Mineral Disorders of Groundnut

A. L. Singh
M. S. Basu
N. B. Singh

ICAR

NATIONAL RESEARCH CENTRE FOR GROUNDNUT
(INDIAN COUNCIL OF AGRICULTURAL RESEARCH)
P.B. 5, JUNAGADH - 362 001, GUJARAT, INDIA

Mineral Disorders of Groundnut

A. L. Singh
M. S. Basu
N. B. Singh

भाकृअनुप
ICAR

NATIONAL RESEARCH CENTRE FOR GROUNDNUT
(INDIAN COUNCIL OF AGRICULTURAL RESEARCH)
P.B. 5, JUNAGADH - 362 001, GUJARAT, INDIA

January, 2004

Citation	:	A.L. Singh, M. S. Basu and N.B. Singh. 2004. Mineral Disorders of groundnut. National Research Centre for groundnut (ICAR), Junagadh, India. pp 85
Published by	:	Director National Research Centre for groundnut P.B. 5, Junagadh 362001, Gujarat, India
Telephone	:	91-0285-2673041/ 2672461
Fax:	:	91-0285-2672550/ 267382
E-mail	:	alsingh16@gmail.com
Printed at	:	New Pragati Printers 2/10, Bhaktinagar Station Plot Near Meladi Maa Mandir Rajkot- 360002 Tel 0281-2461965

Cover photo	:	Mineral deficiencies in groundnut grown in sand culture (top) and in field (below)

Preface

Groundnut is an important food legume and oilseed crop of tropical and subtropical areas and now being cultivated on about 25 million hectare of land in about 100 countries in the world, under different agro-climatic regions where rainfall during the growing season exceeds 500 mm. However, India, China, USA, Senegal, Indonesia, Nigeria, Brazil and Argentina are the major groundnut producing countries. Though, nutritionally groundnut is an energy rich crop, it is grown mainly on energy-starved conditions of poor fertility soils and about 70% of the its production in the world occurs in the semi-arid tropics with average yield is around 800 kg ha^{-1}, lower than the world average (1300 kg ha^{-1}). The production of groundnut corresponds to the area and there are fluctuating trends in area and production of groundnut in India. Now, it is grown on an area of about 8 million hectare, producing about 8 million tonnes. Presently, India has the largest groundnut area (32% of the world) and also till 1992 was the chief-producer in the world. From 1993 onwards, China, due to its higher productivity surpassed India and became the highest producer of groundnut.

In india during 90s the combination of improved varieties and nutrient management practices have contributed significantly to increase in production and productivity. However, India could not maintain the required growth rate of the productivity and became a decade behind of China. This is mainly because, in India, the groundnut crop is mostly grown as rainfed in dry lands, on problem soils under low fertility, and low input management, often subject to the vagaries of the weather conditions. Also the groundnut, being drought tolerant in nature, suffers from the nutrient deficiencies in arid climate, however, in high rainfall areas metal toxicities are the major problem both resulting in low yield. This is probably the reason why researchers and agriculturists are not able to break the barrier of the stagnated yield of groundnut. Though the average yield of groundnut, in India, is around 1 t ha^{-1}, under high management practices more than 6 t ha^{-1} pod yield has been reported at several occasions in some part of the country. This clearly indicates that the yield potential of groundnut has not been exploited even by 30 % and there is tremendous scope to increase the groundnut yield through nutrient and agronomic management.

Groundnut has very high nutrient requirement, but farmers use very less nutrient fertilizer and sometime only one or two nutrients resulting in severe mineral nutrient deficiencies due to inadequate and imbalance use of nutrients for groundnut. To optimize the groundnut production, optimization of the mineral nutrition is the key and it is high time to look into these aspects and advocate the suitable package of practices. Application of macro- and micro-nutrient fertilizers has contributed substantially to the increase in world food production in the last century and the Plant Nutritionists have played a key role. In most of the developing countries where groundnut is grown, soil infertility limit its productivity, where the plant nutrition research can raise productivity by diagnosis of nutrient deficiencies and toxicities of crops on previously unfertilized soils, their correction with minimal fertilizer and treatment costs, and development of cultivars with high nutrient efficiency in deficient soils.

The visible symptoms are often used to help identify the nutritional disorders, which require a good description and high quality photographs of the symptoms that are lacking in groundnut. Written description without photographs have been published for many crops, but least about groundnut. Looking to these, the National Research Centre for Groundnut at Junagadh, took a lead and continuously worked for about 20 years on the various essential elements of groundnut and elements causing their toxicities in problem soils, diagnosis of symptoms, causes, and preventive measures through soil applications time and their mode of application, and selection of nutrient-efficient genotypes and published the finding in various research papers and reports. As most of the time farmer is not able to diagnose the problem due to non-availability of quality photograph, in this monograph emphasis has been given on the diagnosis of mineral disorders symptoms and their remedies through the practical and cost effective solutions for the prevention and correction to enhance the yield and quality of groundnut. The implementation of which will increase its productivity, quality and availability. As, visible symptoms are often used to help identify the disorder, the photograph described were taken either directly from field or developed in sand culture experiment.

We, thankfully, acknowledge the contribution of scientists and researchers, engaged in mineral nutrition of groundnut who have worked very hard and generated valuable information's on groundnut, which has been compiled in this bulletin. The help received from the present and past Directors of NRCG, the mineral nutrition group of this centre specially Mr Y.C. Joshi, Mrs. Vidya Chaudhari, Mr V.G. Koradia, and Mr P.V. Zala and the scientists from ICAR Research Complex for north-east states in the various ways is acknowledged.

We hope that this bulletin will prove valuable for managing the Mineral disorders of groundnut and the physiologist, agronomists, soil scientists, plant protection specialists and extension workers using it will in turn pass on this knowledge to the groundnut growers to increase their pod yield.

M.S. Basu A. L. Singh N. B. Singh

Contents

1. Introduction

The groundnut (*Arachis hypogaea* L.) is an important food legume of tropical and subtropical areas. It is also known as peanut and rank 13th among the principal economic crops of the world. In India it is mainly an oilseed crop, but also use as snack food, however the roasted and various preparation of groundnut are used throughout the world. The crop is grown in different agro-climatic regions between latitudes 40°S and 40°N where rainfall during the growing season exceeds 500 mm. The production of groundnut corresponds to the area under the crop. Though it is now being cultivated on about 25 million hectare of land in more than 90 countries, India, China, USA, Senegal, Indonesia, Nigeria, Brazil and Argentina are the major groundnut producing countries. Nutritionally, groundnut is an energy rich crop, but it is grown mainly in marginal land under energy-starved conditions of poor soil fertility and in rainfed (85 % rainfed) areas. Though the average groundnut productivity is around 1300 kg ha^{-1}, about 70 % of the world groundnut production occurs in the semi-arid tropics under rainfed with an average yield of around 800 kg ha^{-1}.

In India, groundnut shares 3.91 % of the gross cropped area (14.8 % by total oilseeds) producing 24.6 % of the world groundnut production. There are fluctuating trends in area and production of groundnut in India; however, on an average (average of last one decade) it is grown on an area of about 8 million hectare, producing about 8 million tonnes of pod. Presently, India has the largest groundnut area (32% of the world) and also till 1992 was the chief-producer of groundnut in the world. From 1993 onwards, China, due to its higher productivity surpassed India and became the highest producer of groundnut and since then India stands second.

If we look back the Indian scenario, between the decades of 70s and 80s, there is practically little difference in productivity indicating that the increase in production was largely due to the expansion in areas. But in 90s the combination of improved genotypes and nutrient management practices have contributed significantly and the increase in production was mainly due to increase in productivity. However, India could not maintain the required growth rate of the productivity and became a decade behind of China. This is mainly because, in India, the crop is mostly grown as rainfed in dry lands, under low fertility and low input management, often subject to the vagaries of the weather conditions Also the groundnut, being drought tolerant in nature, suffers from the nutrient deficiencies resulting in low yield and this is probably the reason why researchers and agriculturists are not able to break the barrier of the stagnated yield of groundnut. However demand of groundnut both as oilseed and food crop is increasing due to population pressure and many countries are importing to fulfill their requirement.

On the other hand, if we look at the potential yield of groundnut, though the average yield of groundnut in India is around 1 t/ha, in some part of the country it's productivity is very high (5-6 t ha^{-1} pods at Dharwad and part of Maharashtra, and 6-7.5 t ha^{-1} at Kayankulam, Kerala). This clearly indicates that the yield potential of groundnut has not been exploited even by 30 % and there is tremendous scope to increase the groundnut yield through nutrient and agronomic management. The economic value of groundnut is determined by its yield and quality, which are the resultant in part of the grower's ability to exploit the plant genetic make-up and part of less tractable components of the environment in which it is growing. If the growing conditions provide all that the plant needs for full expression of genetic potential, yield and quality will be maximized, but in practice due to environmental constraints and cultural shortcomings this objective is rarely achieved. The achievable yield potential for groundnut seems to be around 15 t ha^{-1} pod yield and up to 10 t ha^{-1} has been achieved so for (Prasad, 1993).

The optimization of the mineral nutrition is the key way to optimize the production of groundnut, as it has very high nutrient requirement and the recently released high yielding groundnut varieties remove still higher amount of nutrients from the soil as compared to the old one. On contrary, the groundnut farmers, in most part of the semi-arid region use very less nutrient fertilizer and sometime only one or two nutrients resulting in severe mineral nutrient deficiencies due to inadequate and imbalance use of nutrients for groundnut. Thus it is high time to look into the mineral nutrition aspects of groundnut for achieving high yield and advocate the suitable package of practices for optimization of yield. As most of the time farmer is not able to diagnose the problem due to non-availability of photograph showing disorder symptoms. Written description without photographs have been published for many crops, but least about groundnut. The visible symptoms are often used to help identify the nutritional disorders, which require a good description and high quality photographs of the symptoms that are lacking in groundnut. In this bulletin emphasis has been given on the diagnosis of mineral disorders and their remedies to enhance the groundnut yield and quality. The symptoms described here were taken either directly from field or developed in sand culture experiment.

2. Groundnut Growing Soils and Their Problems

Though the groundnut cultivation has been extended on almost all soil types in tropical countries, the most predominant soils on which it is grown are Vertisols, Inceptisols, Entisols, Mollisols, Alfisols, Oxisols and Ultisols. In India, though groundnut cultivation has been extended in almost all states and on all soil types, Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra are the major groundnut growing states. The M.P., U.P., Rajasthan, Orissa and Punjab are among the other groundnut growing states contributing significantly to its production. The major portion of the groundnut growing soils, in India, are coastal alluvial (Kutch and Saurashtra of Gujarat) which are medium black calcareous, red and mixed red (A.P., Karnataka, T.N., and portion of Rajasthan, U.P. and M.P.), and laterite (Karnataka and Orissa) and alluvial (Indo-gangetic plains of Punjab and a portion of Haryana and U.P.). The alluvial soils are neutral to alkaline, rich in P and K but poor in Organic carbon and N, however, the coastal alluvials are alkaline and poor in N, P and organic carbon. The red soils are neutral to acidic in pH, rich in Fe, Al and Mn but poor in N, P, humus, Ca and K. The black calcareous soils are generally alkaline, rich in Ca and Mg high CEC (40-60 meq/100g soil) and K but poor in N, P and Organic matter. The laterite soils are acidic (4.0-6.0 PH) poor in Ca, Mg, N, P, K, and organic matter.

The range of soil is so wide that some of the soils are having exceptionally low or excess amount of certain nutrients. The parental material and soil forming processes often determines the nutritional stress problem in soils and many nutrient deficiencies or toxicities can be often predicted from these. More over with long history of cropping the soil, which was once sufficient in nutrients, became depleted in nutrient and hence the nutrient deficiencies are widespread. The N and P deficiencies in soil are most widespread worldwide, but in groundnut as nitrogen fixation is very high, the P, Ca, and Fe deficiencies are most widespread. An effort was made to scan through the available literatures and reports and list out the various states, in India, showing nutritional deficiencies in groundnut and their severity, which are given in Table 1.

Table 1. Deficiencies of mineral nutrients and their severity in groundnut, in various states of India, irrespective of presence of these elements in soil either in sufficiency or deficiency range.

States	Deficiency (+) and sufficiency (-) of mineral nutrients in groundnut											
	N	P	K	Ca	S	Mg	Zn	Cu	Mn	Fe	B	Mo
Andhra Pradesh	++	++	+	++	+	+	+++	-	-	-	-	-
Assam	-	+	-	++	-	+	++	-	-	-	+	-
Bihar	-	++	+	++	+	-	+++	-	-	-	++	-
Chhatishgarh	+	+	-	++	+	-	+	-	-	-	-	-
Gujarat	+	++	+	+	+	-	+	+	-	+++	+	+
Haryana	-	++	-	-	+	-	+++	+	-	++	-	-
Jharkhand	+	++	-	++	+	-	+	-	-	-	-	-
Karnataka	+	++	+	+	-	+	+++	-	+	++	++	-
Kerala	-	++	-	+	-	+	+	+	-	-	-	-
Madhya Pradesh	+	++	-	-	-	-	+++	-	-	-	-	+
Maharashtra	+	++	-	-	-	-	+	-	-	++	-	-
Orissa	++	++	+	++	+	-	++	-	-	-	-	-
Punjab	-	++	-	-	+	-	++	-	-	+	-	-
Rajasthan	+	+	-	-	+	-	+	-	-	+	+	-
Tamil Nadu	++	++	+	++	-	-	++	++	-	++	+	-
Uttar Pradesh	-	+	-	+	+	-	+++	-	+	-	-	-
West Bengal	-	++	+	++	-	+	+	-	-	-	-	-
NE States	+	+++	+	++	-	++	-	-	-	-	+	+

This table has been prepared based on the information's on symptoms and responses of the element, observed by various workers, available so far. The severity of deficiency of various nutrients for groundnut has been indicated as Mild (+), medium (++), and severe (+++) deficiencies.

3. Mineral Nutrient Requirement and Yield Losses

The term 'plant nutrition' generally refers only to 'mineral nutrition' and like other plants; groundnut also requires all the 17 elements for its growth and development. Carbon, hydrogen and oxygen, assumed to be plentiful and mainly required for photosynthesis, are taken up by the plant from air, air space of the soil and water and hence these are called non-mineral nutrients. The essential elements are assimilated into plant through absorption by root or other plant parts as ions from the soil and hence described as mineral nutrients and based on their requirement by plant these are classified as macro-nutrient (N, P, K, Ca, S and Mg) and micro-nutrients (Fe, Mn, Zn, Cu, B, Mo and Cl). In addition nickel (Ni) cobalt (Co) and sometimes Al are also beneficial for groundnut crop. Unlike other plant the groundnut nutrition is unique as the pod develop under soil and most of the seed nutrition is directly through pod rather than those transported from root, shoot and back to the seed.

The nutrient requirement of groundnut crop in the field have been worked out by several workers. Groundnut is an exhaustive crop and depending upon the yield, it removes large amount of macro- and micro-nutrients (Table 2). An average groundnut crop, with 2.0 to 2.5 t ha^{-1} of economic yield, requires, 160-180 kg N, 20-25 kg P, 80-100 kg K, 60-80 kg Ca, 15-20 kg S, 30-45 kg Mg, 3-4 kg Fe, 300-400 g Mn, 150-200 g Zn, 140-180 g B, 30-40 g Cu and 8-10 g Mo (Singh, 1999a). The Ca, K, P and S, among macronutrients and Fe and B among micronutrients are involved in the kernel filling and oil synthesis and hence are required in higher quantity.

The dry matter accumulation in groundnut crop follows the growth pattern characterized by a lag phase in early growth, exponential increase in weight from vegetative to flowering stage, a linear and maximum growth rate during late vegetative to early pod filling, and leveling of weight during late pod filling stage. Similar is the trend of nutrient absorption and uptake in groundnut and it's maximum amount is needed at peak stage of growth. Being comparatively a drought tolerant crop with low transpiration, the groundnut is susceptible to nutritional disorders due to insufficient supply of minerals. The groundnut crop removes 4-12, 42-88 and 6-53 % of the total nutrient during vegetative (0-25 days), reproductive (25-75 DAE) and pod development (75-105 DAE) stages, respectively. The Peak absorption of Ca, Mg, P and K is during 25-75 DAE (Singh, 1999a)

A series of sand culture pot experiments were conducted at NRCG, Junagadh, to find-out the concentration of macronutrients required, in the nutrient solution, for growing groundnut with an adequate supply of all these nutrients at a concentration compatible with absorption and growth (Singh, 1999a). The concentrations of

Table 2. Nutrients removed (uptake) by groundnut crop

Pod yield (t ha^{-1})	Total dry matter (t ha^{-1})	Nutrient removed (uptake) by Groundnut												References
		kg ha^{-1}						g ha^{-1}						
		N	P	K	Ca	S	Mg	Fe	Mn	Zn	Cu	B	Mo	
1.9	5.1	170	30	110	39	15	20	4.34	176	208	68	-	-	Aulakh et al, 1985
0.5	1.0	50	36	26	30	7	12	0.42	35	13	5	42	1	Dwivedi, 1988
2.0	3.6	180	13	94	83	25	43	1.5	128	48	16	154	4	Singh and Chaudhari, 1995
1.6	4.0	160	18	80	130	20	44	3.3	381	155	-	-	-	Singh et al., 1995
1.4	3.6	140	12	100	60	15	30	4.0	300	200	40	160	10	Singh and Chaudhari, 1995
3.0	8.0	192	22	60	77	15	25	-	-	-	-	-	-	Gascho, 1992
5.0*	10.0	300	40	150	150	40	60	10.0	800	600	100	300	50	Projected requirement of 2050

*This is the projected yield and nutrient requirement for producing 5 t/ha pod yield by 2050 to meet the future demand

macronutrients in leaves at 60 DAE and seeds at harvest were the main indicator to assess the mineral nutrient status of groundnut crop. Increasing the levels of any macronutrient, upto certain level in the nutrient solution, increased the concentration of that particular element in the leaves, stems, seeds and shells and their uptakes by groundnut. But, N, along with N also increased P, K, Ca and Mg, K decreased Ca and Mg, and Ca decreased K and Mg concentrations in the plant tissues. The crop received balanced nutrition, and showed best growth, and fruiting at 50, 20, 50, 50, and 20 ppm levels of N, P, K, Ca and S, respectively.

Inadequate and imbalance use of nutrient is one of the major factors responsible for low yields in groundnut, however, limited efforts has been made to quantify the same and suggest the appropriate remedies. India is the world's second largest producer of groundnut where nutritional disorders causes 30-70% yield reductions depending upon the soil types, soil nutrient status and groundnut varieties. The average yield increased due to application of calcium in the pegging zone was 24 % in USA. The sulphur and iron deficiencies causes 15-29 and 14-40% yield losses, respectively, in calcareous soil.

