Fertilizer Research **24**: 85–96, 1990.
© 1990 *Kluwer Academic Publishers. Printed in the Netherlands.*

Effect of different sources of iron and sulphur on leaf chlorosis, nutrient uptake and yield of groundnut

A.L. Singh, Y.C. Joshi, Vidya Chaudhari & P.V. Zala
National Research Centre for Groundnut, Timbawadi, Junagadh-362 015, Gujarat, India

Received 4 August 1989; accepted in revised form 14 May 1990

Key words: Calcareous soil, chlorosis, chlorophyll, excess water, groundnut (*Arachis hypogaea* L.) iron and sulphur nutrition, lime, nutrient uptake, pod yield

Abstract

The pot experiment conducted in calcareous soil of Saurashtra, India showed that application of lime (20% $CaCO_3$) and excess water (irrigation at −0.3 bar) to the soil enhanced chlorosis in groundnut leaves caused by induced deficiencies of iron, sulphur and zinc, which was recovered by applying agricultural grade chemicals containing iron, sulphur and zinc. This chlorosis caused 29.8 and 19.1% reduction in pod yield of groundnut due to lime and excess water, respectively in the untreated control pot and 17.1 and 9.6%, respectively in the pot treated with different chemicals.

Application of iron sulphate, zinc sulphate, iron pyrite, gypsum, phospho-gypsum, elemental sulphur, wettable sulphur and Fe-EDTA decreased chlorosis and increased chlorophyll and carotenoid contents of leaves, uptake of Fe, S and Zn and pod yield of groundnut significantly. The foliar spray of 0.5% aqueous solution of iron sulphate, zinc sulphate and Fe-EDTA at 20, 35, 50 and 65 days after emergence (DAE) was more effective than their soil applications. The Fe-EDTA corrected only iron chlorosis, and gypsum, phosphogypsum and elemental sulphur only sulphur chlorosis. However, iron sulphate and iron pyrite corrected iron and sulphur and zinc sulphate corrected zinc and sulphur chlorosis. Among the soil amendments, application of iron sulphate and iron pyrite showed better responses to groundnut and showed higher Fe and S uptake than other treatments. The responses of gypsum, phosphogypsum and elemental sulphur were at par. The correlation study showed that pod yield of groundnut was negatively correlated with chlorosis and positively correlated with the chlorophyll and carotenoid contents in groundnut leaves.

Introduction

The chlorosis of groundnut grown in calcareous and alkaline soils is a common problem causing slow development of plant and yield reduction [7, 13, 14, 15, 16, 17]. The factors contributing directly or indirectly to chlorosis are excess calcium carbonate and bicarbonate in soil, excess soil moisture, high soil pH (above 8.0), poor drainage and root aeration [1, 3, 5, 6, 9, 12, 14, 16, 20, 21].

In Saurashtra region of India, the high calcium and excess irrigation reduced the availability of iron and sulphur resulting chlorosis in groundnut leaves and reduce the pod yield [14, 16, 17, 18]. The effective control of chlorosis caused by iron and sulphur deficiencies must involve the combined use of efficient cultivars and effective fertilizers which can improve the iron and sulphur nutrition to the groundnut. Therefore, the present investigation was undertaken to study the effectiveness of different iron and sulphur containing fertilizers for the recovery of chlorosis and increasing growth and yield of groundnut in calcareous soil under lime and excess water treated conditions. Since zinc is also reported to be a limiting nutrient in calcareous soil [17], zinc sulphate was also included in the study. In this paper the effects of different iron and sulphur fertilizers on the chlorosis, chlorophyll and carotenoids and pod yield of groundnut and concentrations and uptake of Fe, S and Zn by groundnut are mentioned. The affects on other nutrient concentration and their uptake by groundnut plant is described as research note in another paper.

Materials and methods

Soil and experimentation

A pot experiment was conducted during dry 1987, wet 1987 and dry 1988 seasons at the National Research Centre for groundnut, Junagadh, India in a clayey medium black calcareous soil, the physico-chemical properties of which are given in Table 1. The finely ground soil at 10 kg pot^{-1} was filled in number of polythene lined earthen pots and tapped so as to maintain uniform bulk density. The experiment was conducted in a complete randomised block design in three sets containing normal irrigation (−0.6 bar), excess irrigation (−0.3 bar) and lime treatment to the soil (20% $CaCO_3$ in soil) followed by normal irrigation. There were 11 treatments as described in Table 2, in each set and replicated four times. Altogether there were 132 (11 × 4 × 3) pots. Urea at 200 mg N^- pot^{-1} (40 kg N ha^{-1}), sodium dihydrogen phosphate at 100 mg P pot^{-1}(20 kg P ha^{-1}) and potassium

Table 1. Physico-chemical properties of the experimental soil

Soil texture	Clayey
Sand (%)	27
Silt (%)	30
Clay (%)	43
pH water	7.5
Calcium carbonate (%)	9.8
Organic carbon (%)	0.8
Total N (%)	0.05
Available Olsen P (ppm)	8
Available heat soluble S (ppm)	11
Exchangeable	
K meq/100 g soil	3.07
Ca meq/100 g soil	42
Mg meq/100 g soil	21
CEC meq/100 g soil	92
Available DTPA Fe (ppm)	1.3
Zn (ppm)	5
Mn (ppm)	2
Cu (ppm)	1.1

