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Evaluation of iron pyrites as sulphur fertilizer

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Abstract. A field experiment was conducted for three consecutive winter crop seasons commencing in 1979–80 on the Typic Ustochrept of Pura to evaluate iron pyrites as S fertilizer. Four crops viz, wheat, chickpea, mustard and Egyptian clover were tested for their responsiveness to added pyrites. All the crops responded significantly to added pyrites. Mustard proved most sensitive to S deficiency in soil and wheat the least. Between the two legumes, Egyptian clover was more sensitive to S stress than chickpea. Average biomass production by Egyptian clover was highest followed by wheat, mustard and chickpea. Mustard and Egyptian clover required more S to achieve maximum biomass production compared with wheat and chickpea but they also recovered from the soil a large proportion of added S than wheat and chickpea. Addition of pyrites increased availability of S in soil. Pyrites enhanced mobilization of soil P and its utilization by the crops.

Consumption of fertilizers in India, during the last two decades increased fifteen fold i.e. from 2.17 kg ha^{-1} in 1961–62 to 34.64 kg ha^{-1} in 1981–82. The farm use of S containing fertilizers over the years has largely decreased. In the past, there had been inadvertent application of S through fertilizers like ammonium sulphate, superphosphate and potassium sulphate. In modern agriculture, more emphasis is being given to the production and use of high analysis fertilizers, practically devoid of S, which do not allow periodic addition and accretion of sulphur in soil. Deficiencies of S for sugarcane, grown in West Bengal was reported as early as 1962 by Dutt [10]. Attention towards S deficiency and its need for crop production in Indian soils was, however, drawn during the sixties by Kanwar [11] and Kanwar and Takker [12]. Subsequently, deficiencies of S in a number of alluvial, laterite and red soil associations in the country were reported. This situation has been accentuated through the large scale introduction of high yielding varieties of crops and intensive farming under irrigation. Beneficial effect of S on crop yield was established through actual crop response studies [1, 8, 9, 17]. Das and Datta [9] reported that low rates of S applied through gypsum were inefficient in maintaining a higher residual S status of soil; and emphasised the use of slow release S containing materials such as elemental sulphur and polysulphides. Iron pyrites, being a slow release S carrier may prove a better source of S for immediate and residual effect in mitigating the ever increasing deficiency of this plant nutrient in intensively cropped areas of alluvial soils of

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Uttar Pradesh. Experimental work pertaining to the use of iron pyrites as S fertilizer at present is scanty and very few investigators, hitherto, have given attention to it. Banath [2] was perhaps the first report that iron pyrites, without any special treatment except grinding, increased the dry matter yield of *Trifolium subterraneum* L. Based on these results he declared iron pyrites as an effective S fertilizer. Keeping above facts in view, studies were undertaken for a systematic evaluation of immediate and residual effect of iron pyrites as S fertilizer. Additionally, since there are evidences to suggest that S has the advantage on low phosphate soils to improve phosphorus availability the field work was under taken on a P responsive soil to study this interrelated aspect of S fertilization through iron pyrites.

Materials and methods

A field experiment was conducted in a soil representing Typic Ustochrept at Fertilizer Research Station, Pura (Kanpur), India for three consecutive winter crop seasons commencing in 1979–80. The mildly alkaline soil (pH 8.03) of the experimental field was sandy loam in texture (65% sand, 18.5% silt and 15.5% clay) and contained 0.32% organic carbon, 9 $\mu g\,g^{-1}$ Olsen-P and 6.9 $\mu g\,g^{-1}$ available S. The experiment was a split-plot design with 12 treatments comprising 4 crops viz. wheat (*Triticum aestivum*) Cv Sonalika, Chickpea (*Cicer arietinum*) Cv T-3, mustard (*Brassica juncea*) Cv Varuna and tetraploid Egyptian clover (*Trifolium alexandrinum*) in the main plots and 3 rates of S (0, 60 and 120 $kg\,ha^{-1}$) in the sub plots with four replications. Sulphur was supplied through agriculture grade (30% S) iron pyrites of the particle size less than 5 mm in diameter. N and K were applied as urea and muriate of potash to all the crops according to their requirements viz. 120 and 48 $kg\,ha^{-1}$ for wheat and mustard; 15 and 48 $kg\,ha^{-1}$ for chickpea and 40 and 48 $kg\,ha^{-1}$ for Egyptian clover. Since the role of S in mobilizing soil P was to be studied no P was added as fertilizer to all four crops.

