



Effect of manure on retention by soil profile and uptake by soybean (*Glycine max* L. Merrill) – wheat (*Triticum aestivum* L.) crops of applied sulphur in a Vertisol in central India

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Abstract

A field experiment was conducted in subtropical region of India on S deficient Vertisol to study the effect of organic manure on the fate of sulphur (S) applied through gypsum to soil growing soybean (rainy season) and wheat (winter season) in sequence. Farmyard manure (FYM) was applied before sowing of soybean and S was applied as gypsum at different rates before sowing of both crops for six years. Results of soil and plant sample analysis indicate that application of organic manure resulted in a decrease of the retention of applied gypsum-S particularly in sorbed fraction in upper 90 cm soil profile. Also, manure application caused significant lower uptake of S from applied gypsum. Thus less retention of S in conjunction with less uptake of S from gypsum source caused the S from applied gypsum more prone to leaching in manure treated plots.

Key words: Sulphur, vertisol, farmyard manure, gypsum, soybean, wheat.

Introduction

Several experiments on research farms as well as on farmers' fields have clearly established the S requirement of Indian soils¹. Hence, regular S application is advocated for better harvest of major crops. Various processes of the S cycle, such as leaching, erosion, crop uptake and immobilization in organic pools reduce the availability of applied S in the soil^{2,3}. In case of continuous S fertilization to crops, amount of S input may exceed that of removal, resulting in build up of S in the soil profile. Santhy and Channal⁴ have found significant buildup of S in the upper 60 cm soil depth due to 20 years of intensive cultivation using S containing fertilizer. Also requirement of regular application of organic manure in Indian soil is advocated for higher sustained productivity of crops, as Indian soils are generally found deficient in soil organic matter content⁵. Conjunctive use of manure and sulphur has been found beneficial in increasing productivity of many crops^{6,7,8}. Increased soil organic matter due to continuous manure application may influence various S transformation processes such as immobilization and mineralization by organic matter and adsorption of S by some soil components^{9,10}. Such effect on transformation may influence the retention of applied fertilizer S in the soil profile, thereby influencing S availability in soils and its uptake by crops. Present study was conducted in a Vertisol region to assess the effect of manure application on the movement of applied S in different pathways of the S cycle in soils and its effect on yield and S uptake by soybean-wheat cropping sequence, predominant in central India.

Materials and Methods

A field experiment was conducted during six years at Indian Institute of Soil Science, Bhopal (77°27'E, 23°20'N, 495 m above mean sea level) to determine the S requirement of soybean-wheat sequence on Vertisol (Typic Haplustert). The experimental area has subtropical monsoon type climate (mean annual precipitation 1208 mm) with hot summer and mild winter. About 90% of the annual

precipitation is received during mid June to mid September. The soils of the experimental site are alkaline in reaction with heavy texture. The surface geology of the area is basalt containing mainly feldspar and augite. Soils of the experimental site are alkaline in reaction (pH_{1:2} in water is 7.6) with heavy in texture (55.5% clay). The contents of organic C and free CaCO₃ are 0.51% and 2.6% respectively. Soils are more or less uniform within 90 cm of profile with respect to clay, free CaCO₃ and base saturation. However, organic C content decreased and bulk density increased with depths upto 45 cm depth. Soybean (during July to October) and wheat (during November to March) were grown in sequence in these plots with recommended doses of N, P and K through fertilizer. In this experiment, four cumulative levels of S, *i.e.*, 0 (S₀), 180 (S₁₈₀), 360 (S₃₆₀) and 540 (S₅₄₀) kg S ha⁻¹ with (M₉₆) or without (M₀) cumulative application of 96 Mg ha⁻¹ of farmyard manure (FYM) were applied in the plot size of 10 m x 5 m during six years period. The treatments were replicated four times. Sulphur was applied in the form of gypsum to both the crops; whereas, FYM (containing about 25 to 35% moisture) was applied to only soybean crop during land preparation. Farmyard manure was collected each year from a nearby dairy farm and is composed mostly of nearly decomposed cow dung. After the harvest of 12th crop (wheat), soil samples were collected from the profile (0-90 cm) at 15 cm intervals using a tube auger. Soil samples were air-dried and ground to pass through 0.5 mm stainless steel sieve. The soils were analyzed for two different fractions of S, namely soluble (extracted with 0.15% calcium chloride¹¹) and sorbed (extracted with 16.13 meq l⁻¹ PO₄³⁻ after removal of soluble sulphate¹²). The SO₄²⁻ concentration in the extracts was determined through ion-chromatograph (DIONEX DX-300) following the procedure described by Dick and Tabatabai¹³. Total S content was determined turbidimetrically by following dry ashing method of Steinbergs et al¹⁴. The soil in the experimental field is situated in upland and is dominated by the low S containing minerals *viz.*, quartz, feldspar, vermiculite, mica (in silt) and smectite, kaolinite, and mica (in clay). Hence, it is assumed that presence of sulfide S will be negligible and almost

Table 1. Total yield and S uptake by aboveground biomass of soybean and wheat.