Table 3. Assessment of yield losses due to macro-nutrient deficiencies in various groundnut genotypes in calcareous soil (Singh, 1999a).

Treatments	Pod yield (g/pot=*200 kg ha^{-1})				Yield losses	
	GG 2	FeESG 8	JL 24	Fe-ESG10-1	1994	1995
T1- Control	11.5	14.6	14.4	10.8		
T2- All micronutrients	8.31	7.96	8.89	7.29		
T3-T2+macronutrients	15.9(38)	17.0(16)	20.2(40)	16.4(52)		
T3 minus N	12.6	17.1	13.4	12.2	26.4	17.9
T3 minus P	11.0	12.6	12.7	14.6	12.6	30.7
T3 minus K	11.9	13.9	12.6	13.6	19.0	29.0
T3 minus Ca	12.1	17.1	15.9	16.1	29.9	27.1
T3 minus S	15.6	12.1	14.1	16.0	20.2	24.7
T3 minus Mg	14.9	13.6	14.9	15.1	18.3	29.6
LSD(0.05) Varieties means			0.92			
Treatment means			1.00			
Interactions			1.80			

Figures in parentheses show percent increase over control

Many a times crop do not show any symptoms of nutrient deficiencies, but causes considerable losses mainly due to their hunger sign. In calcareous soils of Saurashtra, soil application of 20 kg ha^{-1} $FeSO_4$, 500 kg ha^{-1} $CaSO_4$, 322 kg ha^{-1} $CaCl_2$, 15 kg ha^{-1} $ZnS0_4$, 4 kg ha^{-1} Borax, 0.5 kg ha^{-1} ammonium molybdate, and 30 kg ha^{-1} $MgSO_4$ increased 39.4, 47.1, 23.3, 41.6, 7, 16.5 and 34.1% pod yield, respectively over control (Singh 1999a). Though Ca is in plenty in calcareous soil, application of Ca, K, and B alone or in combinations improved the pod-filling, pod and seed yields of bold seeded groundnut. The 100 kg ha^{-1} Ca and K and 2 kg ha^{-1} B alone increased 37.9, 10.5 and 4.3 % pod yield, respectively, over control. As there are positive responses of various nutrients, efforts were made at NRCG, Junagadh to measure the yield losses in calcareous soil due to the deficiencies and hunger of macro- and micro-nutrients in groundnut (Tables 3 and 4).

In a pot, the deficiencies of N, P, K, Ca, S, and Mg occurring in groundnut in calcareous soil, were differentiated where macronutrients increased the photosynthetic rate and pod yields 16-31 %. In groundnut the nitrogen deficiency is a major problem and non-supply of the same at sowing shows severe yellowing during the early growth stages (up to 50 days), but soon after the nodules were developed the yellowing was reduced. However, the deficiency of N had already caused yield reduction. The minus P and S caused maximum reduction of photosynthetic rates in leaves.

Table 4. Effects of macro- and micro-nutrients on pod yield and related attributes and assessment of yield losses due to deficiencies of micro-nutrient in groundnut

Details of the Treatments	Pod yield (kg ha^{-1})			Yield losses over full package of macro-and micro-nutrients (T3) (%)			Shelling (%)	100 seed wt (g)	Oil (%)
	1993	1994	1995	1993	1994	1995	1994	1994	1994
T1-Control	979	1292	2005	-	-	-	67	32.3	53.7
T2-Macronutrients	1361	1904	2557	-	-	-	71	34.6	50.9
T3-T2+micronutrients	1903	2131	2795	-	-	-	71	37.3	50.5
T4- T3 minus Fe	1593	1658	2528	16.3	22.2	9.6	66	34.2	50.8
T5- T3 minus Mn	1702	1775	2560	10.6	16.7	8.4	66	34.1	50.5
T6- T3 minus Zn	1649	1705	2360	13.3	20.0	15.5	68	36.4	50.7
T7- T3 minus Cu	1677	1828	2424	11.9	14.2	13.3	69	36.1	52.6
T8- T3 minus B	1626	1576	2328	14.5	26.0	16.7	70	34.3	51.4
T9-T3 minus Mo	1641	1756	2267	13.8	17.6	18.9	68	34.5	51.3
Mean	1570	1736	2425						
LSD (0.05)	177	321	250				NS	2.7	1.6

The macronutrients (N, P, K, Ca , S and Mg at 40, 40, 60, 100, 30 and 10 kg/ha, respectively) were applied 50% as basal in the furrows and 50 % at 30 DAE in all the treatments except control . The micronutrients (Fe, Mn, Zn , Cu, B and Mo at 10, 10, 5, 2, 2 and 1 kg/ha, respectively) were used 50 % as basal in the furrows along with macronutrients and 50 % applied as two foliar sprays at 50 and 70 DAS.

The yield losses due to the deficiencies of N, P, K, Ca S and Mg in groundnut grown in the calcareous soils were 18, 31, 29, 27, 25 and 30 %, respectively indicating that all these macronutrients are required for harvesting high yield in calcareous soil (Table 3).

Application of N, P, K, Ca, Mg, and S increased 27-48 % pod yield and further addition of micronutrients produced 10-12.2% more pod yield over macronutrient.. However, combined application of macro- and micro-nutrients that produced 39-65 % more pod yield than control. The yield losses caused by the deficiencies of Fe, Mn, Zn, Cu, B, and Mo were to the tune of 10-22, 8-17, 15-20, 13-15, 16-26 and 13-19 %, respectively (Singh, 1999a). Phosphorus in combination with micronutrients or with FYM enhanced pod and haulm yields more than P alone. Providing adequate quantity of nutrients can double the production meeting the future challenges.

4. Major Causes of Mineral Disorders

Groundnut plants require all the essential nutrients in balanced proportions and any deviation may result in mineral disorders which may be due to deficiency or the toxicity of a particular nutrient or multi-nutrients. When two or more elements are deficient or toxic simultaneously, the composite picture of symptoms may resemble no single known symptoms. Generally, nutrient deficiency in the plant occurs when a nutrient is insufficient in the growth medium and or cannot be absorbed and assimilated by the plants due to unfavorable environmental conditions. Mineral disorders limit crop production in all types of soil world-wide. Plant grows in an environment facing different climatic conditions and soil types and hence there are several factors causing these nutritional deficiencies and toxicities in plants. Some of these are:

- Continuous withdrawal and inadequate supply of nutrients in the soil
- Leaching, run off and nutrient fixation in the soil
- Edaphic factors (Soil, water, temperature and environmental) preventing absorption of nutrients by plants
- Changes in soil physico-chemical conditions such as pH and EC
- Imbalance use of fertilizers
- Induced deficiency
- Interaction between minerals during uptake
- Antagonism
- Use of intensive nutrient (response) requiring crops and nutrient in-efficient crops
- Biotic (Disease and pests) factors.

These factors are interrelated and interaction between them is very complex, for the absorption and utilization of nutrient by plants. Thus, early detection of mineral deficiency stress is important as these might extend to the entire plant if relief is not employed and continuous shortage of a nutrient or nutrients might cause plant death. Some of these factors are discussed here in details.

4.1. Problem soils and major stresses

Acid and alkali are the two major problem soils causing mineral stresses in crop. These soils occupy about two third (each one third) of the land surface area word-wide. The saline and sodic soils, acid sulphate soils, degraded saline soils, coastal soils, and marshy soils are also the problematic soils causing nutritional stresses in plants.

4.1.1. Acid soils

Acid soils, with pH less than 5.5 in their surface zones, occupy approximately 30% (3950 m ha) of the world's land area and occur mainly in two continents of America and Asia where they have developed under udic or ustic moisture regimes. These are Oxisols, Ultisols, Entisols, Alfisols and Enceptisols. On global level about 70 % of the groundnut is grown on acid soil where productivity is below 800 kg ha^{-1}. India has nearly 25 m ha of acid soils found in hill terrains, medium lands, low lands or valley floors in the Himalayan region, eastern and north-eastern plains, peninsular India and coastal plains under varying environmental conditions of landscape, geology, climate and vegetation (Singh, 2000a) of which groundnut is grown on nearly 3 m ha soil. Soil acidity increases the solubility of iron, aluminium, and manganese and it reaches to toxic level in highly acidic soil.

The acid soils are deficient in Ca, P and Mg, degree of saturation of CEC is low (below 25%) and have excess Al, Mn and Fe. The major nutritional problem of groundnut on acid soils is due usually to a combination of toxicities of Al, Fe and Mn and deficiencies of P, Ca, Mg and K. Besides these the acid soils have low water holding capacity, susceptible to crusting erosion and compaction making them low productive. Soil acidity, which is most detrimental to crop production, once considered a problem confined to tropical agricultural region or high rainfall areas with highly weathered soil, now attracted global attention. Excellent attempts have been made to review the mechanism of tolerance and crop production in acid soils and put forth the views of plant physiologists, agronomist, breeders and biotechnologists (Singh, 2000a).

4.1.2. Calcareous and alkaline soils

Generally the soil having pH value above 7 are calcareous and alkaline soils. The calcareous soils are mainly due to presence of high amount of lime and limestone parental rocks below ground. In calcareous soil high HCO_3^- is associated with increased pH or CO_2 concentration, which reduces the solubility of Fe and Mn causing their deficiencies in plant. Generally the alkaline soils are well supplied with Ca, Mg, and K, but deficiencies of S and toxicities of B may occur. The management practices such as deep ploughing, which brings up carbonate of higher solubility to increase the amount in the surface layers and increases the soil pH should be avoided. Phosphorus availability is often low in calcareous soil and adsorption of added P depends on the number of weakly adsorbing sites. The high bicarbonate content directly affects the uptake of P. Thus utilization of P depends on plant tolerance to alkalinity.

About one third of the soils, in the world, are calcareous where iron deficiency is most common problem (Vose, 1982). India has about 33 m ha of calcareous land, most of which is spread in the groundnut growing belts of Gujarat, Maharashtra, Karnataka, Rajasthan, Bihar, Tamil Nadu and Punjab. The plant growing well on calcareous soils are called calcicoles. Among various soils, the medium to deep black calcareous soils of Gujarat, Maharashtra, Karnataka and Rajasthan, and calcareous alluvial soils of Punjab, Haryana, U.P. and Bihar are productive mainly due to high Ca and cation contents and their easy accessibility. Groundnut generally grows well on these soils due to high Ca requirement (Singh and Joshi, 2000). However, because of high availabilities of Ca and Mg in calcareous soils and their higher uptake by plant show multi-nutrient deficiencies, which are very difficult to diagnose and rectify timely. The chlorosis due to iron and sulpur deficiencies are major problem of calcareous and alkaline soils of Saurashtra (Gujarat), Marathwada (Maharashtra) and part of Tamil Nadu, Karnataka and Rajasthan (Singh 1999). The high free $CaCO_3^{--}$, HCO_3^{-}, pH in calcareous soils are main cause of chlorosis.

4.2 Light and Temperature

The concentrations of elements are also influenced by light intensities and duration and extreme temperature. Light affects the photosynthates produced and alter the ratio of element to dry matter due to dilution effects. Though the light, through photosynthesis, provides energy for active upkate of elements and enhancing concentration, this positive effect is overridden by the dilution effect. Thus increasing light exposure reduces the N, P, K, concentration, but Ca concentration may increase (Jones et al., 1991), however genotypic differences are obvious as changes are genetically controlled. While shading increases the P, K, Al, Ca, Fe, and Mn concentrations and decreases the Cu, Mg, and Zn concentrations in leaves. The adverse effects of excess Na and K associated with high salinity and low light have been partially corrected by high light by helping to maintain plant cation concentrations.

The temperature influences the movements, translocation and utilization of elements by plants, however it is difficult to distinguish the effect of temperature under normal field condition. There is optimal temperature for plant growth and development, which vary from species to species and deviation from these definitely cause abnormality in nutrient uptake. Some of the controlled condition studies reports that the elemental concentration at high temperature is less than that of at low temperature, because high temperature, like light, increases the dry matter production and here also causing dilution effect. But in addition high temperature also enhances respiration, deples photosynthates and increases transpiration which allows more absorption of elements from soil. However, the effects of temperature is masked by concomitant effects of light and moisture prevailing during the cropping season.

4.3. Water

The rainfall increases soil moisture, by bringing the levels within the beneficial range between wilting and field capacity, stimulates the plant growth and hence tends to lower the elemental concentration again due to dilution effects. Though the favorable moisture condition also influences the soil nutrient availability and their movement in plant, all these are overcome by fast growth and dry matter accumulation. The humidity influences the rate of transpiration and thus indirectly affects the nutrient content in plants.

However, flood irrigation aggravates problem of root aeration in groundnut resulting in abnormal respiration, inhibiting root growth and altering metabolic functions. Because of this plant becomes chlorotic due to deficiency of N caused by inability of roots to take up N and ineffectiveness of Nitrogen-fixing bacteria, deficiency of S due to leaching in course texture soil and deficiency of Fe in calcareous soil due to conversion of ferrous to ferric form.

4.4 Interaction of macronutrients

Increasing the levels of any macronutrient, upto certain level in the nutrient solution, increases the concentration of that particular element in the leaves, stems and seeds and their uptakes by plant. But low or excess of any element influence the uptake of other nutrients also that may be synergistic (beneficial) or antagonistic (detrimental) effects. Though interaction of individual nutrients are discussed in the next chapter, in general increasing the level of N increased N, P, K, Ca and Mg concentration, K decreased Ca and Mg, and Ca decreased K and Mg concentrations in plant tissues. The P and S, though did not show any of such interaction with other macronutrients. Singh (1996) in a nutrient solution culture, reported that at sufficiency levels of macronutrient in nutrient solution, the elemental concentrations of groundnut in leaves at 60 DAE and seeds at harvest were 3.14-3.54 and 4.75-4.82 % N, 0.32-0.35 and 0.4-0.41 % P, 1.84-2.25 and 0.78-1.08 % K, 2.5-2.6 % and 440-470 ppm (mg kg^{-1}) Ca and 0.2-0.32 and 0.22-0.25 % S, respectively. The concentrations of Ca and Mg decreased with increasing the levels of K but were high in all the plant tissues except seeds at very low levels of K. Similarly, the concentrations of K and Mg in plant tissues decreased with increasing Ca levels.

5. Diagnostic Methods of Mineral Disorders

To diagnose the deficiency of an element, visible symptoms, plant and soil analysis, pot studies and fertilizer trials in field are the five different diagnostic methods used for groundnut. All of these are important and to be used for accurate diagnostic and remedial measure. A brief about the merit and demerit of these methods for groundnut are discussed in the following lines.

5.1. Visible symptoms

The nutritional disorders produce a characteristic symptom on leave stem or root which can easily be diagnosed visibly under field condition directly without involving any laboratory test and the costly equipments. If the clearcut symptoms are there and the eyes are trained for the same, it is most powerful and cheap technique. However the major disadvantage of visible diagnosis is that, in a number of elements, symptoms is diagnosed only if it is sufficiently sever to produce symptoms and by that time considerable yield loss has already been occurred and it is too late for alleviating the problem for current season.

The nutrient tends to distribute among various plant parts and main cause of the disorder symptoms is the pattern of distribution and redistribution of nutrients within the plant and particularly position of the organ. For diagnosis of various symptoms in groundnut broadly these have been grouped under symptoms may be pronounced on the older leaves and organs, younger leaves and organs, on both young and old leaves and no specific leaf symptoms.

Fully expanded leaves receive a larger share of the water and nutrients entering the shoot. But under excess nutrient, the highest concentration are found in oldest leaves. Thus the older leaves usually show toxicity symptoms first and most markedly. When excess of one element reduce the uptake or utilization of another element the main symptoms may be those of deficiency of other elements. Generally there are three types of symptoms in groundnut:

- In case of N, P, K and Mg deficiencies the plant tend to withdraw these elements from older leaves and redistribute them to young, actively growing plant via phloem as these are phloem-mobile. Thus their symptoms occur first on older leaves.
- The Ca, Fe, Mn and B are phloem-immobile and not redistributed under scarcity, thus their symptoms occur on young actively growing parts of the plant, including root tips. For phloem-immobile element, there should be

continuous supply of element for maintaining healthy groundnut crop. Fluctuations in supply of these nutrients, during the growing season commonly show the deficiency symptoms on the leaves formed during the period of deficiency with healthy leaves both above and below the affected leaves.

- The S, Zn, Mo and Cu have variable mobility in phloem and act as phloem-mobile as well as phloem-immobile depending upon the conditions and factor and their symptoms appear on young as well as old leaves depending upon the factor. In groundnut, however, mostly these deficiencies occur on young leaves first.

Mineral deficiency symptoms are sometimes confused with other complex field events such as damage caused by insect-pest, diseases, salt stress, water stress, pollutants, excess of another element, light and temperature injury and herbicide damage. Therefore, it is necessary to critically observe and define these deficiency symptoms. The symptoms might be distinguished based on the plant part that shows deficiency, presence or absence of dead spots and entire leaf or interveinal chlorosis. A description of initial appearance of disorder symptoms on leaves is given in the next chapter.

5.2. Plant Analysis

There is a functional relationship between the crop yield and concentration of nutrients in the whole plant or an index tissue and based on these the plant analysis can be used as a diagnostic tool. However, the concentration of elements in a given tissues varies with the stage of growth, plant age, cultivar, climatic conditions and interactions. The plant analysis involves a number of steps, sampling, sample preparation, laboratory analysis and interpretation of data and all these must be done carefully. For field grown groundnut, the time of sampling and tissues, which vary from element to element, has been standardized in our laboratory and being recommended below:

Elements	Plant tissues and stages of crop
N, P, K, Ca, S, Mg, Fe, Mn, Zn, Cu, Mo & B	Fully matured top 5 leaves at 40-60 days after emergence (DAE)
N and P	Fully matured top 3 leaves at 20-40 DAE
Fe, B	Youngest fully emerged leaf and seed (B)
Ca, P and Zn	Seed at 80 DAE and at harvest

Though, for most of the element leaf sample at 40-60 DAE is the correct stage, for specific phloem-immobile element the tissue vary. Leaves are the major sink for nutrients accumulation during vegetative stage as a result high nutrient concentration was noticed at 40-60 DAE, but soon as pod development start, the developing pods become the major sink and the macronutrients accumulated in leaves translocate to seeds Singh (1999a). As a result the nutrient concentrations in leaves was lowest, except for K and Ca which were more in leaves and stems than seed, at harvest. The high concentration of Ca in leaves at harvest is due to its phloem-immobility and whatever the pod absorbed directly from the soil solution was available to the seed.

The response curve, which describes the relationship between crop yield and nutrient concentration in index tissues, is drawn to define the critical nutrient concentration (concentration corresponding to 90 % of maximum pod yield) and sufficiency range. As the critical concentration is a single value and varies with condition and genotypes, the sufficiency range was defined and found to be better concept for interpretation of plant analysis. The low, sufficiency and high concentrations of various nutrient in groundnut as worked out by Jones et al 1991 and Singh 1999a is given in Table 5.