Table 2. Treatments and their descriptions

Sr. No.	Treatment and name of chemical	Rate		Mode and time of application	Amount ($kg\ ha^{-1}$) of element added through treatments			
		$kg\ ha^{-1}$	$mg\ pot^{-1}$		Ca	S	Fe	Zn
1.	Control			–	–	–	–	–
2.	Iron sulphate	100	500	Soil, 50% as basal + 50% 30 DAE	–	19	20	–
3.	Iron sulphate	10	50	Foliar, 0.5% aqueous solution applied four times*	–	1.9	2.0	–
4.	Zinc Sulphate	10	50	Soil, 50% basal + 50% 30 DAE	–	1.12	–	2.3
5.	Zinc Sulphate	10	50	Foliar, 0.5% aqueous solution applied four times*	–	1.12	–	2.3
6.	Pyrite (FeS_2)	38	190	Soil, 50% basal + 50% 30 DAE	–	20	18	–
7.	Phosphogypsum	108	540	Soil, 50% basal + 50% 30 DAE	25	20	–	–
8.	Gypsum	108	540	Soil, 50% basal + 50% 30 DAE	25	20	–	–
9.	Elemental sulphur	20	100	Soil, 50% basal + 50% 30 DAE	–	20	–	–
10.	Wettable sulphur	10	50	Foliar, 0.5% aqueous solution sprayed four times*	–	10	–	–
11.	Fe EDTA	10	50	Foliar, 0.5% aqueous solution sprayed four times*	–	–	2.0	–

* The foliar application of chemical was carried out four times at 20, 35, 50 and 65 days after emergence (germination) of groundnut seed.

chloride at 200 mg K pot^{-1} (40 kg K ha^{-1}) were added in all pots. The finely ground lime available locally was mixed with the soil at the ratio of 1 : 4, lime : soil (soil containing 20% lime) and filled in one set of 44 (11 × 4) pots.

The soil amendments (iron, sulphur and zinc containing chemicals) as given in Table 2 were added to the respective pots and mixed with the soil before sowing. The pots were irrigated to 'field capacity' moisture level and the groundnut seeds of variety J 11 were sown in pots at a rate of three seeds per pot. The pots were irrigated with 500 ml of water at the interval of 3 days till the seedling germinated (one week). After germination the tensiometers were installed in the pots at a uniform depth of 20 cm and the pots were irrigated with 250 ml of water whenever the tensiometer reading reached to −0.6 bar in normal and lime treatment and −0.3 bar in excess irrigation treatment. This irrigation pattern was maintained throughout the crop.

The foliar application of chemicals given in Table 2 carried out at 20, 35, 50 and 65 days after emergence (DAE) of seedling in respective treatments. The 0.5% aqueous solution of those chemicals were prepared by dissolving 50 mg salt in 10 ml of water for each pot and sprayed on the foliage four times.

Observations, sampling and analysis

The leaves of groundnut showed different types of chlorosis after 15 days of seedling emergence, which were rated for the severity of leaf chlorosis by determining the per cent of different types of chlorosis and visual chlorosis rating scores (VCR) at 30, 45, 60 and 75 DAE. The per cent chlorosis of three distinct types of yellowing symptoms: A = entire leaf chlorotic showing sulphur deficiency, B = interveinal chlorosis showing iron deficiency and C = mixed type of chlorosis with white papery leaves showing iron, sulphur and zinc deficiencies combinedly were determined on the basis of chlorotic symptoms appeared on the leaves by the following formula:

$$\text{Per cent chlorosis} = \frac{\text{Number of chlorotic leaves}}{\text{Number of total leaves}} \times 100$$

The per cent chlorosis of leaves was observed four times at 30, 45, 60 and 70 DAE. The VCR of five top leaves of groundnut was determined using 1 to 5 scale: 1 = no chlorosis (normal green leaves), 2 = slightly chlorosis on occasional leaves (1–25% chlorosis), 3 = moderate chlorosis on several leaves (26–50% chlorosis), 4 = moderate chlorosis on most of leaves (51–75% chlorosis) and 5 = severe chlorosis on all leaves (76–100% chlorosis) showing yellow-white colour with necrotic spots. The chlorophyll and carotenoid contents of the top 5 leaves mixed together were determined by Holms method [8].

One plant from each pot was uprooted at 70 DAE, washed and leaves and stems were separated. The material was then dried in a hot air oven at 40°C for about seven days and powdered. One gram of the dried material was digested with triacids using HNO_3, $HClO_4$ and H_2SO_4 for Fe and Zn determinations. For S determination 0.5 g of the material was digested with HNO_3 and $HClO_4$. The sulphur content of plant material was determined by the method described by Chaudhary and Cornfield [4] and Fe and Zn were determined by atomic absorption spectrophotometer [10].

The plants were harvested after maturity and separated into leaves stems and pods. The material was washed, dried in the sun for a week and pod yield was recorded. The material was then dried in oven at 40°C, for about two days, powdered and analyzed for Fe, S and Zn by following above mentioned procedures. All these data were analysed statistically.

Results and discussion

Chlorosis and their visual score

The groundnut plants were healthy without any chlorosis till 10 days after their emergence in all the treatments but after that different chlorotic symptoms were observed. Three types of chlorosis were noticed in the top 5 leaves of groundnut plant: (A) the whole leaf including veins yellow, showing sulphur deficiency symptom: (B) interveinal chlorosis due to iron deficiency and (C) Chlorosis with white papery leaves showing combined deficiencies of sulphur, iron and zinc. The intensity of different types of chlorosis varied with treatments and crop growth stages (Table 3). The visual chlorotic rating score (VCR) following 1–5 scale and the percentage leaf showing different types of chlorosis observed at 30, 45, 60 and 75 days (DAE) of crop growth are given in Fig. 1 and Table 3.