Wheat, chickpea and mustard were harvested at maturity and after recording grain and straw yields on dry matter basis the samples were retained for chemical analysis. Four cuttings of Egyptian clover were taken each at intervals of 45 days. Fodder yields were recorded on the oven dry basis and samples were kept for chemical analysis. Soil samples of each plot were collected at 45 day cropping and after harvesting of the crops during all the years of experimentation.

Bray's per cent yield (the yields of crops without added S expressed as per cent of those produced by crops given S at rates which gave maximum yields) was taken as an index of the sensitivity of different crops to S deficiency. Per cent grain yields were taken into account in all crops except Egyptian clover whère in per cent dry matter yield was calculated on the basis of total dry matter production of four cuttings.

Grain and straw samples, freed from all external contaminations, were first dried in a hot air oven and then in an oven at 80° C for 12 hours, and ground in a Wiley mill with all stainless steel parts. The ground grain and straw samples were digested with a diacid mixture of HNO_3 and $HClO_4$ [18] and S was determined turbidimetrically. Soil samples were analysed for available S and P by adopting turbidimetric method [7] and colorimetric method [16], respectively, pH of soil was measured in a 1:2 soil-water suspension, organic carbon by Walkey and Black's rapid titration method and mechanical analysis was done by International Pipette method.

Results and discussion

Yield responses to added S through pyrites

Addition of pyrites to soil over an optimum supply of N and K resulted in a significant increase in grain yield of wheat, chickpea, and mustard and fodder yield of Egyptian clover (Table 1). In India, a beneficial effect of pyrites on grain yield of different crops has been reported earlier [13, 19].

Magnitude of response compared with control generally increased concomitantly with the passage of time, the extent of increase being highest

Table 1 Effect of added pyrites on grain yield of wheat, chickpea and mustard and fodder yield of Egyptian clover (kg ha^{-1})

Rate of pyrites application Kg ha^{-1}	= KgS ha^{-1}	Wheat	Chickpea	Mustard	Egyptian clover*	Mean
			1979–80			
0	0	3050	2138	1362	12545	4774
200	60	3481	2293	1582	14556	5478
400	120	4020	2469	1765	15803	6014
Mean		3517	2300	1572	14302	
			1980–81			
0	0	2725	2010	1058	11230	4256
200	60	3308	2550	1400	13537	5199
400	120	3810	2670	1650	14762	5723
Mean		3264	2410	1370	13176	
			1981–82			
0	0	2594	1047	291	8855	3197
200	60	3452	1299	1319	13599	4917
400	120	3801	1596	1813	17147	6089
Mean		3283	1314	1141	13200	

	Crops	S levels	For different crops at particular S level	For different S levels at particular crop
SE m ± 1979–80	145	147	253	254
SE m ± 1980–81	194	67	215	115
SE m ± 1981–82	611	208	678	361

*Total biomass production of four cuttings on dry matter basis.

during the third year compared with the preceding two years. Such relative increase in yield responses can be attributed to increased S deficiency in soil as a result of cropping. During 1979–80, per cent increase in grain and fodder yields due to pyrites application was largest in wheat (31.8), closely followed by mustard (29.6) and then Egyptian clover (26.0) and chickpea (15.5) in the order; but in subsequent years mustard showed largest response to added pyrites and wheat, the least. Such an interesting reversal in response behaviour of the crops to added pyrites is merely due to difference in their susceptibility to S deficiency in soil. The extent of increase in grain yield of wheat and mustard was of similar order during first year when the deficiency of S in soil was of smaller magnitude; but with cropping larger resultant deficiency of soil S produced maximum reponse by mustard. Apparently, mustard suffered maximum yield loss under no pyrites (control) comparing with pyrites treatment followed by Egyptian clover, chickpea and wheat. These results clearly indicate that relative to the crops studied mustard is more sensitive to S deficiency and has comparatively the highest demand for S (Table 2). Comparatively high S requirement of oilseed crops has also been reported by others [4, 20]. Bray's per cent yield (Figure 1) computed to assess the relative sensitivity of crops tested also indicated amongst the four crops higher sensitivity of mustard to S stress in soil. Between the two legumes, Egyptian clover was more sensitive to S deficiency than chickpea. It is of interest to mention that the yields of different crops under no pyrites (control) decreased sharply during three years of cropping while addition of S through pyrites helped sustaining yield levels. These results are indicative of beneficial effect of added pyrites on maintenance of soil productivity levels.