Table 5. The low, sufficient and high nutrient concentrations in groundnut at various stages (Jones et al., 1991; Singh 1999a)

Nutrient	Upper part of plant prior to bloom stage (25-40DAE)			Upper part of plant at early pegging (40-60DAE)		
	Low	Sufficient	High	Low	Sufficient	High
		Percent				
N	<3.50	3.50-4.50	>4.50	<3.50	3.50-4.50	>4.50
P	0.18-0.24	0.25-0.50	>0.50	<0.20	0.20-0.35	>0.35
K	0.50-1.60	1.70-3.00	>3.00	<1.70	1.70-3.00	>3.00
Ca	<1.25	1.25-2.00	>2.00	<1.25	1.25-1.75	>1.75
S	<0.20	0.20-0.35	>0.35	<0.20	0.20-0.30	>0.30
Mg	<0.30	0.30-0.80	>0.80	<0.30	0.30-0.80	>0.80
		ppm				
Fe	50-59	60-300	>300	<100	100-250	>250
Mn	50-59	60-350	>350	<100	100-350	>350
Zn	20-24	25-60	>60	<20	20-50	>50
Cu	<5	5-20	>20	<10	10-50	>50
B	20-24	25-60	>60	<20	20-50	>50
Mo	<0.1	0.1-5.0	>5	<0.1	0.1-5.0	>5

Nutrient ratio is another method of interpretation of plant analysis if interaction between two elements is very common. Although DRIS (Diagnostic and recommendation integrated system) norm have been proposed, the author did not find its much relevance with groundnut because of its underground fruiting habit.

5.3. Soil Analysis

There is also a functional relationship between the nutrient availability in soil and crop yields and based on these soil analysis acts as a diagnostic tool. Soil analysis can be used to predict the nutritional status of a soil before crop is planted. Like plant, the soil analysis also involves a number of steps such as sampling, handling and sample preparation, chemical extraction, laboratory analysis and interpretation of data. It is assumed that the chemical extractants remove the whole or some part of the plant–available nutrient elements from the soil. As there are many chemical extractant and numerous factors affects the availability of a nutrient, all extractants does not suit for all soil and crops, and hence these needs to be calibrated for a particular soil, crop and its condition against the crop response in field. Once the chemical extractant is defined, the critical value of the nutrient element differentiating deficient from non-deficient soil is worked out through field response curve. However, many soil test value are of limited use to a range of soil and crop genotypes and do not have universal application. Moreover, different genotypes show different critical values for the same soil and climatic conditions, because of differences in their ability to extract the nutrient from the soil, their requirement and rate of nutrient uptake and utilization. Generally the traditional cultivars, due to their prolonged cultivation are more adapted to the low fertility conditions than the newly introduced high yielding cultivars.

The soil and plant analysis are the main basis for the fertilizer recommendation for a groundnut on that particular soil. Further, these recommendations vary with variety as some of the cultivars response very high to fertilizer application whereas a few do not. Plant analyses data can be used to help guide future soil test calibration work and agronomic research. The soil analysis provide a base but many a times mislead as the deficiency of the element, showing their adequate concentration in soil, occur in plant.

Though the soil samples from different states have been analyzed and sufficiency, deficiency and toxicity areas of certain elements have been worked out, but these studies are based on the limited soil samples and crops. However, for groundnut less attempt has been made to work out the nutrient deficiency and toxicity areas in India and their symptoms in groundnut. Based on the soil test from available literatures, the micronutrient deficiency areas of different states of India have been summarized in Table 1. The responses of nutrients to groundnut are very high on deficient and marginal soils, but limited systematic work has been done on these aspects in India. The new soil extractants should be used for predicting the nutritional status of acid and alkaline soils.

5.4. Pot experiments

The pot experiment, under controlled conditions, is a rapid means of measuring the soil nutrient limitation and estimating approximate amount of fertilizer needed to correct these. Though it requires less time and provides diagnostic results more quickly, the Pot experiment may sometimes identify disorders which do not occur in the field either due to water and climatic factors or limited amount of nutrient available to the plant during experimentation.

5.5. Fertilizer trials

The full interplay of plant, soil, management and environment factors occur only in the field, and hence fertilizer trials are essential part of the overall diagnosis. Though it requires large inputs of time and materials, by means of field experiments we can accurately establish the fertilizer requirement. The major limitations of field trial is that, only a small number of elements can be tested at a time and when multiple nutrient disorder exist it fails to identify the correct one and hence inaccurate assessments of the true fertility status of the soil.

5.6. Other diagnostic methods

The Biochemical diagnostic technique offers a new avenue for indirectly detecting nutrient status, however, these needs to be standardized. In groundnut enzyme activities such as peroxidase, Nitrate reductase and ascorbic acid oxidase serve good indicator for diagnosing Fe, N and Cu deficiencies, respectively. The deficiencies of various elements show different florescence in light, the measurement of same standardization of the method can easily diagnose the various deficiencies in the leaf. The chlorophyll meter is a powerful tool for diagnosing N and Fe deficiencies. The prompt gamma ray analysis (PGA) is a non-destructive method for B analysis in plant and soil. The low-altitude aerial photography through computer based image analysis can help in the assessment of plant growth and N status non-destructively. The remote sensing technique can be a new nutritional diagnostic tool, if the satellite data are used to estimate and improve the productivity by appropriate fertilization in groundnut.

6. Main Keys to the Symptoms of Nutritional Disorders

As the nutrient deficiency symptoms reflect the role of that particular element in the plant metabolism and two elements rarely perform the same role, a deficiency of these elements induces characteristic symptoms, which is a key and can easily be used as an aid for the diagnosis. To have a quick reference for diagnosis of various symptoms in groundnut, broadly these have been grouped under following sections:

- Symptoms pronounced on the older leaves and organs.
- Symptoms pronounced on the younger leaves and organs.
- Symptoms prominent on both young and old leaves.
- No specific leaf symptoms

6.1 . Symptoms pronounced on the older leaves and organs

In this category the symptoms begins and occur mainly on older or basal leaves and organs, symptoms localized or affects whole plants, but whole plant growth is affected. The symptoms occurring under this category and the causing minerals are listed below:

S.N.	Main symptoms	Differentiating symptoms	Mineral disorders
1.1	Symptoms common over the whole plants		
1.1.1	Older leaves mainly pale yellow	With pale to yellowish green chlorosis, starting at the leaf tips, and dry up with pale brown necrosis, weak and prolonged thin stem	N deficiency
1.1.2	Older leaves dark green with or without dark yellow chlorosis but often with purple, pigmentation	Older leaves, petiole and veins with purple suffused pigmentation, no orange or brown lesions	P deficiency
1.2	Symptoms localised on older leaves alone	Marginal chlorosis or interveinal spotting, with or without necrotic marginal zones, with or without dying of older leaves	

1.2.1	Older leaves mainly pale green	Pale yellow, interveinal chlorosis sometimes brown, orange and purple lesions or blotches along the mid rib, leaf vein often remains green with sometimes upward curling	Mg deficiency
1.2.2	Older leaves mainly green with purple, red or dark brown pigmentation or lesions, with or without dark yellow chlorosis	Older leaves with small dark brown to red-purple lesions resembling spots	Mn deficiency
		Older leaves with large orange, yellow, purple or brown streaks and lesions	Zn toxicity
		Older leaves with prominent red-purple, lesions having irregular outlines	P toxicity
		Older leaves with marginal yellow, chlorosis of leaf tips margines followed by brown grayish-brown, reddish-brown to dark-brown necrosis.	K deficiency
		Older leaves with yellow white or brown margins and marginal necrosis, and plant often wilted.	S, Na or Cl toxicities
		Older leaves with grey to white necrotic lesions and brown marginal necrosis, and plant often wilted.	Na toxicity
		Plant often appear wilted, yellow interveinal chlorosis and red-purple lesions on the middle leaves.	Cl toxicity

6.2. Symptoms pronounced on the younger leaves and organs.

In this category the symptoms begins and occur mainly on younger leaves and organs and to some extent middle leaves are also affected, sometimes death of the growing points.

S.N.	Main symptoms	Differentiating symptoms	Mineral disorders
2.1	Terminal bud continue to grow		
2.1.1	Young leaves mainly pale green or yellow, chlorosis with or without necrosis		
2.1.1.1	Young leaves not wilted without necrotic spots	Young leaves yellowish-green, later lemon-yellow or yellowish-white with prominent interveinal chlorosis and sharply demarcated green veins; under sever deficiency leaves become white papery and die	Fe deficiency
		Young leaves with faint to pale yellow or yellowish-green, including veins. The symptoms also resembles N deficiency.	S deficiency
2.1.1.2	Young leaves wither and droop like wilted with necrotic spots	Intercostal area pale or light yellow with number of yellowish-white necrotic lesions and young plant twisted to one side.	Cu deficiency
2.1.2	Young leaves mainly pale green to green	Young leaves with torn leaf margins and leaf tips deformed, missing or joined together	Ca deficiency
		Young leaves with broad yellow or white bands between the margins and purpling on lower side	Zn deficiency
		Young leaves with transparent white interveinal lesions	B deficiency
		Reticulate or mosaic like interveinal and intercostal chlorosis with mottling and marbling, green	Mn deficiency

		margin along the main veins form a Christmas tree pattern on moderately old leaves, mottled area get necrotic with red-brown interveinal lesions.	
2.2	Terminal bud die off after development of deformations on young leaves starting at the tips or at basal end	Leaves becomes cupped shape, distorted and hook like near the tip, the lamina dries out and tears beginning from margines, with pale to white-greener grayish-brown tints (crinkle leaf) sometimes violet tinted stem bend down due to collapse.	Ca deficiency
		Growing bud at terminal end thickened and stiff, young leaves turn pale green starting at the basal end of leaves, leaves deformed, twisted and stunted, often thickened, right and brittle, shortened internodes, bushy or rosette appearance of the plant.	B deficiency

6.3. Symptoms prominent on both young and old leaves

In this group, the symptoms appearing on both the young and old leaves and organs, depending upon the time of appearance are mentioned.

S.N.	Main symptoms	Differentiating symptoms	Mineral disorders
3.1	Older leaves mainly dark green young leaves pale yellow	Older leaves with large purple or orange lesions, irregular chlorotic mottling, which develp rapidly into various size necrotic blotched, veins green both sides. Severe Zn toxicity cause early senescence.	Zn toxicity
		Older leaves with small brown or red-purple lesions	Mn toxicity
3.2	Older and young leaves both pale yellow or green	Symptoms similar to N deficiency, with yellowish leaf blotches (yellow spots), yellow mottled leaves with incurled margins.	Mo deficiency
		With or without interveinal chlorosis	S deficiency or Al-toxicity induced Fe and Mg deficiencies

7. Diagnosis and Management of Mineral Disorder Symptoms

Fertilizer management practices and their response vary considerably from situation to situation. As majority of the groundnut area is covered by sole crop, most of the research works on fertilizer management have been dealt considering groundnut as sole crop. The details of the macro- and micro-nutrients, their brief functions, deficiency and toxicity symptoms and their rectification measures are discussed separately for each nutrient in the following text. Also brief mention about the beneficial elements and toxicities of various elements is also mentioned.

7.1. Macronutrients

7.1. 1. Nitrogen

Requirement and Function

Nitrogen is an important constituent of proteins, chlorophyll, amino and nucleic acids, and is required for the vegetative and reproductive growth, nutrient absorption, photosynthesis and production of assimilates for developing pods. It also plays an active role in the enzyme reactions and energy metabolism. The nitrogen requirement of groundnut is much higher than cereals because of its high protein content; however, most of the soils where groundnut is grown in the world are deficient in nitrogen.

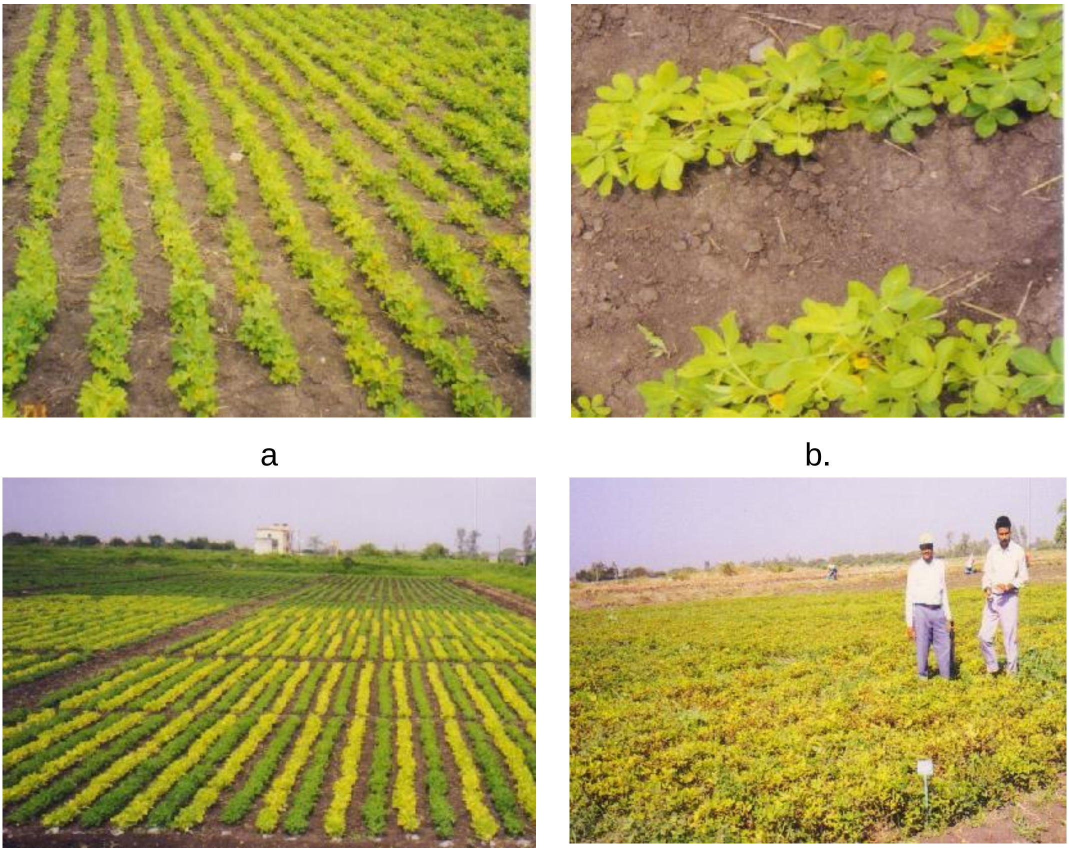
Groundnut produces approximately 30-40 kg of biomass kg^{-1} of N assimilated, and to produce 5-6 t of an average biomass of a good groundnut crop, it needs 180-200 kg of N. This large amount of nitrogen is supplied to the groundnut plant mainly by its root nodules. Groundnut is capable of meeting its 60-80 % nitrogen requirements from symbiotic nitrogen fixation by root nodules and only 20-40 % from soil nitrogen as, depending upon the soil nitrogen status. However, the nitrogen supply to groundnut is very crucial and deficiency is observed in between 10-45 DAE and at pod formation stages (Singh, et al 1991, Singh and Joshi 1993). During reproductive stage, N is mobilized continuously from leaves to the developing pods and hence deficiency may occur at this stage too. For these reasons some N is applied to groundnut.

In soil, both the ammonical and nitrate nitrogen are available in the root zone and their application increases nitrogen in the vegetative and reproductive parts, but the

Table 6. Methods of correcting various nutrient deficiencies

Nutrients	Corrective Measures
Nitrogen	Application of N fertilizer and organic matter to soil, use on N-efficient cultivars
Phosphorus	Application of amendments to maintain soil pH near neutral in acidic soils; application of phosphorus fertilizers, use of P-efficient cultivars
Potassium	Application of crop residue and potassium fertilizers
Calcium	Liming (addition of $CaCO_3$) of acid soils; addition of gypsum or other soluble calcium source where lime is not required
Magnesium	Soil application of dolomite; soil or foliar application of magnesium soil sulfate or magnesium nitrate solutions
Sulfur	Soil application of pyrite, ammonium sulfate; single super phosphate; gypsum or elemental sulfur.
Zinc	Addition of zinc sulfate to soil; foliar spray of 0.1-0.5% solution of zinc sulfate
Iron	Soil application of FeEDDHA or iron sulphate, foliar spray of o.5 % iron sulfate or 0.02-0.05% solution of iron chelate; use of efficient cultivars, fertigation with iron chemicals
Copper	Soil application of copper source of fertilizer or foliar spray of 0.1-0.2% solution of copper sulfate
Boron	Soil application of borax or foliar spray of 0.1-0.25% solution of borax, care not to exceed 1 ppm B in solution in irrigation
Molybdenum	Liming of acid soils; soil application of sodium ammonium molybdate; foliar spray of 0.07-0.1% solution of ammonium molybdate
Manganese	Foliar application of 0.1% solution of manganese sulfate

groundnut absorbs mainly nitrate nitrogen. The Rhizobia fixes atmospheric nitrogen and supplies to the host plant in the form of amide to be incorporated into proteins through glutamyl phosphate pathway. The acetylene reduction activity (ARA), and total N content of the plant estimate the N_2-fixation rate. The Virginia cultivars show high ARA, accumulate N at faster rate and more N in the vegetative parts and maintain higher N content in leaves than the Spanish groundnut. The N accumulation in leaves and stems ceases after the onset of pod development (70 DAS) as the same is diverted to pod. A good groundnut crop accumulates 1-2.5 kg N ha^{-1} day^{-1} during vegetative growth and 3-4 kg ha^{-1} during active reproductive growth. On an average 20-30 g N m^{-2} is accumulated by the crop during its entire life and 60-70 % of this goes in the Kernel (Singh and Joshi, 1993, Williams, 1979).



a b. c. d.

Plate 1. Field view of groundnut crop showing, (a) severe N deficiency in early growth stages (25-30 days after emergence, DAE), (b) close view of a nitrogen deficient crop showing pale to yellowish green colour canopy, (c) nitrogen deficient (yellow) and nitrogen efficient (green) groundnut genotypes planted in an alternate row showing yellow and green canopy at 60-70DAE, (d) nitrogen deficiency at maturity.

Symptoms and diagnosis

The nitrogen deficient crop shows slow and stunted growth with weak and prolonged stem and pale to yellowish green coloration of the older leaves. The chlorosis starts at the leaf tips, and dry up with pale brown necrosis. Nitrogen is very mobile and as the older leaves dies, it is mobilized from older to younger leaves in form of amines and amides. Since there is no early senescence of leaves in groundnut, the characteristic deficiency symptom of nitrogen is the appearance of uniform yellowing of leaves including the veins due to decomposition of chloroplast, being more pronounced on older leaves (Plates 1 and 2).