	Aboveground biomass of soybean (Mg ha ⁻¹)		Aboveground biomass of wheat (Mg ha ⁻¹)		S uptake by above-ground biomass of soybean (kg ha ⁻¹)		S uptake by above-ground biomass of wheat (kg ha ⁻¹)	
	M ₀	M ₉₆	M ₀	M ₉₆	M ₀	M ₉₆	M ₀	M ₉₆
S ₀	25.73 ^{a*}	35.53 ^a	43.49 ^a	56.12 ^a	46.32 ^a	63.96 ^a	60.88 ^a	89.79 ^a
S ₁₈₀	30.60 ^b	36.46 ^a	48.46 ^b	57.00 ^a	55.07 ^b	69.28 ^{ab}	72.70 ^b	85.51 ^a
S ₃₆₀	32.80 ^{bc}	37.76 ^a	51.34 ^{bc}	60.64 ^{ab}	62.31 ^c	67.96 ^{ab}	77.02 ^b	90.96 ^a
S ₅₄₀	34.24 ^c	37.12 ^a	54.97 ^c	62.97 ^b	66.78 ^c	70.54 ^b	87.96 ^c	91.30 ^a
Mean	30.84	36.72	49.57	59.18	57.62	67.93	74.64	89.39

*Column means followed by the same letter are not significantly different among themselves at 5% probability level.

Table 2. Changes in the contents of S fractions (g m⁻³) in different soil layers due to FYM application at different gypsum application rates.

Soil depth	S ₀				S ₁₈₀				S ₃₆₀				S ₅₄₀			
	Soluble	Sorbed	organic	Total	Soluble	Sorbed	organic	Total	Soluble	Sorbed	organic	Total	Soluble	Sorbed	organic	Total
0-15	4.38	-3.63	26.59	27.33	6.9	-6.0	33.5	34.4	6.2	-7.7	27.7	26.1	5.3	-6.3	20.7	19.6
15-30	2.04	5.43	9.63	17.10	4.3	6.2	n.s.	n.s.	4.7	n.s.	n.s.	n.s.	2.6	5.8	n.s.	n.s.
30-45	2.77	n.s.	13.02	13.16	3.3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-6.4	n.s.	n.s.
45-60	3.51	-3.24	n.s.	n.s.	3.4	n.s.	n.s.	n.s.	2.8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
60-75	6.58	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
75-90	n.s.*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*n.s. = not significant at 5% probability level

all the S is present in three extractable forms viz., water soluble, sorbed and bound by organic matter. Therefore, organic S was calculated as the difference between total S and soluble plus sorbed S fractions. Soybean and wheat grain and straw samples were digested with di-acid mixture¹⁵ and S concentration in the acid extracts was determined turbidimetrically following the procedure of Williams and Steinbergs¹¹. Statistical analysis of the results was performed following the methods described by Panse and Sukhatme¹⁶.

Results and Discussion

Yield and S uptake by above ground biomass of soybean and wheat: Application of FYM, on an average increased significantly both total grain and biomass yields of soybean and wheat during six years (Table 1). There were about 19.0% and 19.4% increases in above ground biomass yields of soybean and wheat crops as a result of total application of about 96 Mg FYM ha⁻¹. Increases in grain and straw yields of both the crops due to application of gypsum were much more pronounced in the plots where FYM was not applied. Such increases were, however, either absent or less pronounced in FYM applied plots. There were significant increases in uptake of S by above ground biomass of both crops due to application of both FYM and S. Application of FYM increased total S uptake by 17.9% and 19.8% in above ground biomass of the soybean and wheat crops, respectively (Table 1). The increases in sulphur uptake due to gypsum application by above ground biomass of both crops were more pronounced in no FYM plots as compared to the FYM applied plots. Contribution of applied S to total uptake by the above ground biomass of the crops grown over six years for the gypsum treated plots was calculated by deducting the S uptake value obtained in no gypsum treated plots. Results

(Table 5) showed significantly lower or negligible effect of gypsum application on S uptake by crops in M₉₆ plots as against significant increasing effect (8.8 to 11.4% of gypsum applied S) in M₀ treated plots. Such effects on yield and S uptake can be attributed to the significant contribution by applied FYM to the plant available S pool (Table 2). Contribution from FYM might have satisfied much of the S requirement and thus resulted in less or no enhancing effect on the yield and S uptake by gypsum.