Sulphur uptake and utilization

Total S uptake by different crops increased linearly with increasing rates of pyrites (Figure 2). During all three years, total uptake of S was highest with

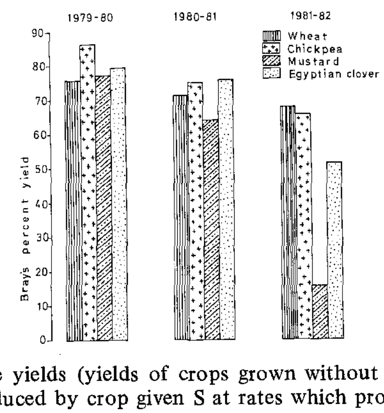

Figure 1. Percentage yields (yields of crops grown without added pyrites(s) expressed as a % of those produced by crop given S at rates which produced maximum yields) as an index of S deficiency in four crops

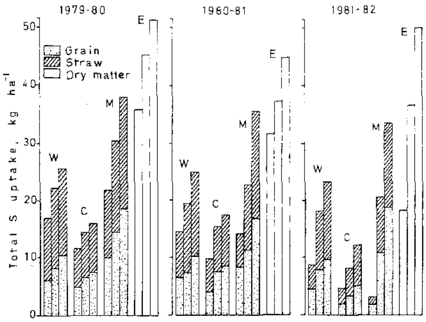

Figure 2. Effect of added S (kg ha^{-1}) on total uptake (kg ha^{-1}) of S by wheat (W), Chickpea (C), Mustard (M) and Egyptian clover (E). The bar on the left is 0 kg, the middle bar for 60 kg and the bar on the right for 120 kg applied sulphur

Egyptian clover followed by mustard, wheat and chickpea. As the cropping progressed these quantities decreased. A mean uptake of S of 39, 24, 19 and 12 kg ha^{-1}, respectively was registered during the years of study. Beneficial effect of pyrites on the content and uptake of S by different crops has also been reported [3, 15].

Total biomass production by Egyptian clover was largest followed by wheat, the values of chickpea and mustard, however, were comparable in the first two years of study while during third year dry matter production by mustard in pyrites treated plots was higher than that of chickpea. Ratio dry matter produced: S absorbed by various crops (Figure 3) clearly shows that on an average, wheat produced more dry matter per unit S absorbed than chickpea, Egyptian clover and mustard. During 1979–80 ratio dry matter produced: sulphur absorbed ranged between 390 and 476 with a mean of 429 in wheat, 360 and 436 with a mean of 392 in chickpea, 309 and 349 with a mean of 327 in Egyptian clover and 166 and 224 with a mean of 192

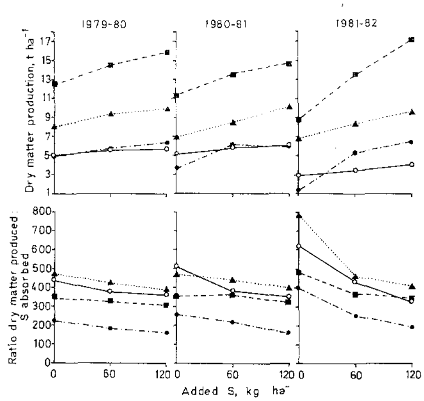

Figure 3. Efficiency of S utilization by four crops ——■—— Egyptian clover, ····▲···· Wheat, •—•●•—• Mustard ——○—— Chickpea

in mustard. Similar trend was registered during 1980–81 and 1981–82. From these data it is clear that wheat proved more efficient in utilizing S than mustard, Egyptian clover and chickpea. It is of interest to mention that mustard required highest quantity of sulphur for each ton of biomass production which in fact indicates higher S requirement of mustard compared with other crops tested. Of the two legumes, Egyptian clover required more S for each ton of biomass production than chickpea and thus had a comparatively high S requirement.