The nitrogen concentrations in leaves decrease with plant age and vary with cultivars making leaf N a difficult diagnostic tool for determination of need. The sufficiency levels of N in leaves at full bloom stage (45-60DAE) has been reported to be in between 3.0-4.5 % and nitrogen deficiency symptom appears when the leaf N concentration falls below 2.2 %. (Dwivedi, 1988; Jones et al., 1991; Singh, 1999a). However the critical concentration of N in leaves at 45- 60 DAE is in between 2.5-3.0 % and vary with genotypes. For optimum yield, the N, P and S ratio should be around 15:1:1 in the 4^{th} leaves from the top.

Increasing the levels of N, increased the concentrations of P, K, Ca and Mg in leaves, but did not affect S and Mg (Singh, 1999a). At sufficiency level of N, the concentrations of N, P, K, Ca, and Mg in leaves during 50-60 DAE were 3.14-3.54, 0.31-0.38, 1.84-1.97, 2.65-2.76 and 0.63-0.65 %, respectively. The concentrations of N, P, K, Ca, S, and Mg, in seeds, also increased with increasing N levels and were 4.75-4.81, 0.40-0.47, 0.87-0.97, 0.042-0.043, 0.24-0.25 and 0.14-0.15 %, respectively at sufficiency level of N.

Control measures

The Spanish, and Valencia bunch groundnut, because of lesser N_2-fixation and short crop duration respond more to nitrogen than the Virginia cultivars. The Native *Bradyrhizobium* are abundant and apparently able to fix adequate N at most of the places in India (except the rice fallows), China, USA and other groundnut growing countries leading to lesser response of its inoculation. In Cyprus, use of inoculation is advantageous to groundnut and increased 42 % higher N yield over uninoculated one (Papastylianou, 1993). Thus N is not needed unless the site is excessively low in N or effective *Bradyrhizobium*, otherwise it may lead to excessive growth and decrease harvest index and pod yield.

Nitrogen needs of groundnut can ordinarily be met through any available N sources. The recommended doses of nitrogen, in India, vary in different agro-climatic conditions and are in between 10-40 kg for rainfed and 20-60 kg^{-1} for irrigated crop (Singh 1999a). In rainfed groundnut, N should be applied as basal, but in irrigated groundnut it should be applied in 2-3 splits (Singh et al, 1991).

a

b.

c.

d.

Plate 2. Nitrogen deficiency in groundnut, (a) pot grown plants showing healthy (left) and N deficiency (right), (b) a field of groundnut crop showing healthy crop (right) inoculated with *Bradyrhizobium* and N deficient crop without *that* (left) in acid soil of north-east states, (c) sever nitrogen deficiency in the old as well as new leaves with chlorosis starting at the leaf tips, and drying up with pale brown necrosis, (d) uniform yellowing of leaves including veins due to decomposition of chloroplast in older leaves, a characteristic symptom of N deficiency.

Application of 10 kg N ha^{-1} as basal followed by two foliar sprays of 1% aqueous solution applied at 30 DAE (500 l ha^{-1}) and 70 DAE (1000 l ha^{-1}) produced highest pod yield in bunch type groundnut and increased the efficiency of N fertilizer for per kg pod production (Singh et al., 1991a).

In groundnut, excess irrigation, flooding and poor areation cause chlorosis due to the combined deficiencies of N, S and Fe which could be controlled effectively by cultivation of groundnut in broad-bed furrow method. The furrow made in system help to drain of excess water thus improve the micro-environment especially aeration in the groundnut field.

Application of Soluble or liquid fertilizer through micro-irrigation system as fertiirrigation substantially increases fertilizer use efficiency and yield of groundnut. The field experiment conducted by Ghetia (1995) in Calcareous soil of Shaurashtra indicated that application of N and P as DAP and urea through drip irrigation increased the fertilizer use efficiency, pod and kernel yields, shelling percent and kernel weight when compared with its soil application. The higher fertilizer use efficiency in fertigation was mainly attributed to reduced leaching and de-nitrification loss of nitrogen and higher concentration of available fraction soil P.

7.1. 2. Phosphorus

Requirement and function

Phosphorus, is present in inorganic form as a component of ATP, RNA, DNA, certain enzymes and proteins, and involved in various energy transfer reactions and genetic informations. It limits nodule development and N_2-fixation, plant growth, seed development and oil synthesis in groundnut. On global level P is the most deficient element, and hence P deficiency is restricted to the areas that are not fertilized with. Most of the Indian soils where groundnut is grown are either deficient in P or having medium P due to its fixation and low availability in the soil due to several factors. The extensive survey conclude that about 45 and 50% of the Indian soil have low and medium available P, respectively, and only 5 % soil were high in available P (Tandon, 1987). Phosphorus enhanced root production and is very critical at flowering and pod formation stages of groundnut crop and its application increased the nodulation, N2-fixation and N contents of the kernel and foliage (Singh et al., 1991).

S*ymptoms*, *and diagnosis*

In groundnut, P deficiency causes purpling of leaf margin and stunted growth but more dark green in colour (Plate 3). The deficiency first occurs on older leaves and later spread to other leaves from the bottom, but it takes minimum of 4 weeks to appear the deficiency symptoms on the plants. The older leaves, petiole and

a b.

c. d.

Plate 3. The P deficiency in groundnut, (a) pot grown plants showing healthy (left) and P deficiency with stunted growth (right), (b) P deficient groundnut crop with stunted growth in the plot without P fertilizer and PSM is seen in the middle and healthy crop in P fertilised and PSM inoculated plot (below) in the acid soil, (c) P deficient plant showing purpling of leaf margin and back with orange yellow spot, (d) leaf with purpling of margin and back, a typical symptoms of P deficiency.

veins with purple suffused pigmentation, without orange or brown lesions. The older leaves may also become orange yellow, then brittle and finally shed. Some older leaves also show yellow symptoms of P deficiency.

Generally, the soil with less than 10 ppm available P are considered low for groundnut, however, the critical levels of soil available P, in upper soil, has been reported to be in between 7.9-10 ppm depending upon the soil types, climate and groundnut genotypes (Singh 1999a). The low P availability in soil decreases nodulation and nitrogen fixation rate. Leaf P content, at flowering is the most standard plant part and age to determine the critical levels and it is reported to be in between 0.20-0.3 % P by various workers, however for Indian groundnut the critical leaf P content is 0.22 % for Spanish and 0.25 % for Virginia cultivars. The sufficiency level of P concentration in leaves, at flowering, is reported to be 0.26-0.35 % for Spanish and 0.29-0.50 % for Virginia cultivars, which did not change during vegetative phase but declined over the time and was lowest (0.12-0.18 %) at harvest (Singh 1999a). However, the sufficiency level of P in seed at harvest is 0.4-0.62 % (Singh, 1999a). Increasing the levels of P, increased the concentration and uptake of P in groundnut leaves, stems, seeds and shells Singh (1996b).

The mobility of P is highest at pH between 6.0 and 6.5. The monovalent $H_2PO_4^-$ is the predominant form of P in a soil having pH below 6.8, which is readily absorbed by plants, however, between pH 6.8-7.2 the HPO_4^{2-} is the predominant anion, which is less readily absorbed. In alkaline soil with pH more than 7.2, the predominant form of P is trivalent HPO_4^{3-} which is virtually unavailable for uptake by plants. Also, P tends to form an insoluble complex with Al and Fe in neutral pH while in basic soil Ca and Mg complexes precipitate the P. Thus P is always limiting factor in calcareous soils.

Control measures

The recommended doses of phosphorus are 30-40 kg P_2O_5 ha^{-1} during rainy (kharif) season and 40-60 kg P_2O_5 ha^{-1} during post rainy season. Tough P fertilization is recommended as basal, its application particularly at flowering and pod formation stages were more beneficial (Singh et al., 1991a). The optimum level of P range from 20-60 kg P_2O_5 ha^{-1} causing 30-60% increase in yield. However, the calcareous soils are deficient in P, and application, of P increased the nodule biomass upto 200 kg P and pod number, yield and nutrient concentration upto 100 kg P ha^{-1} (Singh and Chaudhari (1996b). Among various P sources single super phosphate was better than DAP and triple super phosphate (Pasricha et al, 1987). The oil and protein contents in kernel are reported to increase with P and K application (Jain et al., 1990).

The response of P to groundnut is not consistent due to transformation of P into unavailable form after coming into contact with soil colloids. Thus the management practices to P application need to be dealt cautiously. A significant correlation between the dominant form of Ca-P (calcium bound P) and groundnut yield (r = 0.71) indicated that Ca-P is the chief fraction involved in the P nutrition of groundnut (Pasricha et al., 1988). In broad-bed and furrow system, the response of P increase. Drilling of P below the seed at the time of sowing is a superior practices to broadcasting. Application of 20 kg P_2O_5 ha^{-1} as basal followed by two foliar sprays of 1% aqueous suspension of single super phosphate (SSP) at 30 and 70 DAS at 500 and 1000 l/ha, respectively produced maximum pod yield in bunch type groundnuts (JL 24 and GG 2) with high fertilizer efficiency (Singh et al. , 1991 a).

Groundnut forms symbiotic association with vesicular arbuscular mycorrhiza (VAM fungi known to augment plant phosphorus (P) uptake ability from soils deficient in this element. Groundnut roots show extensive VAM colonization and inoculation with *Gigaspora calospora*, *Glomus fasciculatus* and *Glomus mosseae* resulted in growth stimulation and P uptake (Singh and Chaudhari, 1996b; Bell et al. 1988). Using "a double pot system", it was demonstrated that Ca-P and Al-P fractions of accumulated P in the acid soil around mycorrhizal root are mobile and available to groundnut plant.

There are number of reports about the non-responsiveness of groundnut to P application even in apparently low available P. This has been attributed mainly to low yield levels, P-efficient crop as it can absorb P from its low concentration, and inadequate moisture as a limiting factor (Dwivedi et al., 1987; Patel and Kanzaria, 1985) and the beneficial effect of native mycorrhizal fungi. The P deficiency enhances root exudation of organic acids to mobilize sparingly soluble P on acid and calcareous soils. In acid soil, tartaric acid is the main component of exudates while malic and citric acids are in calcareous soil. The root "contact reactions" have shown that groundnut has superior ability to solubilizing Fe- and Al-bound P, than many other crop and take up P from soils with low P. Looking to this advantage, research started on the selection for P-efficient genotypes and some of them are listed below:

- P-efficient : GG 5, NRCG Acc 7085-1, 6919, 1308, 3498, and SP 250A
- P-inefficient : VRI 3, B 95, PBS 16003, 20012 and 18057

7.1. 3. Sulphur

Requirement and function

Sulphur, constitutes methionine, cysteine and cystine amino acids and inpart in oil synthesis in groundnut. It improves nodulation and pod yield, reduce the incidence of diseases and is as important as P. Sulphur increases, chlorophyll and decreases chlorosis in calcareous soil by increasing availabilities of micronutrient in soil (Singh et al., 1990a). The Groundnut grown on coarse-textured sandy soils generally suffers from S deficiency due to leaching of SO_4-S causing 10-25 % yield losses. In India, the S deficiency is severe in Bihar, Gujarat, Punjab, M.P., U.P., Karnataka and A.P. in more than 150 districts. The deficiency is mainly due to use of S free fertilizers, adoption of high yielding varieties and losses of S through leaching and erosion. The increasing role of S application in raising groundnut production has been established in almost all states throughout India, however more common in A.P., Gujarat, Bihar Rajasthan and Punjab.

Symptoms and diagnosis

The S deficiency symptom is like nitrogen but occur on young leaves. Though S element is mobile, in groundnut, the symptoms appear mainly on young leaves first and extend to middle showing pale yellow colour with vein showing white (Plate 4). The S stored in the older leaves as sulphate is easily mobilised and transferred to growing organ to a certain extent, but not the one that has already been incorporated into organic compound. However, the S mobilised from older leaves is not sufficient to maintain the normal growth, as a result the youngest leaves remain small and more or less yellow owing to lack of protein and chlorophyll. The severe chlorosis is due to disturbance of protein metabolism in the chloroplast and chlorophyll synthesis. The S content of older leaves is thus some what higher than the young leaves.

The adequate concentration of S in the leaves is in between 0.2-0.35 % and the critical S concentrations in leaves are 0.18 and 0.2 %, at pegging and pod formation stages, respectively (Jones et al., 1991; Singh 1999a; Supakamnerd et al., 1990). The critical levels of S is also related to the N content and is 0.2% at 2.5-3.0% N and 0.25% at 3.5-4.0% N maintaining the N:S ratio of about 15:1 (Lund and Murdock, 1978). Also the kernel protein content of less than 26 % seemed indicative of S-deficient condition. Increasing S levels, increased its concentration in leaves, seeds, stems and shells and at sufficiency level of this element its concentration was 0.2-0.32, % in leaves at 60 DAE and 0.22-0.25 %, in seeds at harvest (Singh, 1996b).

a

b.

c.

d.

Plate 4. Sulphur deficiency in groundnut, (a) field view of a crop showing S deficiency on young leaves, (b) pot grown plants showing severe S deficiency with chlorosis and stunted growth (left) and healthy crop (right), (c) young leaves showing pale yellow colour with vein white, a typical S deficiency and, (d) a plant showing S deficiency in most of the leaves.

Survey of S status of soil (0-15 cm) in groundnut growing areas of India has shown that the critical level of available S is 10 ppm, however, depending upon the soil type and climate, it may vary in between 8-11 ppm. Taking 10 ppm S, as the critical level, most of the soils in India where groundnut is grown are deficient in S. Of these the calcareous soil and red laterite soils are more S deficient soil as their heat soluble available sulphur level is in between 8-12 ppm and application of 20-30 kg S ha^{-1} produced 18-25% more pod yield (Singh, 1999b).

Control measures

Sulphur requirement of groundnut can be met through a number of S-containing materials such as gypsum, elemental S, pyrite and phosphogypsum. Plant takes up S mainly as into SO_4^2 and the sources of S added to soil are subjected to microbial transformation by *Thiobacillus* sp. into SO_4^{2-} before it is taken up by the plants. Generally application of 30-40 kg S ha^{-1} to groundnut was found beneficial and yield response are observed up to 60 kg S ha^{-1} due to S deficient conditions prevailing in most part of the country, however, 20 kg of S ha^{-1} is sufficient to meet the nutrient requirement of groundnut if applied every year (Sahu et al 1991; Singh 1999b; Singh and Chaudhari, 1995; Singh and Chaudhari, 1996a). Application of 1 kg of nutrient S produced 12.9 kg more pod and 4.3 kg more oil ha^{-1} in the experimental plot, in the demonstration plots 250 kg ha^{-1} of Gypsum applied in the pegging zone at flowering increased 21 % pod yield (Singh et al., 1991b).

To economise the dose, research was initiated and application of 10 kg S ha^{-1} as basal followed by 3 foliar sprays of 0.5 % aqueous suspension of elemental S at a rate of 500, 500 and 1000 l/ha at 30, 50 and 70 DAE was found best which produced 11-30 % more pod (Singh et al., 1995 b). The natural deposits of gypsum and pyrites are found in abundance in India and are effective source of S for this crop. Pyrite is reported to be a good and cheap sulphur source for calcareous soil. The combined application of S with micronutrient is useful (Singh et al, 1990). Application of sulphuric acid at 500 ppm S also increased the pod yield in calcareous soil, however, its higher application was not beneficial (Savani et al., 1991). There are reports of increasing oil content due to sulphur application (Tandon, 1991a).

There is interaction of S with P and K where the S has synergistic effect both with K and P on yield and nutrient uptake (Singh and Chaudhari, 1996a).

7.1. 4. Potassium

Requirement and function

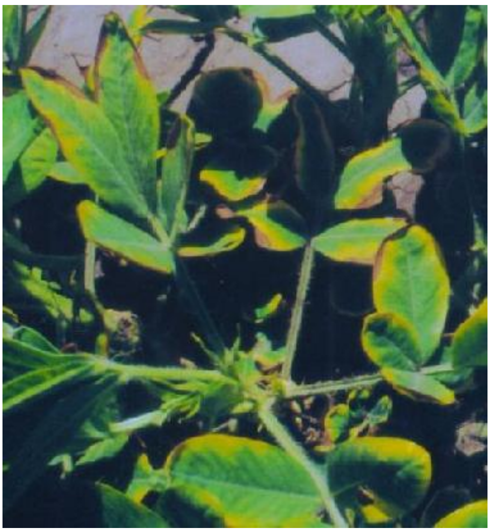
Though potassium is not a constituent of any compound or structurally bound in groundnut, it is required for translocation of assimilates and involved in maintenance of water status of plant especially the turgor pressure of cells and opening and closing of stomata, and increase the availability of metabolic energy for the synthesis of starch and proteins. Besides It increases peg formation, synthesis of sugar and starch and help in pod growth and filling. The nitrate reductase, EDTA-osmoticum, and productivity of groundnut under water deficit conditions were increased due to K application Dwivedi et al (1997). Most of the Indian soils are reported to be rich in K, yet the deficiency occur in Orissa, part of A.P., U.P., Gujarat and Maharashtra. However, the response of K in groundnut s common Throughout India mainly due to very little or no potassium application in the soil inspite of its very high requirement by groundnut and intensive cropping. Moreover, the groundnut vines, which are rich in protein and are used as fodder, remove considerable amount of K from the soil.

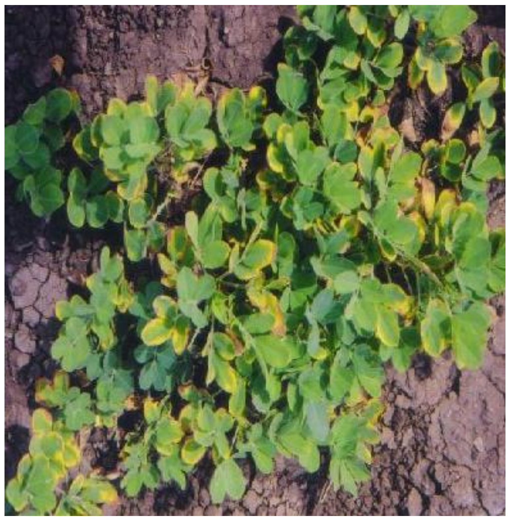
Symptoms and diagnosis

The potassium deficiency in groundnut is more common on the older leaves. The K^+ is highly mobile in both xylem and phloem which enables the plant to regulate their K budget easily. The K deficiency symptoms first appear in the older leaves characteristically developing mottling or chlorosis (Plate 5). The yellowing of leaves starts from the tips or margins of leaves extending towards the center of leaf base. Drying up of leaf margin with hallow yellowed margin and necrotic symptoms and reddish coloration of tip of branches. The stem becomes red accompanied by excess storage of starch and leaves become light green. Some times, there is interveinal chlorosis too.