Accumulation of S in soil profile: Water soluble S in the soil is considered readily available to plants. Organic manure application in S₀ treatment (Table 2) resulted in a significant increase of S content in all the layers within top 75 cm depth. Accumulation was higher in the 0-15 cm and 60-75 cm layers. High accumulation of applied S in organic fraction (discussed in later part of this section) in surface layer might have maintained equilibrium with water soluble pool through its mineralization resulting in the observed increase in the later pool. Downward movement of SO₄⁻² through percolating rain and irrigation water may be the cause for observed increase in the lower profile. In the gypsum-applied plots, FYM application resulted significant increase in soluble S content up to 60 cm depth in S₁₈₀ treatment and up to 30 cm in S₃₆₀ and S₅₄₀ treatments. Sulphur release from applied gypsum has masked the effect of FYM application in increasing soluble S content in deeper layers. Retention of applied S in a particular fraction in the upper 90 cm soil layer was calculated on the basis of amount of S added and the content in the particular fraction in the soil layer. As experimental site is far away from industrial area, S input from atmosphere is considered very small and uniform to all the plots. As all the plots were surrounded by 7-10 cm high bunds, rainwater and irrigation water were generally retained in the plots. Therefore,

Table 3. Retention (%) of applied S in upper 90 cm soil profile.

	Soluble		Sorbed		Organic		Total	
	M ₀	M ₉₆	M ₀	M ₉₆	M ₀	M ₉₆	M ₀	M ₉₆
S ₁₈₀	5.5	6.5	16.2	13.1	7.1	3.3	28.8	22.8
S ₃₆₀	8.1	8.1	18.7	13.3	10.3	13.2	37.2	34.6
S ₅₄₀	13.7	12.2	18.3	14.5	14.7	16.8	46.7	43.5
Mean	9.1	8.9	17.7	13.6	10.7	11.1	37.5	33.6

Table 4. Organic C content (%) in soil layers.

Soil depth (cm)	M ₀	M ₉₆
0-15	0.48 ^{a*}	0.82 ^a
15-30	0.4 ^b	0.46 ^b
30-45	0.37 ^b	0.40 ^c
45-60	0.31 ^c	0.33 ^d
60-75	0.31 ^c	0.32 ^d
75-90	0.32 ^c	0.34 ^d

*Column means followed by the same letter are not significantly different among themselves at 5% probability level.

loss of S through run-off water is assumed very small. About 5.5 to 13.7% of the applied S was retained in the soluble fraction in 90 cm depth of the profile, the magnitude increased with increasing levels of applied S. Application of FYM did not have significant effect on the retention of applied S in this fraction (Table 3). Sulphate is adsorbed onto soil materials (mainly kaolinites, iron and aluminium oxides) by ligand exchange with hydroxyl groups and positive charged sites are involved¹⁷. Farmyard manure application had contrasting effect on this sorbed fraction of S content (Table 2). While it caused decrease in surface layer, the content in this fraction of S increased in subsurface layer (15-30 cm) in case of all the levels of applied S. The changes were insignificant in depths below the 30 cm. It is likely that continuous application of manure

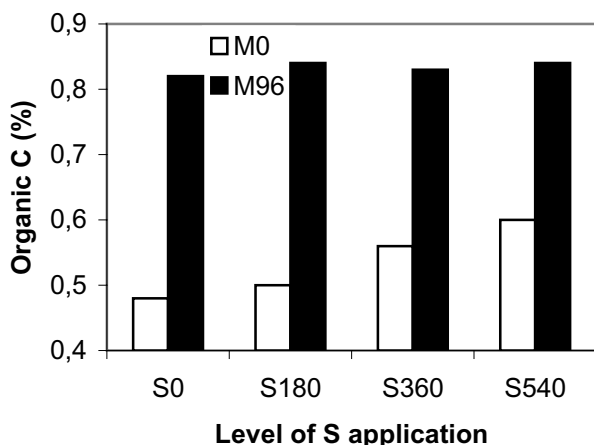
Sulphur in organic fraction exists as carbon (C) bonded and as sulphate ester. Sulphur content in organic fraction recorded significant increases in upper 45 cm soil layer due to continuous application of FYM for six years (Table 2). The magnitude of increase in this fraction was the maximum (26.6 g S m⁻³) in the surface layer (0-15 cm) and decreased significantly with depth. Such an increase in this fraction was due to increase in organic matter content in the soil layers caused by application of FYM (Table 4). In Denmark, Eriksen and Mortensen¹⁸ also observed increasing effect of long-term animal manure application on the S content in organic fraction in a low organic matter containing Inceptisol. Such an effect of manure application in that study was however, absent in Alfisol with higher organic matter content. In gypsum treated soils, the significant increase in organic bound S due to FYM application was recorded only in the surface layer. The maximum magnitude of increase in this fraction was observed in S₁₈₀ level and the values decreased with increase in the levels of S application. The observed higher increase in S₁₈₀ level of S application was related to the higher magnitude of increase in organic carbon content (Fig. 1). Average retention of applied S in this fraction in upper 90 cm soil layer was not significantly changed due to continuous application of FYM (Table 3). Results of total S analysis in the soil indicate (Table 2) that application of FYM each

Table 5. Contribution (g m⁻²) of applied S to different pathways of S cycle.