Application of lime and excess water induced chlorosis in groundnut leaves. The majority of chlorosis showed iron deficiency symptoms at most of the growth stages during all the three seasons (Table 3). The sulphur and zinc deficiency were also observed but their frequency was lesser than iron. This chlorosis due to iron, sulphur and zinc deficiency was induced by lime and excess water. This study supported the observations of Alcantara et al. [1] who observed that chlorosis score was inversely correlated to

Table 3. Per cent of groundnut leaves showing different types of chlorosis during the crop growth stages (Average of four observations made at 30, 45, 60 and 75 days after emergence)

Treatments Symbol (T)	Normal			Lime			Excess irrigation		
	A	B	C	A	B	C	A	B	C
Dry, 1987									
1	5	30	15	10	60	10	0	60	5
2	0	20	10	0	50	0	10	40	10
3	0	10	0	0	20	0	5	20	0
4	0	15	15	0	40	0	10	30	15
5	0	15	20	0	50	0	15	60	0
6	0	20	15	0	40	20	5	40	5
7	0	30	10	0	40	20	5	40	10
8	0	20	10	0	40	5	10	30	5
9	0	20	15	0	30	10	0	30	25
10	0	10	15	0	20	10	0	30	30
11	10	10	0	10	25	0	20	0	10
Wet, 1987									
1	15	30	10	20	50	20	10	40	20
2	0	20	5	5	30	10	5	25	10
3	5	10	0	10	15	5	0	10	10
4	0	20	5	5	20	5	10	20	10
5	0	10	10	5	20	15	0	20	9
6	0	10	5	0	20	15	0	20	5
7	5	10	10	0	20	5	5	15	10
8	0	10	15	0	20	15	0	20	15
9	0	30	5	10	30	20	10	30	10
10	0	20	10	10	20	10	5	20	10
11	10	10	0	15	10	0	20	10	0
Dry, 1988									
1	20	20	15	20	40	10	10	35	10
2	0	15	10	5	20	5	5	20	5
3	0	5	0	0	5	5	5	5	0
4	10	15	10	10	15	10	5	20	5
5	5	10	5	5	10	15	10	10	5
6	0	10	5	0	15	10	0	15	5
7	0	10	10	5	15	5	5	15	5
8	0	10	10	5	10	10	5	10	15
9	0	15	10	0	20	10	0	20	5
10	0	15	5	0	15	10	0	15	10
11	5	0	5	15	5	0	15	5	5

The details of treatments are given in Table 2.A, B and C are different types of chlorotic symptoms as mentioned in materials and methods.

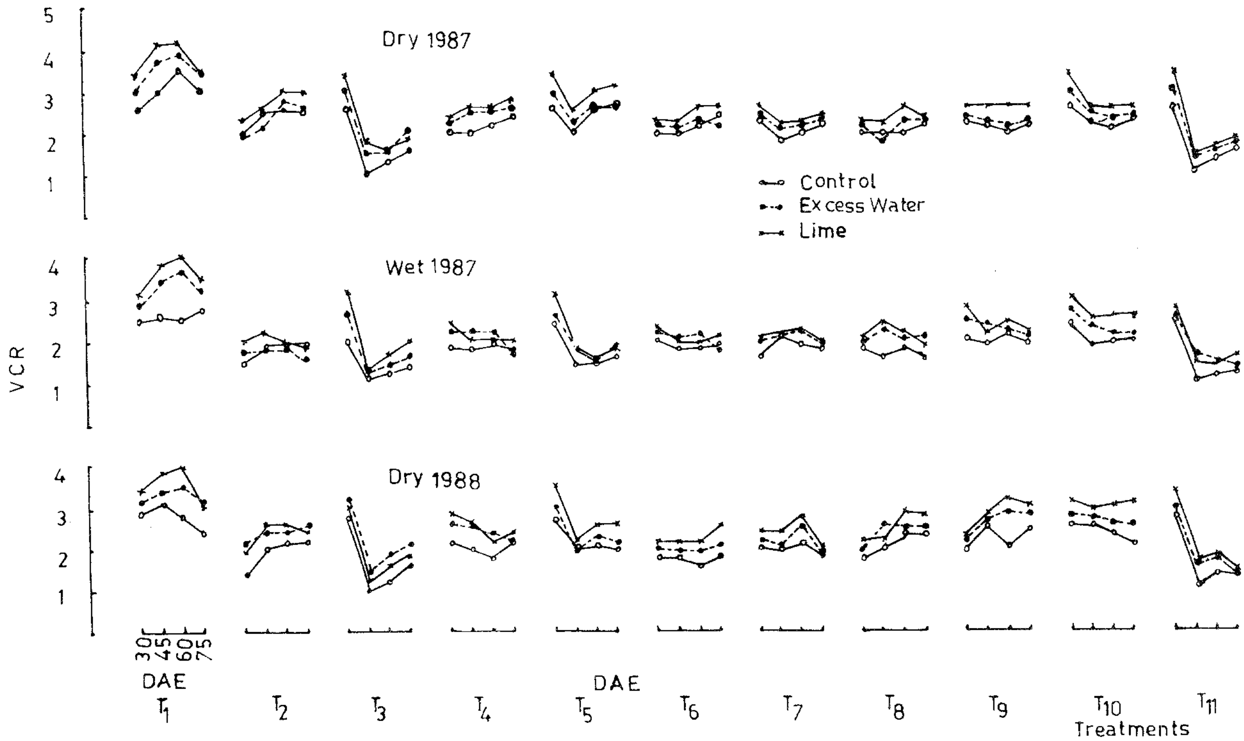

Fig. 1. Effect of iron and sulphur sources on the visual chlorotic rating score (VCR) of the groundnut leaves at different growth stages (30, 45, 60 and 75 DAE), grown under normal water (○——○), lime (*——*) and excess water (● - - - - ●) treatment conditions. The $T_1, T_2, \ldots T_{11}$ are the treatments as mentioned in the Table 2.

chlorophyll and iron concentrations in the upper most leaves of sunflower. Coulombe et al. [6] observed that bicarbonate inhibits the regulatory Fe-stress response and reduces iron uptake, iron and chlorophyll contents in leaves and growth of soybean.