Availability of S in soil

In spite of higher withdrawals of S in pyrites treatment, available S content of soil increased significantly (Table 2). Per cent increase in the availability of S was higher during 1981–82 compared with preceding years, which is associated with continuous decrease in available S content of soil under no pyrites (control) and build up in available S status of soil under pyrites treatment. It is evident that S status of soil under no pyrites (control) depleted continuously with cropping while pyrites treatment prevented depletion. Despite higher removal of S by mustard, available S content of surface soil was maximum under this crop.

Table 2 Effect of added pyrites on the availability of sulphur in soil at 45 day of cropping

Rate of pyrites application		Available S($\mu g\ g^{-1}$)				
Kg ha^{-1}	= Kg S ha^{-1}	Wheat	Chickpea	Mustard	Egyptian clover	Mean
			1979–80			
0	0	9.0	8.5	8.5	7.5	8.4
200	60	11.5	13.0	12.0	13.5	12.5
400	120	18.0	21.5	18.5	18.0	19.0
Mean		12.8	14.3	13.0	13.0	
			1980–81			
0	0	10.5	7.8	8.0	8.0	8.6
200	60	12.0	15.8	12.5	14.8	13.8
400	120	13.5	20.5	19.5	16.0	17.4
Mean		12.0	14.7	13.3	12.9	
			1981–82			
0	0	6.7	4.7	3.3	5.3	4.9
200	60	7.6	14.7	8.0	13.3	10.9
400	120	8.0	22.7	16.2	17.4	16.1
Mean		7.4	14.0	9.2	12.0	

	Crops	S levels	For different crops at particular S level	For different S levels at particular crop
SE m ± 1979–80	0.24	0.51	0.76	0.88
SE m ± 1980–81	0.53	0.47	0.85	0.82
SE m ± 1981–82	0.32	0.37	0.62	0.65

Effect on soil P mobilization by added pyrites

Addition of pyrites caused significant increase in available P content of soil after 45 days of cropping in each case during all three years of experimentation (Table 3), the extent of increase being largest during 1981–82 compared with preceding years. Such an increase in available P content can be ascribed to mobilization of native soil P to soluble forms consequent upon pyrites application. This is in accord with well established fact that pyrites, on oxidation, leads to the formation of sulphuric acid which reacts with different insoluble salts in soil [5, 6, 14]. Available P content of soil during 1979–80 under no pyrites-control was highest under wheat cropping (15.5 $\mu g\, g^{-1}$) followed by chickpea (15.0 $\mu g\, g^{-1}$), mustard (14.2 $\mu g\, g^{-1}$) and Egyptian clover (13.8 $\mu g\, g^{-1}$) in the order which consequent upon decreased to 13.4 $\mu g\, g^{-1}$ in wheat, 9.9 $\mu g\, g^{-1}$ in mustard, 7.6 $\mu g\, g^{-1}$ in chickpea and 7.2 $\mu g\, g^{-1}$ in Egyptian clover during 1981–82. However, with the addition of pyrite, available P content of soil increased significantly, the values being 20.5 $\mu g\, g^{-1}$ in case of wheat, 18.2 $\mu g\, g^{-1}$ in chickpea 17.8 $\mu g\, g^{-1}$ in mustard and 17.2 $\mu g\, g^{-1}$ in Egyptian clover during 1979–80. In the subsequent years, though the available P content of soil could not be maintained to that level

Table 3 Effect of added pyrites on the availability of phosphorus in soil at 45 day of cropping