The groundnut roots are highly efficient in obtaining soil K and hence the optimal soil K levels for high yield and quality vary with soil types. In order to provide insurance, the minimum sufficiency level of K in soil has been fixed 20 ppm by Mitchell and Adams (1993), but soil having less than 150 kg ha^{-1} exchangeable K was deficient in K. The K is luxuriantly absorbed by groundnut at their higher levels and accumulate in leaves, stems and shells, but not in seeds as seed do not require much K unlike N (Singh, 1999a). The adequate K contents in leaves at 45-60 DAE is in between 1.6-3.0 % and the critical level is 1.5 %, but the deficiency occur when the K content goes below 0.5 % (Jones et al., 1991, Singh 1999a). However, Fageria (1974), reported 3.4-3.8 % of K as the adequate and 2.8 % as critical concentration in leaves of a 39 day old plants.

a b.





c. d.

Plate 5. Potassium deficiency symptoms in groundnut, (a) developing characteristically mottling, chlorosis and necrosis in older leaves, (b) yellowing started from the tips and margins of leaves extending towards the center of leaf base, (c) drying up of leaf margin with hallow yellowed margin and necrotic symptoms with reddish coloration of tip of branches, (d) field grown plant showing severe K deficiency.

Increasing the levels of K, increased the concentrations of K, and N in leaves and only K in seeds, stems and shells, but decreased Ca and Mg concentrations in leaves, stems and shells. In fact seed K content were correct diagnostic measure for the sufficiency of K content (Singh, 1999a). At low levels of K, the cations like Ca and Mg were more absorbed by plant to balance the anions, but these were proportionally taken up sufficiency levels of K. The concentrations of N, K, Ca and Mg were 3.27-3.50, 1.84-2.25, 2,5-2.7 and 0.55-0.60 %, respectively in leaves at 60 DAE and 3.88-4.28, 0.78-1.08, 0.44-0.062 and 0.13-0.21 %, respectively in seed at sufficiency level of K.

Control measures

Though the response of K upto 100 kg K_2O ha^{-1} is observed depending upon the agroclimatic situation and groundnut varieties, the recommended doses of K are 25-45 kg K_2O ha^{-1} for rainy season and 40-75 K_2O ha^{-1} for post rainy season irrigated crop. However the large seeded groundnut require more K for better grain filling and SMK. It should be applied as basal in the furrows. Potassium decreased transpiration and increased the stomatal resistance, solar energy harvesting efficiency and energy partitioning in kernel, nodulation, podding, and yield improvement to the extent of 20-70 % (Dwivedi, 1989; Ravichandran et al, 1991; Singh 1999a). Pande et al (1971) reported that 40 kg K ha^{-1} increased the pod yield from 959 to 1276 kg ha^{-1} and oil content from 47.8 to 48.8 %. The shelling percentage, 100 and kernel weight also improved with K application (Singh, 2003).

7.1. 5. Calcium

Requirement and function

Calcium is more important for groundnut and often lack of Ca reduce the yield and quality more than any other element. Calcium maintains the cell integrity and membrane permeability, enhance pollen germination, activates the number of enzymes for cell division and takes part in protein synthesis and carbohydrate transfer. Recently it has been implicated as a second messenger in certain hormonal and environmental responses and regulating enzyme activities. In its physiological effects, Ca is usually regarded as counterpart to K. Calcium influences the stability of structure of protoplast and owing to its dehydration properties, it opposes the plasma-expanding action of K. The calcium requirement is very high especially for gynophore’s development and pod filling. Field work showed that calcium and potassium levels in the fruiting zone affected seed quality (Cox et al, 1982; Zharare et al, 1997). Early ovule abortion was prevented by adequate calcium supply.

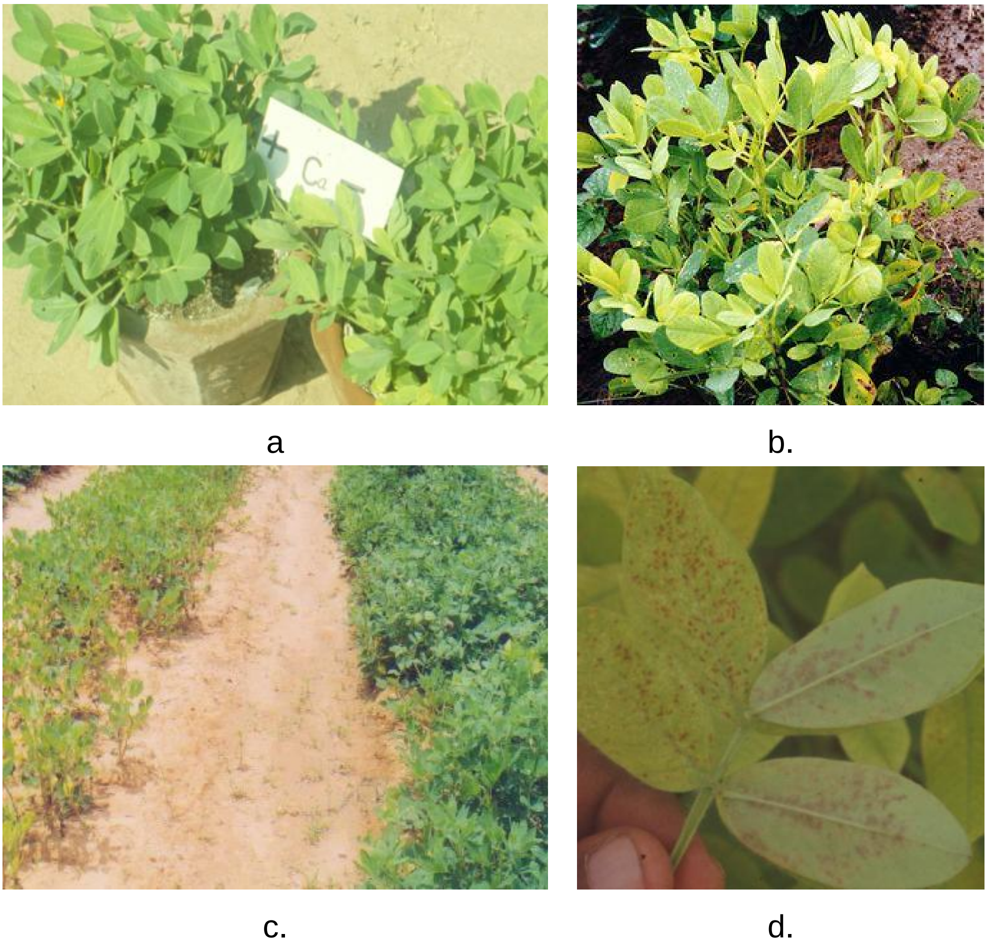
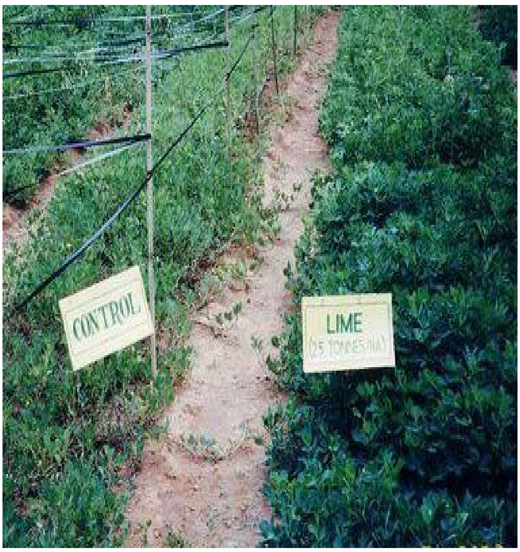


Plate 6. Figures showing Ca deficiency in groundnut (a) pot grown plants with healthy (left) and Ca deficient chlorosis of leaves(right), (b) Ca deficient plant showing severe chlorosis in the acid soil of north-east states, (c) Ca deficient plants with stunted growth and pale to greener grayish-brown tints (crinkle leaf) and dieback of shoot, the lamina drying out and tears beginning at the tips and margins in fresh leaves, (d) leaf showing localized pitted area a typical symptoms of Ca deficiency.

a

b.



c.

d.

Plate 7. Figures showing Ca response to groundnut in highly leached acid soils of, Tripura in northeast, (a) a luxuriant lust green crop with lime, (b) poor crop without lime showing yellowing in first plot and better crop with lime in second plot, (c) screening groundnut genotypes with and without lime in acid soil for Ca-efficiency and tolerance of soil acidity and Al-toxicity, (d) pod bearing in groundnut plant grown with (left) and without (right) lime in acid soil.

It is taken up by plant as a divalent cation (Ca^{2+}), which is abundant in soil and rarely deficient under natural conditions. However, its availability from soil to plant is affected by the concentration of availanble Ca^{2+}, the pH of the soil, the cation exchange capacity (CEC) of the soil and plants and Ca^{2+} saturation of the soil colloids. The acid soils, because of their low base saturation due to leaching of bases owing high rainfall, are deficient in Ca and require liming. About one third of Indian soils are acidic, still the calcium is least researched in India (Singh, 2000a). Because of non fertilization with Ca-fertilizer, about two third of the groundnut in India mainly in Andhra Pradesh, Bihar, Chhatishgarh, Jharkhand, Kerala, Punjab, MP, Orissa, U.P., Tamil Nadu. and West Bengal, suffer from hidden Ca-deficiency resulting in poor pod filling and yield.

Symptoms and diagnosis

Since calcium play a major role in cell division its deficiency appear in meristematic and growing region of plants. Moreover once it is absorbed, Ca is not mobilized from the older leaves, hence its deficiency occurs on the fresh and emerging leaves (Plates 6 and 7). However, under field condition, the visual deficiency of Ca in plant is rarely observed except in extreme condition of acidic soil having pH less than 5.5. The Ca deficiency in leaf is characterized by development of localized pitted area on lower surface of leaves which later on converts into large necrotic spots. Leaves becomes cupped shape, distorted and hook like near the leaf tip, the lamina dries out and tears beginning at the tips and margines, with pale to white-greener grayish-brown tints (crinkle leaf) cracking of basal stem and dieback of shoot at later stage of growth. Severe Ca deficiency results in the death of root tips and terminal buds.

The calcium ion (Ca^{2+}) is transported exclusively in xylem tissue upward with transpiration stream but its downward movement from the leaves through phloem is practically nil (Mengel and Kirkby, 1987). As soon as peg penetrate soil it ceases to transfer root absorbed water and hence looses access to root absorbed Ca, thus developing fruit absorbed phloem-immobile Ca^{2+} directly from the soil since the groundnut fruit develop underground. The inadequate supply of Ca results in pods without seeds called "Pops" or blackened plumule inside the seed known as "Black heart" (Cox and Reid, 1964).

The adequate concentration of Ca in leaves is in between 1.2-2.0 % (Jones et al., 1991, Singh 1999a) at 50-70 DAE and the tissue concentration less than 1.2 % is considered low, but plant show the deficiency symptoms at less than 0.7 % Ca (Singh, 1999a). However, as this calcium is immobilized in the leaves, the Ca content of leaf do not serve the reference for groundnut, but the Ca content of seed do serve as seed is the final sink. At proper nutrition, the healthy groundnut seed contained 0.045-0.12 % Ca, however the critical concentration of Ca in seed needed for maximum germination and survival was 400 ppm for large seeded groundnut and 300 ppm for small seeded groundnut (Singh (1999a). The leaflet Ca for maximum fruit yield is 1.8 % in 12 week old plant and the minimum Ca content in seed needed for maximum germination and survival are 368-445 ppm (Adams et al., 1993). The critical level in term of Ca/total cation molar activity ratio is 0.25 for maximum pod fill. The accumulation of Ca in pod is positively correlated with the pod surface area, days to maturity, and negatively correlated with the pod thickness.

The critical levels of soil Ca is about 250 ppm (1.25 meq/100 g or 560 kg ha^{-1}) in root zone and 600 ppm (3 meq /100 g) in pod zone, however the soil Ca

concentration of more than 2 meq/100 g in root zone and more than 4 meq/100 g in pod zone was found to be an ideal for groundnut. Accordingly the soil has to be fertilized with Ca sources. The Ca has antagonistic effect with excess K in the soil and vice-versa. Increasing the levels of Ca increased the concentration of Ca and N, but decreased K and Mg concentrations in leaves and seeds.

Control measures

In general, the calcium requirement is greater for pod filling than flowering, and it is greater for flowering than vegetative growth. The high calcium is required in the 5-10 cm of soil. The runner genotypes disperse their pods more than bunch genotypes typically providing double the soil volume available for calcium exploitation by pods. Higher levels of soil Ca is needed to produce seed of maximum quality than are needed for maximum yields and SMK. The shelling percentage and oil yield of groundnut increased with application of Ca.

The lime-stones, dolomites, gypsum, phosphogypsum calcium ammonium nitrates and Ca-rich waste product are useful which are mainly applied as basal at a rate of 1 t ha^{-1}. Shallow incorporation of 1000 kg ha^{-1} lime-stones (90% $CaCO_3$) in the furrows before planting or topdressing of 1000 kg ha^{-1} gypsum increases the availability of Ca in the pegging zone producing maximum yield. Some times, lime (CaCO3) is better than gypsum as the gypsum is leached below pegging zone due to heavy rain, but $CaCO_3$ remains in place. The lime has to be added in a manner to ensure that fine lime in the pegging zone (in the top 9 cm of soil) during fruit development. The soluble Ca sources, which are top-dressed, are gypsum and anhydrite $CaSO_4$ which has to be applied in the pegging zone. Maintenance of 75 % Ca saturation in soil cause steep gradient of Ca concentration between pod and soil which result in increase in the availability of Ca, Mg and S and to pod and thus increased groundnut yield (Ramachandrappa and Kulkarni, 1992). Depending upon the Ca level of soil lime and gypsum application from 500-1000 kg ha^{-1} is sufficient to meet the requirement of groundnut for good pod filling in most of the soils in India. However in eastern and north-eastern states of India, invariably the recommended doses of lime or gypsum is 2-2.5 t ha^{-1} or higher depending upon the soil acidity and lime requirement. Calcium oxide is also an effective source of Ca (Ramachandrappa and Kulkarni, 1992). As there is genotypic differences in Ca uptake from soil, efforts were made to search for Ca-efficient groundnut genotypes performing well under low as well as high soil Ca level .

Ca-efficient:	ICGHNG 88448, and NRCG Acc. 7085-1, 6155,
Ca-inefficient:	BAU 13, TG 26, NRCG 7472 and 162

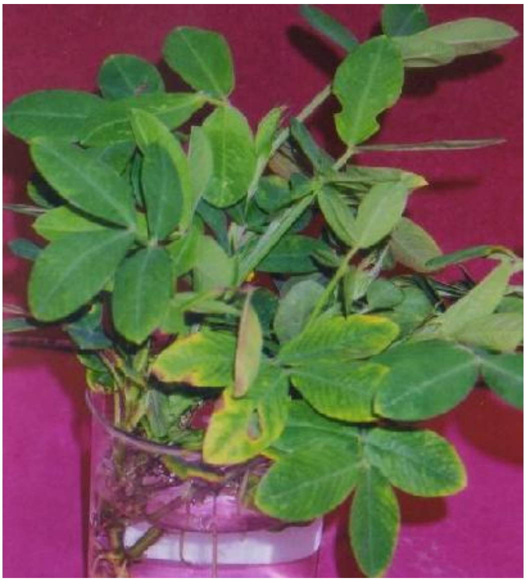
Cultivation of groundnut in set-furrows is a common practice in Saurashtra region of Gujarat where groundnut is being grown in same rows for the past 40-50 years. In this system, the FYM, fertilizers and ties (Calcium rich Murrhum) are applied in the furrows making it more fertile and airy compared with remaining soils. Silt or sand and cement are also mixed in furrows, for growing groundnut, during the field preparation to alter the soil physical condition to be suited for groundnut crop and Ca availability in the pegging zone. Mixing FYM in furrows is a common practice to improve fertility status of soil.

Excess of Ca content will produce a deficiency of either Mg or K. The excess calcium in the form of calcium carbonate increases the alkalinity and decreases the availability of Mn, Fe, Zn, Cu, B and P. Lime-induced iron-chlorosis is the major problem of calcareous soil (Hartzook, 1975; Singh and Joshi, 1997).

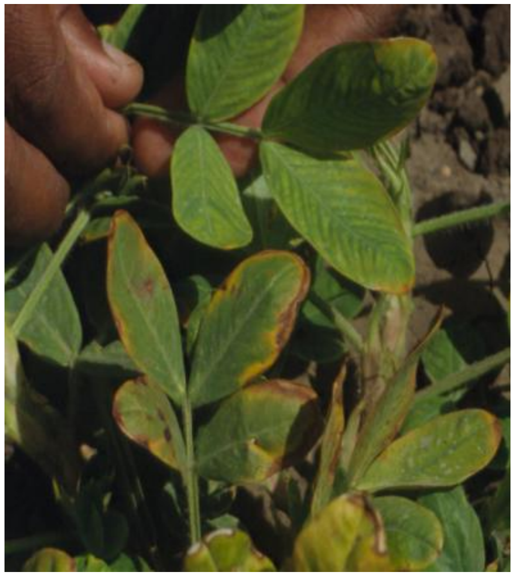
7.1. 6. Magnesium

Requirement and function

Magnesium is present in chlorophyll, as a bridge between pyrophosphate structures of ATP or ADP and the enzymes molecules and it serves as a cofactor in most of the enzymes activating phosphorylation. The deficiency of magnesium is also a problem of sandy and strongly acid soils as under high rainfall, the Mg is leached out more easily in these soils. In India, the Mg is deficient in acid soils particularly of Karnataka, Tamil Nadu, part of A.P. and eastern and north eastern regions. Magnesium is present as carbonate in the form of dolomite ((CaMg) CO_3) and magnesite in calcareous soils. It is taken up by plant as the divalent cation (Mg^{2+}) from the soil. A magnesium ion resembles Ca in its behavior on ion exchange and as an exchangeable ion, Mg is second in abundance to calcium. But with increase of pH in alkaline soils the Mg becomes non-exchangeable. Magnesium also influences the phytohormone balance and nitrate reduction. Like K the groundnuts are very efficient in extracting Mg from the soil, hence it rarely shows deficiency symptoms.



a



b.

c.

d.

Plate 8. Magnesium deficiency symptoms in groundnut, (a) plant with interveinal chlorosis in basal leaves, the most pronounced Mg symptom, (b) interveinal chlorosis and orange, purple and bright yellow blotches, (c) the entire plant is affected and both old and young leaves are showing irregular chlorosis motteling, marbling and with yellow blotches, (d) Intercostal chlorosis and bright yellow blotches is the typical Mg deficiency.

Symptoms and diagnosis

Due to breakdown of chlorophyll in the region that lies between the veins, the interveinal chlorosis is the most pronounced symptom in Mg deficient plant. The chloroplasts in the vein are less susceptible to Mg-deficiency and retain their chlorophyll much longer. As Mg is mobile the basal leaves are first affected and the deficiency starts from leaf margin and advances towards midrib and under extreme stress the young leaves are also affected. Intercostals chlorotic lesion or blotches is the typical Mg deficiency, which are usually bright yellow, sometimes brown, orange and purple (Plate 8).