The control and Fe-EDTA treated pots showed sulphur deficiency in the normal irrigated pots, but in the pots with excess water and lime, the sulphur deficiency symptoms appeared in most of the treatments (Table 3). This was probably due to lesser availability of this nutrient in soil where the available amount of sulphur was diluted with addition of lime and excess water. The liming of soil increases the availability of sulphate sulphur through desorption of SO_4^{--} from soil colloids, increased mineralization rates and solubilization of sparingly soluble hydroxy sulphate compounds [2, 11]. This sulphate sulphur might have precipitated as $CaSO_4$ with lime in this study and hence probably decreased the availability of S in the soil. These studies were in agreement with our earlier study [17] and studies of Wallance et al. [21]. The 5–20% chlorosis in groundnut leaves due to the combined deficiencies of iron, sulphur and zinc was also observed in almost all the treatments which did not show any variation with the application of lime or excess water but the application of iron sulphate, zinc sulphate and iron pyrite reduced its intensity (Table 3). The VCR of groundnut leaves varied with the crop growth (Fig. 1) and maximum chlorosis was due to lime application. The groundnut leaves in untreated control pot showed maximum VCR (upto 4) at 60 DAE. Our earlier field study [16] reported that the maximum chlorosis in groundnut leaves was between 40–60 DAE, and decreased after 60 DAE. The foliar application of iron sulphate, zinc sulphate and Fe-EDTA decreased chlorosis after 30 DAE and repeated application of these chemicals could control excess chlorosis and maintain an uniform pattern throughout.

The soil application of iron sulphate, iron pyrite, gypsum, phosphogypsum and elemental sulphur resulted in low VCR of groundnut leaves at the beginning of crop growth but increased with the duration of crop upto 60 DAE and decreased thereafter (Fig. 1). Here also the maximum chlorosis was observed at 60 DAE which is a critical stage of crop. Singh et al. [16] in a field study observed that excess irrigation increased chlorosis by 23.5% in GAUG-1 groundnut and application of iron sulphate showed 29.4% recovery of chlorosis. Among the soil amendments, iron sulphate and iron pyrite proved to be better in this study for chlorosis recovery in groundnut.

Chlorophyll and cartotenoid contents

Variation in the chlorophyll and carotenoid contents of groundnut leaves at 40 and 70 DAE were observed with the treatments (Fig. 2). The application of iron sulphate, iron pyrite, gypsum, phosphogypsum and Fe-EDTA increased the chlorophyll significantly. The significant increase in the carotenoid contents of leaves was also observed due to application of different chemicals but the treatments did not show significant

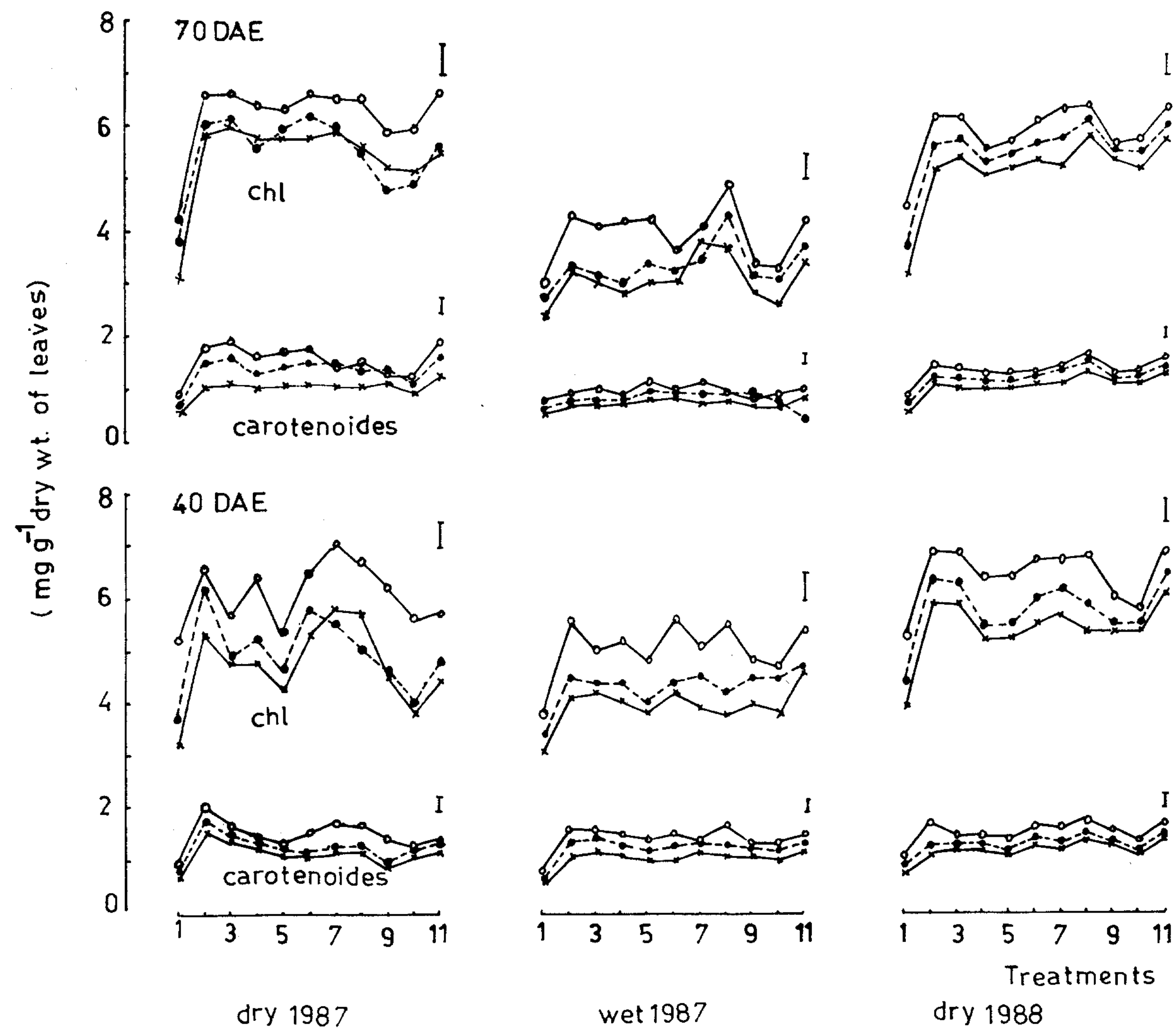

Fig. 2. Effects of iron and sulphur sources on the chlorophyll (chl) and carotenoides contents (mg g^{-1} dry wt of leaf) of groundnut leaves at 40, and 70 DAE, grown under normal irrigation (O——O), lime (*——*) and excess irrigation (● - - - - ●) conditions. The figure 1, 2, 3, . . . 11 are the respective $T_1, T_2, T_3, \ldots T_{11}$ treatments. The LSD values (0.05) are drawn at the right side of each figure (I).