	Total crop uptake		Retention in 90 cm soil depth		Leaching below the 90 cm soil depth	
	M ₀	M ₉₆	M ₀	M ₉₆	M ₀	M ₉₆
S ₁₈₀	2.06 (11.4%)*	0.10 (0.6%)	5.19 (28.8%)	4.10(22.8%)	10.76(59.8%)	13.80(76.6%)
S ₃₆₀	3.21 (8.9%)	0.52 (1.4%)	13.38(37.2%)	12.47(34.6%)	19.41(53.9%)	23.01(63.9%)
S ₅₄₀	4.75 (8.8%)	0.81 (1.5%)	25.20(46.7%)	23.50(43.5%)	24.05(44.5%)	29.69(55.0%)

* Values in parenthesis are expressed as % of applied S

have blocked the SO₄⁻² adsorption sites of the inorganic solid particles, including various oxides, resulting in decrease in their SO₄⁻² sorption capacity. Such an effect is expected to be more in the surface layer, which showed highest increases in organic matter content in the surface layer. However, Chao et al.¹⁹ have observed decrease in sulphate adsorption capacity of the soil due to removal of organic matter. They speculated that amphoteric nature of organic compounds in soil might develop positive charge on them under certain circumstances causing increase in their ability to absorb sulphate. Total retention of applied S in this fraction in 90 cm profile layer was about 4.1% less in M₉₆ treated plots than M₀ treated plots.

**Figure 1.** Effect of FYM application on changes in organic C content in the surface layer (0-15 cm) at different levels of S application.

year for six years resulted in significant increase in upper 45 cm soil layer in case of no gypsum applied plot (S₀) and in upper 15 cm soil layer only in case of gypsum applied plots. The maximum magnitude of increase (34.4 g S m⁻³) due to FYM application was in S₁₈₀ treatment and such magnitude became lesser as the level of S application increased. The significant increase in total S due to organic matter application was mainly because of increase in organic bound fraction of S content. Analysis of a large number of samples of FYM showed the average S content in the FYM to be 0.27% on dry weight basis. On the basis of this content, 0-90 cm depth of soil profile was found to retain about 53% of the S added through FYM. Retention of applied S in the upper 90 cm depth of the profile in no FYM plots were 28.8, 37.2 and 46.7 % for S₁₈₀, S₃₆₀ and S₅₄₀ levels (Table 3). Application of FYM resulted significant decrease in the retention values. There were 8.5, 4.2 and 5.1 % less retention in FYM treated plots as compared to no FYM treated plots of S₁₈₀, S₃₆₀ and S₅₄₀ levels respectively.

Conclusions

Assuming S loss through erosion minimum, sulphur leaching below the 90 cm soil depth of gypsum treated plots was calculated by deducting the amounts of S removed by above ground biomass of the crops and S retained in the 90 cm soil layer from amount of S added through gypsum. Results showed (Table 5) that the amount of S leached below the 90 cm soil depth varied between 44.5 to 76.6% of the applied S through gypsum. Although total amount of S leached down the profile increased, its proportion (of applied S) decreased with increase in amount of S applied through gypsum.

Magnitude of S leaching was more (by an average of 12.4% of applied S) in FYM treated plots as compared to no FYM treated plots. This observed increase in S leaching was related to less retention of applied S in 90 cm soil layer as well as less uptake of applied S by crops due to FYM application. The magnitude of leaching (as % of applied S) was higher at lowest level (S_{180}) of S application as compared to higher levels. Thus, continuous application of organic manure resulted in a decrease in the retention of applied gypsum-S particularly in sorbed fraction, but increased both soluble sulphate and organic S content in soil. Soybean and wheat crops grown on this soil preferred S more from manure source than from gypsum source when both the sources were applied simultaneously. Mineralization of organic S occurs via both biological and biochemical processes involving microbial and enzymatic activity¹⁹, which results in increase in plant available pool. However in pot experiment, Eriksen²⁰ concluded that animal manure, though contain considerable amount of S, is of little value as source of sulphate for plants. Less retention of S in conjunction with less uptake of S from gypsum source caused the applied gypsum S more prone to leaching in presence of FYM.

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