The Mg deficiency is conducive to the occurrence of tikka disease. The concentration of Mg in leaves depends upon the crop genotype age and position of leaf. The adequate concentration of Mg in leaves at 50-70DAE is 0.30-0.80 % and the critical levels is 0.25 % for Spanish and Valencia cultivars and 0.20 % in Virginia runner cultivars (Singh 1999a; Walker et al, 1989). Depending upon the crop requirement and intensity of cropping the soil analysis is useful for diagnosing Mg deficiency of groundnut. The critical level of Mg in top soil is 11 ppm of extractable Mg, however sufficiency level is above 15 ppm.

Control measures

Though high amount of Mg is required by groundnut, there are hardly reports available on the response of Mg fertilization in groundnut in India and only a few in the world. This is mainly because of lesser occurrence of Mg deficiency symptoms and unawareness of use of Mg for increasing yield. However, in a recent study, though the clearcut Mg deficiency was not observed, the hunger sign of Mg deficiency caused upto 25 % yield losses of groundnut which suggest its fertilization (Singh 1999a). In Mg-deficient soils, particularly of acid soils of NE states eastern region and Karnataka, application of 20 kg $MgSO_4$ ha^{-1} is helpful in alleviating the deficiency, preventing occurrence of tikka diasease and finally offsetting yield losses. In the other areas, where groundnut is grown year after year, application of 20 kg $MgSO_4$ ha^{-1} at least once in two year take care of the requirement.

7. 2. Micronutrients

7. 2. 1. Iron

Requirement and function

Iron is the fourth most abundant element in the earth crust and soil, still its deficiency is most widespread in the world mainly due to its availability in root zone rather than abundance. Iron is a component of cytochrome oxidase, ferredoxin protein, and several enzyme systems and precursor of chlorophyll. It is involved in nitrate and sulphate reductase nitrogen assimilation and energy (NADP) production. Among all micronutrients, iron deficiency is most commonly observed in groundnut and it is most severe on calcareous and alkaline soils. Due to its high Ca requirement by pods, the groundnut is preferably grown on calcareous soil, where it suffer from lime-induced iron-deficiency chlorosis. About one third of the world soils are calcareous (Vose, 1982). India has about 33 m ha of calcareous land, most of which is spread in Gujarat, Maharashtra, Karnataka, Rajasthan, Bihar, Tamil Nadu and Punjab and a portion of these land is used for groundnut where iron-deficiency causes 16-40 % yield losses. Besides that, In India, approximately 7% population is facing Fe-Deficiency; B and Zn deficiencies are also reported and groundnut being a very good source of micronutrients, has to play a major role in combating these deficiencies.

The major factors enhancing iron-deficiency, in groundnut, are high free $CaCO_3$, HCO_3^-, moisture, heavy metals, pH and available P, poor aeration, heavy manuring and low organic matter content in acid soils and root damage. In groundnut, the Fe-deficiency appear 10-15 days after emergence in the field and remains throughout the cropping season, but its maximum intensity was observed in between 30-70 DAE (Singh and chaudhari, 1991, 1993). There is also self recovery of chlorosis as leaves becomes older, but the newly emerging leaves further show chlorosis (Singh 1994a).

Symptoms and diagnosis

In groundnut, the Fe-deficiency first appears as chlorosis of young rapidly expanding leaves which is characterised by interveinal chlorosis and later under severe deficiency, the veins also become chlorotic and leaves become white papery (Singh et al., 1991a, b) (Plates 9 and 10). These areas later become brown and necrotic. The acute deficiency leads to dying of plant in the field and crop failure. The Fe deficient plant showed lesser peroxidase activity in their leaves, stems and roots, and the root peroxidase activity was identified as an indicator of iron deficiency (Singh and Chaudhari, 1992). The Fe deficiency also limits nodule development in groundnut in

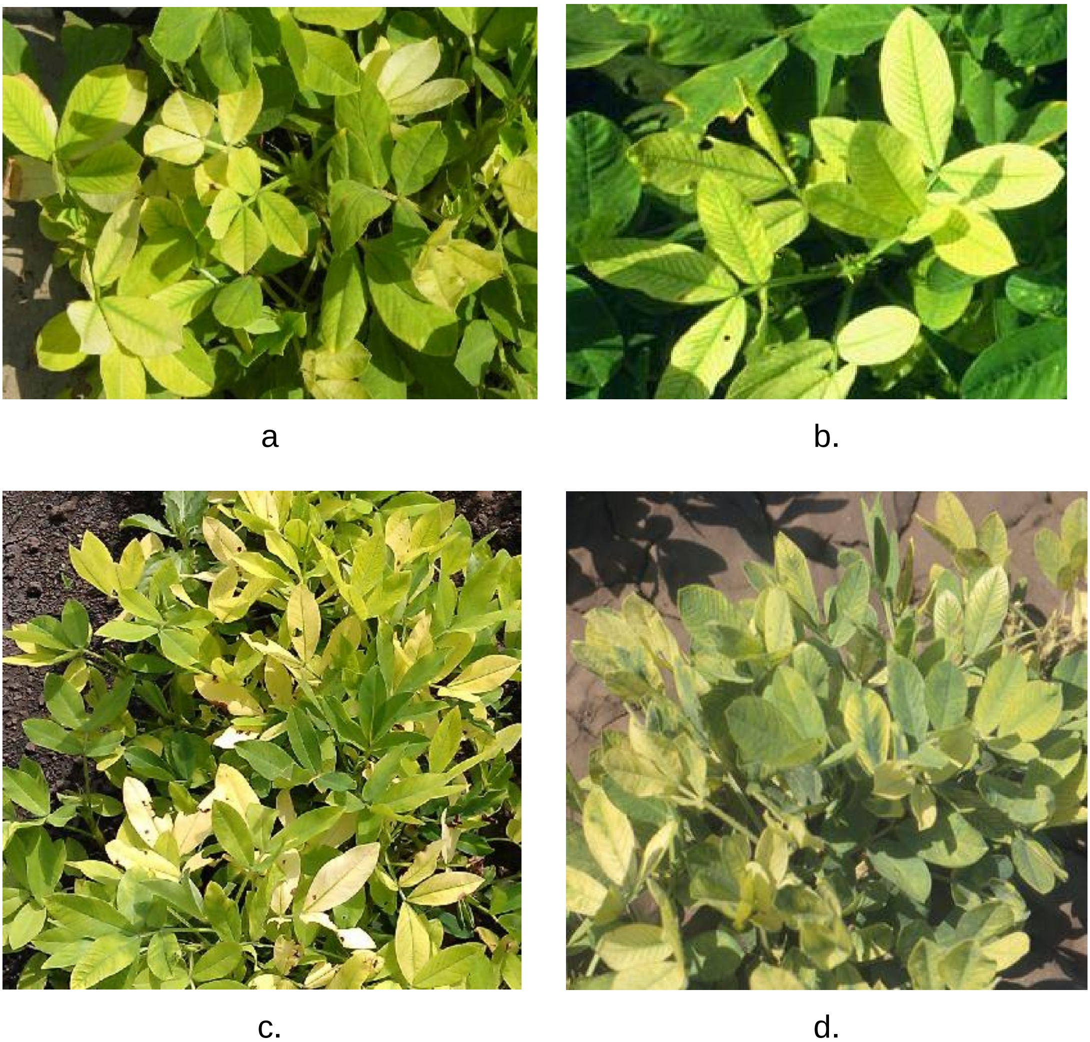


Plate 9. Fe-deficiency symptoms in groundnut, (a) interveinal chlorosis of young rapidly expanding leaves, (b) under severity conditions veins have also became chlorotic (c), sever iron-chlorosis with chlorotic white papery leaves, brown and necrotic spots on chlorotic leaves causin death of plant, (d) regreening and recovery of iron-chlorosis of leaves by foliar application of iron-sulphate.

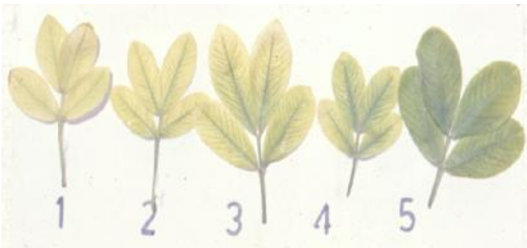
calcareous soil resulting in the N deficiency. The sufficiency level of Fe in groundnut leaves is 50-300 ppm and the critical limit is 40 ppm, but Fe-deficiency in groundnut is visible when tissue concentration falls below 30 ppm in leaves (Singh, 1994 b). However, the total iron content of leaves some times may not show differences between the chlorotic and green plant. In that case determination of active iron (Ferrous iron) is taken as criterion where the chlorotic plants showed less than 12 ppm active Fe (Singh, 1994b).

The soil containing less than 5 ppm DTPA extractable Fe showed Fe deficiency in groundnut, however in calcareous soil other factors are more important which decreases the availability of Fe (Singh, 1994 b). On an average the green and chlorotic plant showed 7.15 and 2.02 mg chl g^{-1} dry wt. of leaves, which produced 8.6 and 5.4 g pod and 15.5 and 11.3 g fodder, $plant^{-1}$ (Singh et al., 1987). To get rid of iron-chlorosis, the peroxidase activity (Δ O D g^{-1} s^{-1}) in leaves, stems and roots of groundnut should be higher than 0.15, 0.3, and 0.6, respectively, and NR activity in young expanded leaves above 8 μ mol NO2 g^{-1} fr. wt h^{-1} and the genotypes showing lower activities showed iron chlorosis.

Control measures

Efforts are being made, at global level, to find out the remedies of lime-induced Iron-chlorosis (LIIC), through soil and foliar application of iron containing fertilizers and also though selection of Fe-efficient groundnut varieties. However, there are only a few laboratories taking field experiments on the iron nutrition of groundnut in calcareous soil (Papastylianou, 1990; Singh et al, 1990). For the prevention of Fe-deficiency chlorosis to occur, the soil amelioration of iron sulphate, gypsum, phosphogypsum, elemental sulphur and pyrite at a rate of 20 kg Fe ha^{-1} are recommended which could recover the chlorosis of groundnut, increased chlorophyll, pod yield and Fe uptake by groundnut. However, the recovery was best achieved with iron sulphate and pyrite. Agricultural grade pyrite is a cheap source of Fe and S and which are present as reserves at Amjhore, Bihar in plenty and is being marketed by Pyrites, Phosphates and Chemicals LTD. Further pyrite and elemental S are most effective when applied to soil half as a basal and remainder in two equal doses at 25 and 50 DAE. The chelated Fe such as FeEDDHA (ethylene diamine di -(O-hydroxy phenyl acetate) are very effective as soil application at a rate of 5-10 kg Fe ha^{-1} in controlling the iron deficiency in calcareous soil, but costly and not available in India. The Fe containing ferilizer is most effective if applied as drip along with water.

For recovering the groundnut plant from Fe-deficiency in the standing crop the Fe sources such as FeEDTA, FeSO4, iron sulphate + citric acid, and iron citrate were effective when applied as aqueous solution containing 0.1% Fe. The best control was achieved by spray of 0.5% FeSO4 + 0.02% citric acid at a rate of 500, 500 and 1000 l/ha at 30, 50 and 70 DAS which also increased pod yield 16-24% in groundnut (Singh and Dayal, 1992; Singh and Joshi,1997).



a

b.

c.

d.

Plate 10. (a) Various stages of Fe-deficiency in groundnut, (b) severe Fe-deficiency showing interveinal chlorosis to complete chlorotic white papery leaves, (c) application of iron-sulphate through drip irrigation recover the iron deficiency in calcareous soil, (d) Plant showing deficiencies of Fe, Mn and S simultaneously.

Table 7. Groundnut genotypes showing their reaction (tolerance) of iron-chlorosis in calcareous soil.

Groundnut genotypes	Category of tolerance of iron-chlorosis		
	Tolerant	Moderately tolerant	Susceptible
Released cultivars of India	GG 2, JL 24, TG 17, VRI 2, TAG 24, TG 26, M 13, ICGV 86031, ICGV 86522, ICGV 86590, SG 84, GAUG 10, GG 11, MH 2, MH 4, Punjab 1, CSMG 84-1, CSMG 9101, ICGS (FDRS)10	Somnath, TG 1, M 37, M 335 Chandra, G 201, UF 70-103, CSMG 884, MA 10, MA 16, Jyoti, Jawan, TMV 7, ICGS 76, J(E) 2, ICGV 86008, DH 8, Kopergaon 1, Tifspan, S 206, DH-3-30, GG 4, GG 5, GG 6, K 134	VRI 3, ICGS 11, ICGS 44, ICGS 65, Chico, Robut 33-1, GAUG 1, Kadiri 2, TG 3, Co 1, Latur 33, ICGV 87276,
Advanced breeding lines	PKVG 8, Akola Sel., I_1, PBS 70, 89, 189, PBDR 41, 4-9-1, 7-6-13 B, 7-6-26	CGC 3, NDN 19, PBS 13, 145, 90, 91, PBDR 39, 7-6-17	AK NRCG 1, I2 PBDR 13, 36, 2-21
Germplasm accessions	NRCGs 389, 1114, 1308, 2588, 3498, 4255, 5389, 5513, 6450, 6820, 6919, 7027, 7085, 7258, 7267, 7347, 7417, 7607, 7599,	NRCGs 4015, 5118, 7110, 4659	NRCGs 7472, 162, NCAc 17090

As there is a strong association between iron-efficiency and productivity, and the genotypic variation exist, selection of iron-efficient tolerate genotypes which does not show any deficiency symptoms in early generations is most viable solution to this malady. A number of groundnut genotypes consisting of released varieties, advanced breeding lines and germplasm accessions were screened for their tolerance of iron chlorosis and the tolerant, moderately tolerant and highly susceptible genotypes are listed in Table 7. The induced chlorosis was partially corrected by inoculation with *Bradyrhizobium* and *Pseudomonas* which improve iron nutrition by synthesis of chelates (siderophores) that keep iron in soluble form and correct iron chlorosis of groundnut in calcareous soil (Jurkevitch et al., 1988; O Hara et al., 1988).

The soil application upto 500 ppm of Fe did not show any toxic symptoms in groundnut leaves (Singh, 1994b). Iron may accumulate to several hundred ppm without any toxicity symptoms. Toxicity of Fe produces a bronzing of the leaves with tiny brown spots which some times occur in the acid soils (Plate 18c).

7. 2. 2. Manganese

Requirement and function

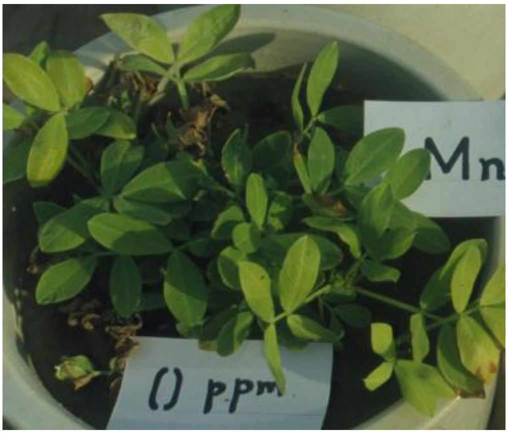
The manganese impart oxidation reduction process, photosynthesis, oxygen evolution, activates IAA oxidase and acts as a bridge for ATP and enzyme complex phosphokinase and phosphotransferases. Several enzymes activated by Mn and Mg can also function instead, but, the photosynthesis and regulation of IAA are the highly Mn specific activity. Without Mn plant accumulates H_2O_2 causing cell damage. The Indian soils are rich in Mn, yet the deficiency is common in Punjab, Tamil Nadu, M.P. and Karnataka and Gujarat. The Mn deficiency is a problem of high pH soil and the Mn content are inversely related to Ca and Mg levels. However, in groundnut the Mn deficiency is also reported on soil pH as low as 5.8. The calcareous soils are Mn deficient owing to immobilization as insoluble MnO_2 at high pH, however majority of groundnut is grown on calcareous soil wher Mn deficiency is bound to occur causing 8-17 % yield losses (Singh, 2001).

Symptoms and diagnosis

In groundnut, the Mn deficiency appears as interveinal chlorosis of younger leaves and continues on older leaves producing bold pattern of dark green major veins (Plate 11). Appearance of varied but characteristic necrotic spotting or lesions on the leaf margins distinguish the Mn deficiency from iron-deficiency. The reticulate or mosaic like interveinal and intercostal chlorosis with mottling and marbling; green margin along the main veins form a Christmas tree pattern on moderately old leaves; mottled area get necrotic with red-brown interveinal lesions. The critical Mn concentration in soil for growth is in between 3-5 ppm (Singh, 1994b). The sufficiency level of Mn in leaf is 50 to 350 ppm at 50-70 DAE and concentration below 50 ppm is considered low. However the deficiency occurs when the leaf Mn concentration dropped below 20 ppm (Singh, 1994b).

Control measures

The Mn deficiency could be alleviated with soil application of 2-4 kg Mn ha^{-1} through any one of the Mn sources such as $MnSO_4$, MnO_2, $MnCO_3$, or $MnCl_2$ along with fertilizer. Foliar application of 0.2 % $MnSO_4$ at 30, 50 and 70 DAS at a rate of 500 l ha^{-1} recover the Mn deficiency in standing crop and increased pod yield (Singh, 1994 b; Singh et al., 1993a). The responses of various micronutrients including Mn are given in table 8. The ferilizer Mn is also effective if applied as drip along with water.



a

b.

c.

d.

Plate 11. Manganese deficiency in groundnut, (a) severe Mn deficiency in young developing leaves, (b) interveinal and intercostal chlorosis of younger leaves with characteristic necrotic spotting or lesions on the leaf margins distinguish the Mn-deficiency from iron-deficiency, (c) reticulate or mosaic like interveinal and intercostal chlorosis with mottling and marbling; green margin along the main veins form a christmas tree pattern on moderately old leaves, (d) the severely affected young leaves show brown necrotic spotting or lesions on the leaf margins.

In acid soil at low pH, the availability of Mn increases to a toxic level. Though the groundnut is relatively tolerant to Mn toxicity, at about 200 ppm of DTPA extractable soil Mn the Mn-toxicity is observed (Singh 1994b). The excess of Mn causes interveinal chlorosis, the Fe deficiency in lower (3rd to 4th) leaves with brown spots or pink colour on the lamina in between the veins (Plate 12c and d). The chlorosis starts from the leaf base and moves towards the margin and tips. There is a dark brown marginal leaf spotting. Necrotic pattern on leaves is observed if the Mn concentration in leaves reaches 4000 ppm.

Table 8. Influence of micronutrient on the dry matter production and nodulation at 45 DAE and pod, haulm, and oil yields of groundnut at harvest (Singh and chaudhari, 1996b).