variation in carotenoid contents. The wet season groundnut crop contained lesser chlorophyll than the dry season crop but the carotenoids were not affected by the season (Fig. 2). The higher chlorophyll during dry season was probably due to more sunshine hours and higher light intensity during dry season than the wet season which might have allowed more chlorophyll synthesis. On the other hand the lesser light intensity and sunshine hours during wet season caused lesser chlorophyll synthesis. The more chlorophyll during dry season also may cause more effective utilization of nutrient than wet season. The groundnut plant at 40 DAE contained more chlorophyll than that at 70 DAE. At 40 days of crop growth the entire canopy was exposed to the sun but at 70 DAE some degree of shading was observed due to mutual overlapping of branches and leaves which probably led to lesser amount of chlorophyll in leaves at 70 DAE. Moreover, the leaves at the latter part of growth period get lesser nutrient than their requirement resulting in early maturity.

The foliar application of iron and zinc sulphate showed lesser chlorophyll content in the groundnut leaves, than the soil application at 40 DAE but increased afterwards. Application of iron increased the amount of chlorophyll in the leaves significantly (Fig. 2). Since iron is required for chlorophyll synthesis its supply increased chlorophyll in groundnut leaves. Our earlier observation [16] reports that green and chlorotic plant of groundnut contained 7.2 and 2.0 mg chlorophyll g^{-1} dry wt. of leaf, respectively and application of iron sulphate to chlorotic plant increased the chlorophyll contents upto that of normal leaves. In the present study the foliar application of iron sulphate, Fe–EDTA and zinc sulphate increased the chlorophyll contents of leaves up to 63, 67 and 58%, respectively at 70 DAE (Fig. 2) causing corresponding decreases in VCR.

Pod yield

The pod yield of groundnut increased significantly due to the application of different chemicals either as soil amendments or as foliar spray. But the application of lime and excess water decreased pod yield significantly (Table 4). The groundnut plant with lime and excess water treatment showed chlorosis in their leaves causing reduction in the rate of photosynthesis and productivity. The yellowed foliage and reduced plant growth due to lime-induced iron chlorosis are well known for reducing yield of groundnut [7, 16, 19]. Singh et al. [16] observed that providing excess irrigation (−0.3 bar) to the field shown groundnut in calcareous soil induced chlorosis in

Table 4. Effect of iron and sulphur sources on the pod yield (g pot^{-1}) of groundnut grown under different soil conditions

Treatments Symbol (T)	Dry, 1987				Wet, 1987				Dry, 1988			
	Normal	Lime	Excess water	Mean	Normal	Lime	Excess water	Mean	Normal	Lime	Excess water	Mean
1	4.1	3.2	3.6	3.6	3.5	2.5	3.0	3.0	5.5	3.5	4.0	4.3
2	7.6	6.5	7.0	7.0	5.8	4.5	5.0	5.1	8.1	7.0	7.4	7.5
3	7.7	6.4	6.8	7.0	5.6	4.6	5.1	5.1	7.8	6.5	7.0	7.1
4	6.6	5.8	6.0	6.1	4.6	3.8	4.1	4.2	6.8	6.0	6.5	6.4
5	6.5	5.3	6.2	6.0	4.8	3.9	4.3	4.3	6.5	5.8	6.8	6.4
6	7.5	5.8	6.4	6.6	5.5	4.8	5.3	5.2	7.2	6.0	6.5	6.6
7	7.0	6.0	6.3	6.4	5.6	4.2	5.1	5.0	7.5	6.4	6.6	6.8
8	6.3	5.2	5.5	5.7	5.7	4.0	4.8	4.8	7.3	6.2	7.0	6.8
9	6.2	5.2	5.5	5.6	4.8	3.6	4.2	4.2	6.5	6.3	6.8	6.5
10	6.2	5.3	5.3	5.6	4.4	3.5	3.9	3.9	6.4	5.8	6.2	6.1
11	7.0	6.0	6.3	6.4	5.2	4.6	4.8	4.9	7.2	6.1	6.5	6.6
Mean	6.6	5.5	5.9		5.1	4.0	4.5		7.0	6.0	6.5	
LSD (0.05)												
1. Treatment means		0.6				0.3				0.3		
2. Main plot means		0.4				0.5				0.4		
3. Interactions		0.3				0.5				0.5		

The details of the treatments are in Table 2.

groundnut crop causing yield reduction and the application of iron sulphate increased 29% pod yield and 15% fodder yield of GAUG-1 groundnut. In another study Singh et al. [16] reported that healthy and chlorotic plant produced 8.6 and 5.4 g pod per plant, respectively which indicated that chlorosis reduced 37% pod yield of groundnut. The average of three seasons data in this study revealed that 29.8 and 19.1% reduction in pod yield of groundnut was observed due to application of lime and excess water, respectively in the untreated control pots. However, these reductions were 17.1 and 9.6%, respectively in the pots treated with different chemicals. This indicated that the chlorosis affected severely the production of groundnut and the application of iron and sulphur sources could recover it. The iron sulphate applied either as foliar or in the soil proved to be the best for high pod yield. The constant supply of iron and sulphur from the iron sulphate and iron pyrite and iron from Fe-EDTA and sulphur from gypsum, phosphogypsum and elemental sulphur resulted in the better growth and higher pod yields than those of untreated control.