Rate of pyrites application kg ha^{-1}	= kgs ha^{-1}	Available P($\mu g\, g^{-1}$) Wheat	Chickpea	Mustard	Egyptian clover	Mean
			1979–80			
0	0	15.5	15.0	14.2	13.8	14.6
200	60	17.2	14.8	15.5	16.7	16.1
400	120	20.5	18.2	17.8	17.2	18.4
Mean		17.1	16.0	15.8	15.9	
			1980–81			
0	0	13.8	11.2	12.6	10.5	12.0
200	60	18.5	14.5	14.0	15.0	15.5
400	120	22.0	16.0	18.0	14.8	17.7
Mean		18.1	13.9	14.9	13.4	
			1981–82			
0	0	13.4	7.6	9.9	7.2	9.5
200	60	17.1	12.6	10.8	10.8	12.8
400	120	20.2	14.4	14.5	12.6	15.5
Mean		16.9	11.5	11.7	10.2	

	Crops	S levels	For different crops at particular S level	For different S levels at particular crop
SE m ± 1979–80	0.36	0.51	0.81	0.89
SE m ± 1980–81	0.60	0.41	0.83	0.71
SE m ± 1981–82	0.28	0.35	0.56	0.60

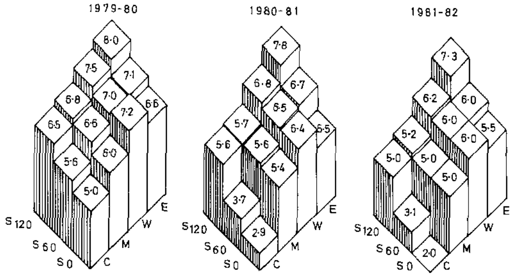

Figure 4. Effect of added S(kg ha^{-1}) on Olsen-P content ($\mu g\, g^{-1}$) of soil after the harvest of wheat (W), chickpea (C), mustard (M) and Egyptian clover (E)

even after pyrites application, the magnitude of decrease in available P content was smaller than under no pyrites control.

At final harvest also, addition of pyrites markedly increased available P content of soil compared with no pyrites-control (Figure 4). Available P content of soil under no pyrites-control decreased gradually from initial value of 9.0 $\mu g\, g^{-1}$ to 6.0 $\mu g\, g^{-1}$ after wheat, 2.0 $\mu g\, g^{-1}$ after chickpea, 5.0 $\mu g\, g^{-1}$ after mustard and 5.5 $\mu g\, g^{-1}$ after Egyptian clover of 1981–82 while under pyrites treatment (@ 400 kg ha^{-1}) these values were 6.2 $\mu g\, g^{-1}$, 5.0 $\mu g\, g^{-1}$, 5.2 $\mu g\, g^{-1}$ and 7.3 $\mu g\, g^{-1}$ after these crops, respectively. In spite of higher withdrawl of P from soil, available P after Egyptian clover was relatively higher. Excessive moisture during Egyptian clover cropping favoured solubilization of native soil P and its replenishment through the biomass left in the plots after harvest of the crop.

Total P uptake by all the crops increased significantly with added pyrites up to highest level (Figure 5) the average P uptake for all the three years being 7.72, 7.70, 10.80 and 8.71 kg ha^{-1} in wheat, chickpea, mustard and Egyptian clover, respectively. Beneficial effect of added pyrites on content and uptake of P in different crops has also been reported [3, 21].

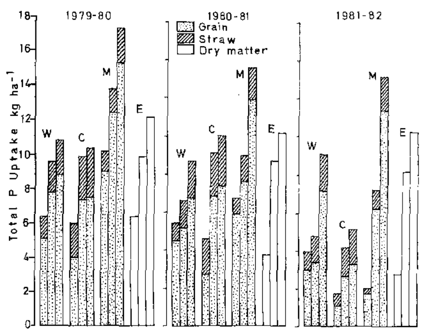

Figure 5. Effect of added S (kg ha^{-1}) on total uptake (kg ha^{-1}) of P by wheat (W), chickpea (C), mustard (M) and Egyptian clover (E). The bar on the left is 0 kg, the middle bar for 60 kg and the bar on the right for 120 kg applied sulphur

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