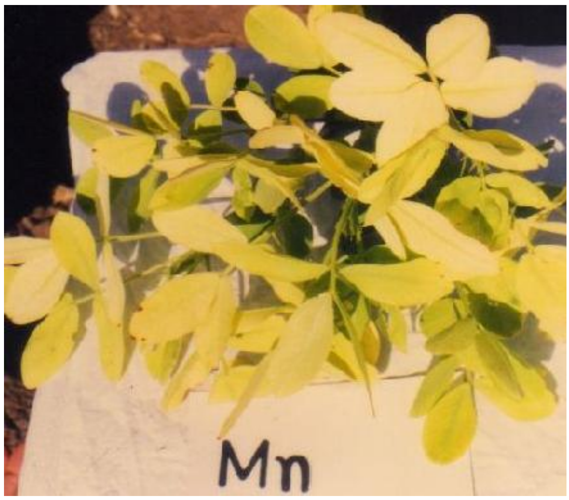
Treatments	At 45 DAE		At harvest			
				Yield (kg ha^{-1})		
	Dry matter ($g\ m^{-2}$)	Nodule wt ($g\ m^{-2}$)	Plant height (cm)	Pod	Haulm	Oil
Control			63	1040	1779	352
Fe	435	3.92	74	1243	2100	422
Zn	419	3.80	73	1179	1997	400
Mn	423	3.88	72	1164	1990	395
L.S.D. (0.05)	32	0.31	2.9	35	116	42

7. 2. 3. Zinc

Requirement and Function

The Zinc is a much worked micronutrient in India, since 60's. Carbonic anhydrase is a very specific enzyme activated by Zn, besides it is involved in many enzyme systems. The problem of Zn is also much more of its availability rather than abundance. About 50% of the soils in India showed Zn deficiency (Takkar et al., 1989). The Zinc deficiencies in groundnut are found in almost all states but are of more common in Haryana, M.P., U.P., A.P., Bihar, Punjab, Tamil Nadu and in calcareous and alkaline soils that are low in organic carbon, high available P and bulk density and low soil temperature. In calcareous soil, the Zn deficiency causes 15-20%, yield losses (Singh, 2001).

a   b.



c.   d.

Plate 12. (a) Toxicity of Cu causes chlorosis and bleaching of leaf colour, wavy leaf margin, rolling of leaves owing to loss of turgor in young leaves, (b) severe toxicity of Cu caused complete chlorosis and bleaching showing white papery appearance and dying of plant from the top, (c) Toxicity of Mn causing interveinal chlorosis with pale yellow and white appearance of young leaves which under. (d) severe Mn toxicity f caused complete chlorosis and bleaching.

Symptoms and diagnosis

In groundnut, the Zn deficiency occurs mainly in the upper leaves showing irregular mottling with yellow-ivory interveinal chlorosis (Plate 13). Reduction in size of young leaves which are some times clustered or borne very closely. Young leaves with broad yellow or white bands between the margins and mid vein in lower half of leaf. Under severe deficiency, the entire leaflets become chlorotic. Faint chlorosis of the lower leaves between the vein, leaf margin and tips are also observed. The Zn deficiency can be separated from Fe with its wider strip, which may not run entire length of the leaflets. Under high temperature, the leaf bronzing with occasional small necrotic spots are also observed.

The sufficiency range of Zn in leaf during flowering and fruiting (40-70 DAE) is 25-60 ppm and Leaf tissue less than 20 ppm showed its deficiency (Dwivedi, 1986; Singh, 1994 b). The critical levels of zinc in the soil are in between 0.5-0.7 ppm DTPA extractable zinc (Singh, 1994b, 1999a). However, Takkar et al. (1975) reported that the DTPA extractable zinc below 1.2 ppm reduced groundnut yield.

Control measures

To offset the yield losses, the deficiency of zinc can easily be corrected by adding inorganic sources and zinc containing fertilizers such as $ZnSO_4$, ZnO, but ZnSO4 is superior. Application of 2-4 kg Zn ha^{-1} as $ZnSO_4$ in soil is most common. In the standing crop, foliar application of 0.2% zinc sulphate could recover the zinc deficiency of groundnut (Singh, et al 1993). The field response of micronutrients including Zn in calcareous soil are mentioned in Table 8. Also the Zn deficiency could be corrected with the use of zincated SSP which is very useful (Singh and Chaudhari 1996b). Maximum response of groundnut to Zn application was reported in A P followed by Bihar (Takkar et al 1989). The application Zn containing fertilizers through drip irrigation was more beneficial than its soil application.

Groundnut is more susceptible to zinc toxicity than other crops. Excess of zinc cause golden yellow colouration of the leaf margin which proceed towards the center. The zinc toxicity cause early senescence of leaves and stunted growth (Plate 16d). At the available levels of Zn more than 20 ppm in the soil and 200 ppm in the leaves and plant tissue, the Zn showed toxic effects (Singh (1994b). However leaf Zn was affected more by soil pH than by soil Zn as an increase in soil Zn from 1.0 to 10 ppm increased leaf Zn 202 ppm at soil pH 4.6 and only 9 ppm at pH 6.6 (Parker et al., 1990). In Georgia, USA the Ca:Zn ratio of 50 or less showed Zn toxicity in groundnut rather than high concentration of leaf Zn per se (Parker et al., 1990).

a

b.

c.

d.

Plate 13. Zinc deficiency in groundnut, (a) plants with sever Zn deficiency as interveinal to complete chlorosis in young developing leaves with bronzing and necrosis, (b) the chlorotic young leaves showing purple pigmentation and irregular mottling, (c) upper leaves showing chlorosis yellow-ivory chlorosis and pigmentation on the lower surface of leaves, (d) the Zn deficient leaves show pale yellow color (left) and differentiated from P deficiency (right) green leaves, both showing pigmentation.

7. 2. 4. Copper

Requirement and function

The copper participate in protein and carbohydrate metabolism and nitrogen fixation and is a constituent of chloroplast protein, plastocyanin, and part of many enzymes such as cytochrome oxidase, ascorbic acid oxidase and polyphenol oxidase. Copper is also involved in the de-saturation and hydroxylation of fatty acids. The copper deficiency is a major problem of organic and acid soils and occur in UP, Gujarat, Kerala, Punjab and Tamil Nadu. In calcareous soil the Cu deficiency causes 13-15 %, yield losses (Singh, 2001).

Symptoms and diagnosis

In the copper deficient groundnut plant, the young leaves are curled (Plate 14). The entire leaf becomes cupped and leaflet margins turn upwards. The plant become stunted, rosettes, interveinal crinkling and marginal wilting occur due to weakness of cell wall, but not due to water stress. Irregular leaflets with marginal necrosis, mild chlorosis and small yellow-white spots on the foliage. Bronzing and necrosis of the outer edges of the leaflet occur if deficiency is prolonged. Copper deficiency also reduces root growth more than shoot growth creating an unfavorable shoot : root ratio. The pigments in flower decreases.

The sufficiency level of Cu in the leaf during flowering and fruiting (40-70 DAE) is 5-20 ppm and the groundnut shows deficiency when the tissue concentration falls below 5 ppm (Singh, 1994 b). The critical concentration of Cu in soil is 0.2 ppm. The activity of ascorbic acid oxidase was reduced in Cu-deficient plants (Singh and Chaudhary, 1992).

Control measures

Copper is rarely applied as nutrient to the crop, but as fungicide it is commonly applied. Application of 2 kg Cu ha^{-1} as CuSO4, CuS and bordeaux mixture in the soil alongwith fertilizer alleviate Cu deficiency, but it is recommended to apply 2-6 kg Cu ha^{-1} as CuSO4 in the soil having less than 0.2 ppm DTPA extractable Cu once in a 3 to 4 years. The chelates of Cu are also effective both as soil and also as foliar spray. The recent results of the field experiments conducted in calcareous soil have shown that application of CuSO4, as seed dressing was more beneficial and increased the pod yield, shelling percent and 100 seed weight, however as soil applications in furrows copper chloride and copper acetate were promising (Singh, 2002). If the deficiency is noticed in the field foliar spray of 0.1% copper sulphate effectively controls Cu deficiency of groundnut (Singh et al., 1993 a). In Tamil Nadu copper application increased 22.9 % oil yield and 6.7 % pod yield.

a

b.

c.

d.

Plate 14. Groundnut leaves showing, (a) copper deficiency as mild chlorosis with yellowing of main vein in upper leaves margin of leaflet turning upward, bronzing and necrosis of the outer edges is also seen, (b) Irregular leaflets with marginal necrosis and small yellow-white spots on the young leaves, a typical Cu deficiency, (c) leaves showing deficiency of K (first from left), Zn (2nd from left) S (3rd from left) and Fe (4th), (d) groundnut plant showing deficiencies of N, K, P and Mg together.

Excess of Cu cause Fe deficiency as interveinal chlorosis, inhibit root growth, leaf margin become wavy in structure, smaller leaves, rolling of leaves owing to loss of turgor (Plate 12a and b). Sometimes leaves are completely bleached showing white papery appearance.

7. 2. 5. Boron

Requirement and function

In groundnut, boron facilitate translocation of sugar and fat synthesis and is important for RNA (uracil) synthesis, cell division, differentiation, maturation and pollen germination. The B is transported primarily in xylem and is relatively immobile in phloem. The B deficiency is reported to occur in neutral to alkaline and highly weathered soils. The factors influencing B deficiency are soil low B, organics in soil, low humic gley, moderate to heavy rainfall, dry weather and light intensity. The B deficiency in groundnut is more common in Tamil Nadu, and Karnataka, India. However, the response of B is also reported in Gujarat, Maharashtra, Punjab, Rajasthan and Bihar. In calcareous soils, the B deficiency causes 16-26 %, yield losses (Singh, 2001). Thailand is a hot spot for B deficiency where `hollow heart' of groundnut is more common.

Deficiency symptoms, and diagnosis

The B deficient groundnut plant shows retarded growth of the apical portion. As the B is immobile and deficiency occur on the growing points, death of the stem apex, and regeneration from the lateral bud, malformation of the leaf vein, chlorosis, necrosis of basal margins in emerging leaves are commonly observed (Plate 15). The B deficiencies are similar to Ca except that in B the necrotic areas are localized near leaf margins but in Ca they are distributed over the entire surface. The internodes are shortened and margin of leaflets develop light brown colour bushy or rosette appearance of the plant. The young leaflets some times appears as rudimentary with purple red, orange yellow or blue green tinting. Roots become blackened and growth of root nodules is suppressed. The deficiency of B causes low pod filling and hollow darkening or off-colour area develop in the center of the seed known as `hollow heart' of groundnut reducing the quality of seed.

The B deficiency occurred when the hot water soluble B of the soil is less than 0.2 ppm, however, depending upon the soil the critical limits of B may vary from 0.2-0.4 ppm (Singh, 1994b). The sufficiency level of B in the leaf during flowering and fruiting (40-70 DAE) is 25-60 ppm and the critical level is 20ppm. The groundnut kernels containing less than 17 ppm B showed the incidence of hollow-heart.

a b.

c. d.

Plate 15. Boron deficieny in groundnut, (a) plant showing retarded growth of the apical portion, bushy or rosette appearance, malformation of the leaf vein, chlorosis, and necrosis near margins in emerging leaves, (b) 'hollow heart' a typical B deficiency in groundnut (c) pod setting with addition of 2 ppm B is best, however 50 ppm B is toxic showing poor pod bearing, (d) Chlorotic young leaflets with purple red, tinting.

Control measures

In B deficient soils, application of 0.5-1.0 kg ha^{-1} B as borax or boric acid recover the deficiency The B should be applied prior to bloom stage. Foliar application of 0.05-0.1% aqueous solution of boric acid is effective in alleviating B deficiency of groundnut in the standing crop in the field (Singh et al., 1993 a). The response of boronated SSP in calcareous soil is also promising. Golakia and Patel (1986) observed that 2 ppm B gave maximum yield of groundnut and yield was highest when Ca:B ratio was 218-224. In Thailand, application of 0.25-0.5 kg B ha^{-1} increased the number and weight of pod and seed and proportion of large seed to small seed and decreased percentage of hollow-heart from 13-49% to less than 1% with, (Keerati-Kasikorn and Panya, 1988a). The drip application of B increased 33 % kernel weight over control. The boron deficiency in Tamil Nadu is more common and there is significant response of boron application increasing 5-10% oil yield.

Boron is important both at deficient as well as toxic level in soil. It is required in very small quantity and application of 5-10 kg ha^{-1} B show toxicity symptoms in leaves. The 5 ppm of B in the soil was toxic to the plant (Singh, 1994 b). Excess of B causes leaflets tips to become yellow, interveinal chlorosis followed by necrosis. The B toxic leaves show curling with scorch sign, the chlorotic area were golden yellow colour at margin. Leaves assume a scorch appearance and fall off (Plate 16a b c).

7. 2. 6. Molybdenum

Requirement and function

In groundnut, molybdenum is essential for nitrogen fixation as well as involved in several enzyme systems. The nitrogenase and nitrate reductase are the main enzymes influenced by Mo. Of all the micronutrients, though Mo is needed in the least amount, the Mo deficiency disrupt the nitrogen metabolism and the plant shows nitrogen deficiency because of role of Mo in Nitrogen fixation. The factors influencing Mo deficiency are low soil Mo, acid soil high organics, high free Fe which. Though Mo availability increases with pH, the deficiencies are quite likely to occur on soil with high pH also. In calcareous soil the Mo deficiency causes 13-19 % yield losses (Singh, 2001).

Symptoms and diagnosis

In groundnut, the Mo deficiency reduce chlorophyll and the leaves show bright yellow, green interveinal chlorotic mottling (Plate 17). The symptoms first occur in older leaves and then progress towards the younger until plant die. At later

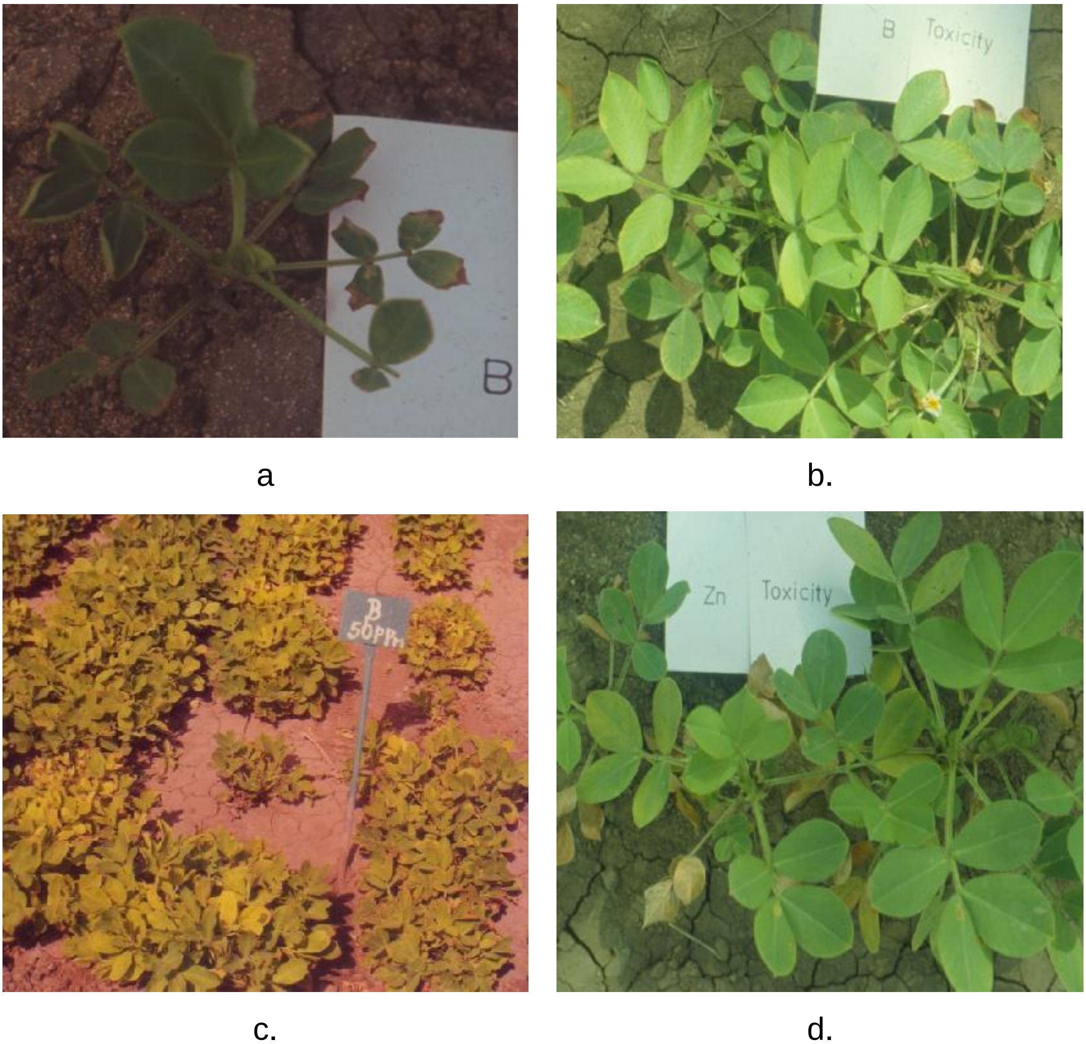


Plate 16. Plant showing toxicity symptoms, (a) B toxic leaves showing curling with scorch sign and, (b) interveinal chlorosis followed by necrosis (c), sever B toxicity where leaflet have become yellow, chlorotic area golden yellow at margin and scorching at tips and falling off leaf, (d) zinc toxicity caused early senescence of old leaves with, golden yellow colouration of the leaf from margin proceeding towards the center.

a

b.

c.

d.

Plate 17. Molybdenum deficiency in groundnut, (a) plant showing severe Mo deficiency as yellowing of old and young leaves, with very few nodule and curled leaf margin, (b) another Mo deficient plant with bright yellow colour and chlorotic mottling in both young and old leaves symptoms like N deficiency, (c) leaves bright yellow and dead spots have started developing, (d) pod setting with 0.5 ppm Mo is best, but 5 ppm Mo is toxic showing poor pod bearing.

stages, leaf margin curled and leaves collapse completely. The Mo deficient plants show very few nodule and the deficiency generally occur in acid soils.

The sufficiency level of Mo in leaf during flowering and fruiting (40-70 DAE) is 0.3-5 ppm which need to be maintained to have a good crop yield. However, the critical limit of Mo was found to be 0.04 ppm in soil and 0.2 ppm in the leaves (Singh, 1994 b). As the nitrate reductase activity reduced in Mo deficient plant, it is a good indicator of Mo status of groundnut plant (Singh and Chaudhari, 1992, 1993b).