Among the soil amendments, iron sulphate and iron pyrite both resulted in maximum reduction of iron and sulphur chlorosis and increased the pod yield. The pod yield in gypsum, phosphogypsum and Fe-EDTA applied treatment was at par but higher than application of elemental sulphur. The dry season crop showed more pod yield than the wet season crop probably due to more efficient utilization of light and soil nutrients during dry season than wet season. Papastylianou [13] reported that the chlorosis of groundnut in calcareous soil was mainly due to lack of available iron in the soil and in the Mandria area of Cyprus the groundnut field with moderate chlorosis gave a yield of 3.3 t ha^{-1} without iron chelate application, but application of 20, 40 and 80 kg ha^{-1} of sequestrene 138 Fe as chelate produced 4.2, 4.7 and 5.4 t ha^{-1} of pod, respectively. This suggested that application of iron chelate can increase the pod yield upto 64%. Singh et al. [17] in a recent study reported that three foliar spray of iron increased 43% pod and 35% fodder yield. Hartzook [7] conducted a multilocational trial on the high calcium containing soil of Israel for three years and concluded

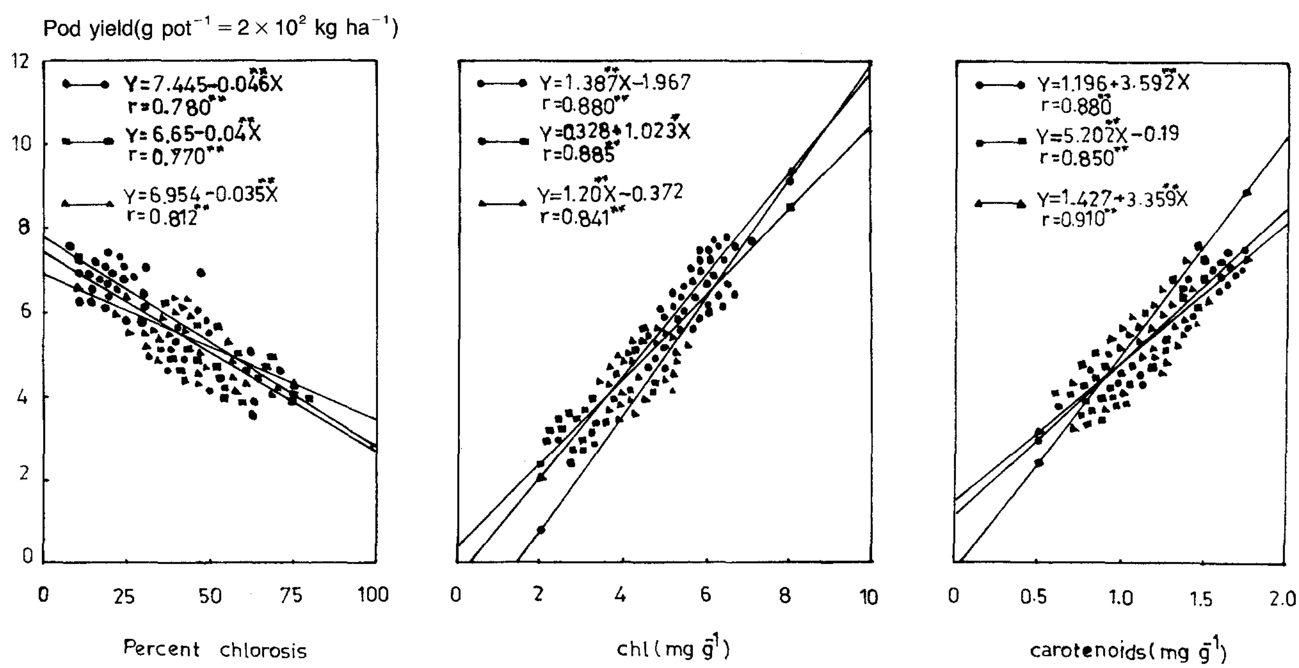

Fig. 3. Graph showing correlation between average per cent chlorosis, chlorophyll (Chl) and carotenoid contents (mg g^{-1} dry wt of leaf) of groundnut leaves and pod yield (g pot^{-1} = 2×10^2 kg ha^{-1}) of groundnut grown under Normal irrigation (●——●), excess irrigation (▲——▲) and lime (■——■) treated conditions. ●, ▲ and ■ are observed values.

that application of iron chelates as Fe-EDDHA or Kelafer increased the pod yield of groundnut from 6 to 17.6%. He further reported that optimal time of foliar application of chelate was between 40 and 50 days after emergence; the iron chelate treatment corrected the chlorosis seven to ten days after application, increased the number of pod per plants and the pod and kernel weights. Similar observations were also reported in this study.

The correlation and regression study showed that the pod yield of groundnut was negatively correlated with chlorosis and positively correlated with chlorophyll and carotenoid contents (Fig. 3).

Nutrient concentration and uptake

The concentration of S, Fe and Zn in leaves and stem at 70 DAE and their uptake by groundnut at harvest increased significantly due to addition

Table 5. Effect of iron and sulphur sources on the sulphur uptake (mg pot^{-1}) by groundnut grown under different soil-conditions

Treatments	Dry, 1987				Wet, 1987			
	Normal	Lime	Excess water	Mean	Normal	Lime	Excess water	Mean
1	33	22	26	27	31	23	27	27
2	68	52	56	59	64	49	55	56
3	62	47	52	54	51	39	52	47
4	54	42	46	47	43	31	37	37
5	51	39	44	45	46	37	40	41
6	68	48	51	56	58	47	53	53
7	63	47	49	53	57	44	46	49
8	56	43	47	49	58	43	46	49
9	63	47	51	54	53	38	41	44
10	50	40	44	45	47	36	41	41
11	59	49	52	53	44	32	36	37
Mean	57	43	47		50	30	43	
L.S.D. (0.05)								
Treatment means		7				5		
Main plot means		4				7		
Interactions		10				8		

See table 2 for details of the treatments.

