 to 0.54 μg S cm-2d-1 (15DAI) to 0.07 to 0.09 μg S cm-2d-1 (90DAI) (Table 3). This suggested that the potential of mineralization of native organic S of soils, even after 90 days of incubation was very low under different moisture regimes. This is probably due to the slower microbial activity. Mineralization of native S was faster during the Initial 30 days as the accumulation of $SO4^{-2}$ S was high. The initial rapid rate of organic S mineralization was presumably the result of short period of rapid decomposition.
Many microorganisms satisfy their S requirement from $SO4^{-2}$ S and microbial activity may decrease with prolonged incubation. Similar reports have been reported by De Neve *et al.*, (2000) [6]. The rate of mineralization of native Sulphur in all moisture regimes was higher at 15 DAI compared to 30, 45, 60 and 90 DAI. At 15 DAI, the alternate wetting and drying moisture regime witnessed the highest mineralization rate followed by moist moisture regime. However, the mineralization rate at 15 DAI under submerged condition was at par with field capacity moisture regime in soils of new alluvial zone. The reduction of sulphate under submerged condition may be attributed to lower mineralization rate of native Sulphur in soils (Brajendra *et al.*, 2012) [2]. Under submerged soil conditions, two genera of Sulphur reducing bacteria *Desulphovibrio* and *Desulphotomaculam*reduce sulphate to sulphide ion through thepotential inorganic intermediates- thiosulphate, tetra-thionate and colloidal Sulphur (Sokoleva and Sorokin, 1958) [17]. Therefore, due to limitation of oxygen, the reduction of sulphate to sulphide increases to a relatively high amount and combines with iron in soil to form iron sulphide and is thus retained in the soil.

Conclusion
Moisture regimes have profound influence on the rate of mineralization of native S and the available S content in soils of new alluvial zone of west Bengal. The rate of mineralization of native Sulphur in all moisture regimes was higher at15 DAI compared to 30, 45, 60 and 90 DAI. At 15 DAI, the alternate wetting and drying moisture regime witnessed the highest mineralization rate followed by moist moisture regime. Apart from the moisture regime various others soil property such as pH, EC, organic carbon, microbial biomass carbon has pronounced effect on such mineralization rate.

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