Table 6. Effect of iron and sulphur sources on the iron uptake (mg pot^{-1}) by groundnut grown under different soil-conditions

Treatments	Dry, 1987				Wet, 1987			
	Normal	Lime	Excess water	Mean	Normal	Lime	Excess water	Mean
1	26	16	21	21	24	16	20	20
2	57	43	38	46	40	34	37	37
3	59	52	44	52	37	29	34	33
4	42	32	34	36	31	23	26	27
5	44	31	33	36	31	24	27	27
6	56	37	41	45	37	30	34	34
7	48	32	37	39	37	27	27	30
8	54	30	34	39	37	27	30	31
9	44	37	38	40	32	27	28	29
10	35	29	32	32	30	25	25	27
11	53	39	45	46	38	31	34	34
Mean	47	34	36		34	27	29	
L.S.D. (0.05)								
Treatment means		7				5		
Main plot means		11				4		
Interactions		13				8		

See table 2 for details of the treatments.

Table 7. Effect of iron and sulphur sources on the zinc uptake (mg pot^{-1}) by groundnut grown under different soil-conditions

Treatments	Dry, 1987				Wet, 1987			
	Normal	Lime	Excess water	Mean	Normal	Lime	Excess water	Mean
1	8	4	7	6	8	5	6	6
2	18	10	14	14	15	10	12	12
3	17	9	15	13	13	9	11	11
4	16	14	16	14	14	11	11	12
5	16	14	15	15	14	11	12	12
6	17	8	12	12	13	10	11	11
7	17	8	12	12	13	9	9	10
8	16	7	12	12	13	9	11	11
9	17	8	15	13	12	9	10	10
10	14	7	12	11	10	9	9	9
11	17	11	15	14	14	11	12	12
Mean	16	9	13		13	9	10	
L.S.D. (0.05)								
Treatment means		3				4		
Main plot means		3				3		
Interactions		7				6		

See table 2 for details of the treatments.

of different iron and sulphur sources (Tables 5, 6, 7 and Figs. 4, 5). The application of lime and excess water showed lesser Fe, S and Zn concentration in both leaves and stem and their uptake than normal treatment (Table 5, Fig. 4, 5). This was probably due to lesser availabilities of these nutrient in soil where the available amount of these nutrients were diluted with addition of lime. The addition of lime enhances the availability of sulphate-sulphur at the initial stages of crops [2]. This SO_4-S might have been precipitated as $CaSO_4$ or leached down in the base of pot with irrigation water in this study and hence decreased the availability of S to groundnut crop at later stages. When the soil moisture increases, microbial respiration increases, gas exchange decreases and the partial pressure of CO_2 increases which result in the increase of bicarbonate concentration in soil and reduce the availability of Fe in their absorption. This was supported by Inskeep and Bloom [9] who observed that in moist soil the available Fe was much lower than air dry soil. The root growth and active nutrient uptake require energy. The photosynthate from the shoot is used for growth and is also respired by the roots. The root respiration use O_2 and produce CO_2, so gas exchange between air in the soil's pore space and the atmosphere is needed which was partially blocked by excess irrigation in this study and created partially anaerobic condition in the root zone of soil resulting slow

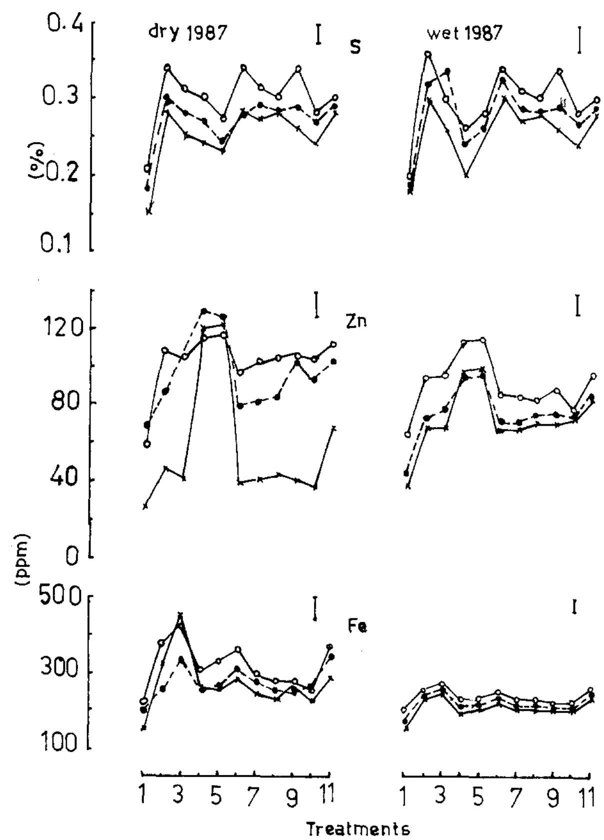

Fig. 4. Effect of iron and sulphur sources of the S, Fe and Zn concentration of leaves (at 70 DAE) of groundnut grown under normal irrigation (O——O), lime (*——*) and excess irrigation (● - - - - ●) conditions. The 1, 2, 3, . . . 11 are the respective treatments as mentioned in Table 2. The LSD (0.05) values are drawn at the right side of each figure (I).

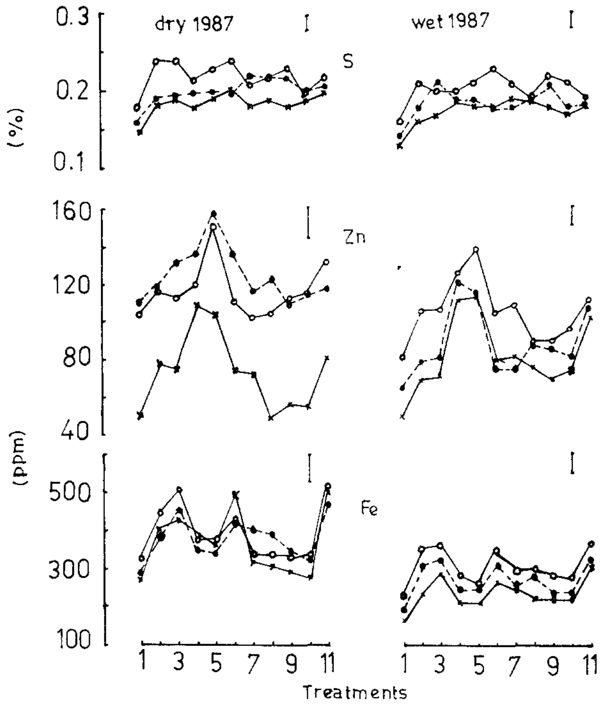

Fig. 5. Effect of iron and sulphur sources on the S, Fe and Zn concentrations of stem (at 70 DAE) of groundnut grown under normal (O——O), lime (*——*) and excess irrigation (● - - ●) conditions. The 1, 2, 3, . . . 11 are the treatments as mentioned in Table 2. The LSD (0.05) values are drawn at the right side of each figure (I).

metabolic activities and finally lesser absorption of the nutrients by the plant.

Application of iron sulphate in soil or as foliar spray, iron pyrite and elemental sulphur in the soil showed higher S uptake than other treatments (Table 5). The Fe concentration in leaf and stem and its uptake was significantly more with soil application of iron sulphate, iron pyrite and foliar application of iron sulphate and Fe-EDTA than other treatments (Figs. 4, 5, Table 6). The Zn concentration and its uptake in groundnut was, however, higher in Zinc sulphate treatment (Figs. 4, 5 and Table 7). These increase in concentration of Fe, S and Zn were mainly due to the addition of these nutrients, however, the lime and excess water treatment restricted their uptake and hence caused lower concentration of these nutrient in leaves.

Conclusions

It is concluded from the study that in calcareous soil application of lime and excess water caused chlorosis in groundnut mainly due to the deficiencies of iron and sulphur and application of agricultural grade chemicals containing these nutrients recovered chlorosis and increased nutrient uptake and yield. The repeated foliar application of 0.5% aqueous solution of chemicals such as iron sulphate was more effective for controlling iron and sulphur deficiencies in the standing crop of groundnut.

Acknowledgements

We are grateful to Dr. P.S. Reddy, Director, National Research Centre for Groundnut, Junagadh for providing necessary facilities during the conduct of experiment and Dr. M.S. Patel, Head, Soil Science, Gujarat Agricultural University, Junagadh for providing atomic absorption spectrophotometer facilities.

References

1. Alcantara E, Romera FJ and Guardia MD del la (1988) Genotypic differences in bicarbonate-induced iron chlorosis in sunflower. J Plant Nutr 11: 65–75
2. Bolan NS, Syers JK, Tillman RW and Scotter DR (1988) Effect of liming and phosphate addition on sulphate leaching in soil. J Soil Sci 39: 493–504
3. Chaney RL (1984) Diagnostic practices to identify iron deficiency in higher plant. J Plant Nutr 7: 47–67
4. Chaudhary TA and Cornfield AH (1966) The determination of total sulphur in soil and plant material. Analyst 91: 528–531
5. Clark RB (1982) Plant genotype differences to uptake, translocation, accumulation and use of mineral elements. In: Genetic specificity of Mineral Nutrition of Plants. Ed. MR Saric. pp 41–55. Scientific Assemblies Vol 13. Belgrade Serbian Academy of Science and Arts
6. Coulombe BA, Chaney RL and Weibold WJ (1984) Bicarbonate directly induce iron chlorosis in susceptible soybean cultivars. Soil Sci Soc Am J 48: 1297–1301
7. Hartzook A (1975) Lime-induced iron chlorosis in groundnut: Treatment and Prevention. FAO Plant Protection Bull 23: 1–3
8. Holm G (1954) Chlorophyll mutations in barley. Act Agric Scand 4: 455–471
9. Inskeep WP and Bloom PR (1986) Effects of soil moisture on soil PCO_2, soil solution bicarbonate, on iron chlorosis in soybeans. Soil Sci Soc Am J 50: 946–952
10. Jackson ML (1967) Soil chemical analysis. Prentice-Hall of India Ltd, New Delhi, India
11. Korentajar L, Brynes BH and Hellums DT (1983) The

effect of liming and leaching on the sulfur-supplying capacity of soils. Soil Sci Soc Am J 47: 525–530
12. Mengel K and Geurtzen G (1986) Iron chlorosis on calcareous soils. Alkaline nutritional condition as the cause for the chlorosis. J. Plant Nutr 9: 161–173
13. Papastylianou I (1987) Cultivation and research activities in Cyprus. Intl Arachis Newsl 2: 6–7
14. Patel MS and Patel JJ (1985) Effect of different levels of lime, sulphur, iron and moisture on yield and nutrient absorption by groundnut. Indian J Agric Res 19: 124–130
15. Sahu MP and Singh HG (1987) Effect of sulphur on prevention of iron chlorosis and composition of groundnut on alkaline calcareous soils. J Agric Sci Camb 109: 73–77
16. Singh AL, Joshi YC and Koradia VG (1987) Assessment of yield losses caused by iron chlorosis in groundnut. In: Micronutrient stresses in crop plants: Physiological and Genetical Approaches to Control Them, pp 20–21. Mahatama Phule Agricultural University, Rahuri, India
17. Singh AL, Joshi YC and Koradia VG (1989) Effect of micronutrient in combination with sulphur on groundnut (Arachis hypogaeas L.) in calcareous soil. In: Proceedings of the International Congress of Plant Physiology. New Delhi, India Feb. 15–20, 1988 (In press)
18. Tendon HLS (1986) Sulphur Research and Agricultural Production in India. Fertilizer Development and Consultation Organisation, New Delhi, India
19. Young PA (1967) Peanut chlorosis due to iron deficiency. Plant Dis Reptr 51: 464–467
20. Wallace A, Wood RA and Soufi SM (1976 a) Cation-anion balance in lime-induced chlorosis. Commun Soil Sci Plant Anal 7: 15–26
21. Wallace A, Romney EM and Alexander CV (1976 b) Lime-induced chlorosis caused by irrigation water. Commun Soil Sci Plant Anal 7: 47–49