Control measures

Application of 0.5-1 kg ha^{-1} ammonium or sodium molybdate with seed or fertilizer or foliar application of 0.01 % sodium molybdate alleviate Mo deficiency in groundnut and increase yield (Singh 1994b; Singh et al., 1993a). Though there are very few information of the response of Mo application to groundnut, its role is vital particularly in acid soils. Seed pelleting with Mo at 100 g ha^{-1} as well as application of 60 kg N ha^{-1} increased pod yield by 24 and 14 %, respectively (ICRISAT, 1990). However, Keerati-Kasikern and panya (1988) reported that Mo application increased seed yield by 30%, and number of seed 26 %.

The groundnut is very sensitive to Mo toxicity and soil Mo concentration of above 1 ppm was toxic (Singh, 1994b). However in nutrient solution 5 ppm Mo showed toxicity (Singh and Chaudhari, 1993 b). The Mo toxicity appear in the young leaves which become complete yellow with brilliant yellow to sulphur yellow colour (Plate 18 a & b). Emerging leaves are folded towards the upper side; leaf margin wavy in structure, as the toxicity increases appearance of amber yellow to pale yellow colouration of leaves was noticed. Leaves start drying from margin leaving golden yellow brown colour. But the lower leaves show green colour with less toxicity symptoms.

7. 2. 7. Chlorine

Chlorine, along with Mn, is required for oxygen evolution in photosynthesis. It is involved in osmosis (movement of water or solutes in cells), ionic balance necessary to take up mineral elements. Chlorine ion is ubiquitous in nature and highly soluble and plant extract it from the soil more rapidly than many other ions and accumulates excess of Cl^- than their requirement. In plant chlorine is a major counter ion maintaining electrical neutrality across membranes and osmotically active solutes in the vacuole. It is also required for cell division in both leaves and shoots.

Plant deprived of Cl exhibit reduced growth, the symptoms first appear on young actively growing leaves as wilting of the leaf tips and normal chlorosis,

a

b.

c.

d.

Plate 18. (a) Mo toxicity in groundnut in the young leaves showing complete yellow with brilliant to sulphur yellow, (b) sever Mo toxicity cause amber yellow to pale yellow coloration of leaves and drying of the same from margin leaving golden yellow brown colour with the lower leaves still green, (c) Iron toxicity produces a blackening and bronzing of the leaves with tiny brown necrotic spots, (d) Cobalt toxicity causing pale to white colour of leaves with marginal necrosis

stubby roots, yellowing and bronzing. Most soils contain sufficient Cl and receive enough of it in fertilizer especially potassium thus the deficiency is rarely observed. In groundnut as the deficiency of Cl^- has not been reported so for, no effort was made for its diagnosis and remedial measure.

7.3. Beneficial elements

The other elements regarded as micronutrients or “beneficial elements” are aluminium, nickel, cobalt, silicon, vanadium, fluorine and sodium, and heavy elements. As not all these have been studied in groundnut, here, we restrict the description of a few beneficial elements only.

7. 3. 1. Nickel

Nickel has been recently added to the list of essential elements for plant , however its role in groundnut is being worked out. It is required in extremely small quantity. The Ni is known to be a component of urease and hydrogenase and needed for mobilization of nitrogen during seed germination and early seedling growth thus seeds need nickel to germinate.

Ureides are the common form of nitrogen present in legumes which are formed in root nodules during nitrogen fixation and transported via xylum throughout the host plant and finally transported to developing seeds for storage. The break down of the ureides, in Ni-deficient plants, produces urea which accumulates to toxic level showing its symptoms. Hydrogenase, recover the hydrogen for nitrogen-fixation and Ni-deficient plant depress the nitrogen-fixation.

7. 3. 2. Cobalt

In nitrogen fixing legumes, the cobalt is essential elements required for the symbiotic nitrogen fixing bacteria but not by the host. It is a constituent of vitamin B_{12} essential for human. Though the beneficial effect of Co in groundnut was reported about three decade ago (Reddy and Sivraj, 1975), its clear-cut requirement, functions and deficiency symptoms has not been demonstrated yet.

As Co is scarcely soluble at pH 6 and above, the groundnut grown in calcareous soil may show low Co. It is presumed that Co induce N-deficiency, however, there are no known deficiency symptoms of Co deficiency. Howevr, excess of Co cause chlorosis like that of Fe and Mn deficiencies as it is assumed to replace these metals from their metabolic active sites. High Co concentration cause pale to white colour of leaves with marginal necrosis leading to death of the plant (Plate 18d).

7. 3. 3. Aluminum (Al)

Though Al is not considered a plant nutrient, its presence in plants can affect the normal function of some other elements. However high concentration of Al cause its toxicity and Al-induced Ca and P deficiencies. In an experiment on the standardization of Al doses for its toxicity in groundnut, it was observed that 200 µM of Al was beneficial for some of the groundnut genotypes which showed better growth at this dose than at no Al clearly indicating that some genotypes may require Al and hence possibility of tolerance of higher Al dose in groundnut might exist in nature. However most of the genotypes showed Al-toxicity at 600-1000 µM of Al.

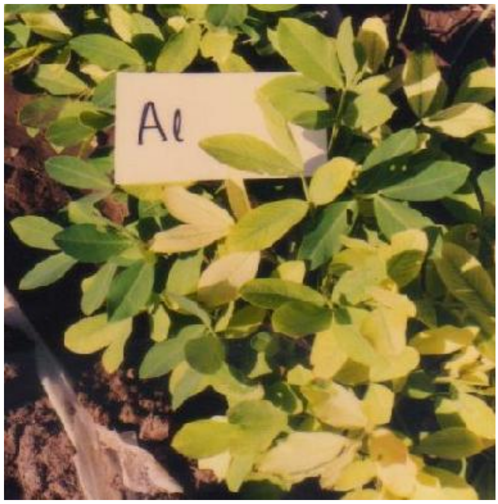
The Al concentration upto 200 ppm in groundnut leaf is desirable, but its levels in excess of 400 ppm is undesirable. However, groundnut plant grown in acid soils of NE states of India showed extremely high Al-concentration (960-2500 ppm) and high Fe (1600 ppm) and Mn (1200 ppm) content and low Ca (1.5%) and P (0.15%) content in their tissues (NRCG, 2002). The high Al concentration measurement in field grown groundnut is sometimes due to dust and soil contamination as with Fe, probably no accurate measure of the Al status of the plant can be obtained unless the tissue is free from dust and soil contamination. Poor soil aeration due to compaction or flooding usually increases Al in plants.

The, low Ca content (sometimes below 300 ppm in seed) in groundnut seed and leaves causing low shelling and viability were observed. Application of lime (2 t ha^{-1}) increased Ca and P content of plant and seed and brought down the Al, Fe and Mn contents.

Excess of Al caused stunted growth in groundnut. The first symptoms of Al-toxicity arrest root growth followed by reduction of shoot growth, yellowing of both young and old leaves with interveinal to complete chlorosis (Plate 19). Severe Al-toxicity causing Fe and Zn deficiencies as interveinal to complete chlorosis with white papery.

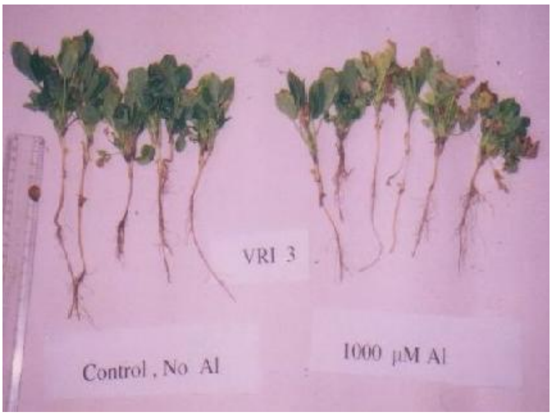
7.3.4. Sodium

Sodium is involved in osmotic (water movement) and ionic balance in plants. It enhances the growth when K is deficient and is an important quality factor in feed stuff. Thus care should be taken to maintain adequate Na, the deficiency of which causes reduced growth, chlorosis and necrosis in leaves.



a

b.



c.

d.

Plate 19. Groundnut Plant showing Al toxicity, (a) yellowing of both young and old leaves with interveinal to complete chlorosis and reduction of size, (b) severe Al-toxicity causing Fe and Zn deficiencies as interveinal to complete chlorosis with white papery leaves, (c) Al-toxicity caused reduction of shoot and root growth, (d) pod bearing in a groundnut genotype showing beneficial effect of Al at lower dose and toxic effect at higher dose (lesser and blackened pod).

7.3.5. Silicon

Silicon (Si) is a component of cell walls and provide mechanical barrier to piercing - sucking insects and fungi. Foliar sprays reduce populations of aphids on some plants. Enhances leaf presentation; improves heat and drought tolerance, and reduces transpiration. The deficiency of Si cause wilting, poor fruit and flower set, increased susceptibility to insects and disease.

7.4. Toxic elements and their symptoms

The excess of heavy metals and micronutrients in soil interfere with the absorption and uptake of essential elements and plant metabolism and show their toxicity symptoms on foliage in form of chlorosis showing either deficiency symptoms of the essential elements or necrotic symptoms showing toxicity causing death of plant. The symptoms of the micronutrient toxicities have already been discussed earlier in their respective paragraph. While the photographs showing toxicity symptoms are depicted in plates 12, 16, 18 and 19 along with detail descriptions of their symptoms.

8. Screening and Selection of Genotypes for Problem soils

As mentioned earlier the acid and alkaline soils are the major problem soils in India causing nutritional disorders in groundnut. The first option, in the soil low in available nutrients, is to correct the mineral deficiencies by supplying fertilizers. However, as the plant-available nutrients are generally a small fraction of the total nutrient and in problem soils it is further reduced due to soil factor, the second option is to the use of nutrient efficient genotypes which is very efficient and allows the resource poor farmers to harvest reasonable yield without any extra inputs (Plates 20 to 22).

Calcareous and alkaline soils

In calcareous soils, because of high availabilities of Ca and Mg and their higher uptake by plant, the plant show multi-nutrient deficiencies of K, P, S, Fe, Zn, and Mn. The chlorosis due to iron, zinc and sulpur deficiencies are visible and are considered major problem of calcareous and alkaline soils. The Ca-induced deficiencies of K, P and Mn also occur in calcareous soil, but do not show any clearcut visible symptoms and hence are neglected. However, they are easily diagnosed through their response study. Further as these deficiencies appear either due to antagonistic effect of Ca and Mg or Ca-induced multi-nutrient deficiencies they continue to occur in the field and it is are very difficult to rectify them. Selections of nutrient efficient genotypes are the only solution (Plate 20 & 21).

Looking to the severity of these, the NRCG, Junagadh took lead to identify nutrient efficient groundnut genotypes having tolerance of these deficiencies (Singh, 1999a; Singh and Chaudhari, 1991, 1993). The lime-induced iron-chlorosis tolerant (Fe-efficient) and sensitive (Fe-inefficient) groundnut genotypes and cultivars are already mentioned while dealing with Iron (Table 7). The yield evaluation for five consecutive years have shown that some of the Fe-efficient genotypes NRCG Acc. 7085-1, 7085-3, 2588 and 6919 of Spanish and 7599 of Valencia group have good yield potential and hence may be grown in the area where the problem of Fe-deficiency is very severe. The Fe-inefficient groundnut genotypes can be grown in Fe-toxic areas of acid soils.

a

b.

c.

d.

Plate 20. Screening of groundnut genotypes for nutrient efficiency in calcareous soil (a) an Iron efficient line growing luxuriantly without any chlorosis at NRCG during rabi-summer season, (b) close view of some iron-chlorosis tolerant and susceptible lines (c) reaction of iron-chlorosis tolerant (green) and susceptible (yellow) groundnut genotypes during peak (60-70 DAE) growth stages in calcareous soil, (d) reaction of nitrogen-efficient (green) and N-inefficient (yellow) groundnut genotypes in field.

a

b.

c.

d.

Plate 21. (a) Reaction of Nutrient (Fe, Ca and S) inefficient (left side) and efficient (right) groundnut genotypes at medium doses of these elements, (b) screening of groundnut genotypes for tolerance of iron-deficiency chlorosis, a susceptible line (NRCG 5306) is seen in between, (c) to avoid water logging and Al-toxicity the crop, in high rainfall area of Meghalaya, is grown on the raised bunds made along the slope, (d) screening of groundnut genotypes for tolerance of Al-toxicity, and P and Ca deficiencies both under unfertilized (control) and fertilized conditions

In an effort to screen groundnut genotypes for macronutrient using minus nutrient, the genotypic variations were noticed and the minus treatment of all the macronutrient produced less pod and fodder yields. Some of the nutrient-efficient and nutrient-inefficient genotypes for calcareous soils are given below:

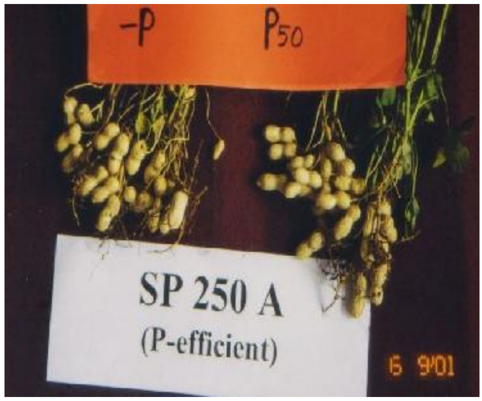
Nutrients	Efficient	Inefficient
N	NRCG 6919	
Fe	TG 26 and I1	NRCG 162 and VRI 3
Ca	NRCG 5513 and 7599 NRCG 7085-1	NRCG 6155 and 7417
S	NRCG 2588 and 1306 NRCG 7085-1	NRCG 3498 and 4659

Acid Soils

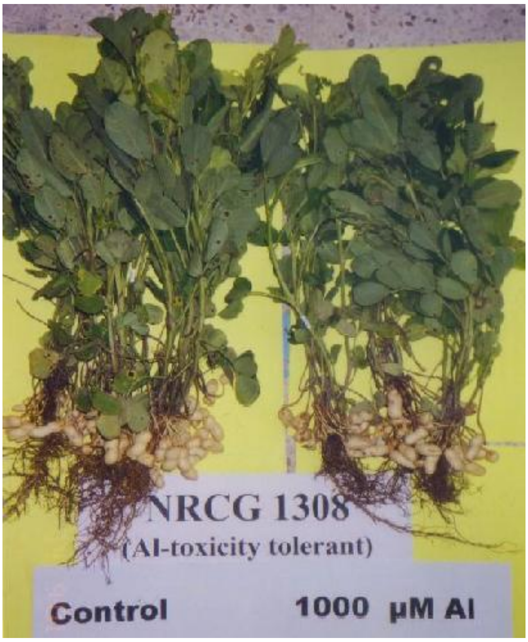
The acid soils show P, Ca, Mg, B and Mo deficiencies and have problem of Al, Mn and Fe toxicities. In India, the eastern and north eastern parts of the country have acid soils where groundnut is grown in scanty, but bright prospects are there for improvement as yield realization is very high due to high organic matter. Liming is the viable solution but cost effective. As these are not easily rectifiable, the concepts of fitting plant to soil may be more economical than the soil rectification. However, this can be easily achieved by screening for nutrient efficient groundnut genotypes which can tolerant the toxicities of Al, Mn and Fe and Al-induced deficiencies of P, Ca, Mg, B and Mo. As there are about six thousand germplasm lines and more than 120 groundnut varieties aee available in India, our strategy should be towards the massive screening of groundnut for these disorders (Plate 21c and d and 22 c and D). In the responses of plant adaptation in low pH soil, it is reported that native plant growing in acid soil require Al for growth to a certain extent; however, the characteristics of Al accumulation in organs are different among different species.

The NE states of India provide the hot-spot for screening for soil acidity, Al, Fe and Mn-toxicities and Ca and P-deficiencies. Accordingly, in a collaborative project between ICAR Research Complex in NEH and NRCG, Junagadh initiated during 1997, the foot-hill upland of ICAR Res. Complex, Imphal, (Manipur) and Barapani and 'Tilla' lands of Lembucherra (Tripura), were identified as hot spot for such screening and 50 recently released groundnut varieties and 300 germplasm lines were evaluated during 1997 to 2002 kharif seasons. The four years of study revealed that groundnut cultivars ICG 76, and ICGV 86590 and TKG 19A were most suitable for the acid soil and could tolerate the above adversities and hence recommended for their cultivation (Singh et al 2003).

a



b.



c.

d.

Plate 22. (a) Pod bearing in P-efficient and P-inefficient genotypes at adequate level of P, (b) Pod bearing in P-efficient plant genotypes in P-fertilized (50 kg P ha^{-1}) and unfertilized plot in calcareous soil at NRCG, Junagadh, India (c) An Al-toxicity tolerant genotype (NRCG 1308) showing little reduction in growth and yield at 1000 µ M of Al in sand culture on a contemporary (d) an Al-toxicity sensitive genotype showing sever chlorosis and reduction in biomass and yield at 1000 µ M of Al in sand culture experiment.

Of the 300 genotypes tested (each for two years) the soil acidity and Al-toxicity tolerant and sensitive genotypes were identified:

- Tolerant: ICG 813, 1001, 1021, 1048, 1056, 1064, 1355, 3606, 10964,11183.
- Sensitive: ICG 2120, 4407, 6727, 6855, 7288, 7600, 7787, 7821, 10580, 11748.

Also 55 groundnut genotypes were screened for their tolerance of Al-toxicity under simulated conditions in sand culture pot experiments at 1000 µM of Al and based upon the four years of study, the tolerance and sensitive genotypes were identified. The Al-toxicity tolerant genotypes were NRCG 7599 and 1038, 3498 and, FeESG 8.

As Al-induced P and Ca deficiencies are the main problem of acid soils and the fertilizers are becoming costly, efforts were made for the selection of nutrient efficient genotypes which can grow and yield well under low available nutrients where the normal genotype show deficiency and four years of study identifies following nutrient efficient and inefficient genotypes:

P-efficient	GG 5, NRCG Acc 7085-1, 6919, 1308, 3498, and SP 250A
P-inefficient	VRI 3, B 95, PBS 16003, 20012 and 18057
Ca-efficient	ICGHNG 88448, and NRCG Acc. 7085-1, 6155,
Ca-inefficient	BAU 13, TG 26, NRCG 7472 and 162

In field study several genotypes were screened for their tolerance of P deficiency stress at 3.65 mg kg^{-1} available P in Manipur, Assam and Meghalaya and varieties ICGV 80338, ICGV-88348, ICG (FDRS)-40, ICG (FDRS)-50 were the highest yielder without P application and were resistant to Tikka leaf spot.

Saline soils

Saline and sodic soils also limit groundnut cultivation specially in coastal and highly irrigated areas where the salinity is building. Unfortunately less work has been done on these aspects, as the groundnut is susceptible to salinity. Germination and seedling vigour is suppressed by different salt concentrations, and sodium carbonate is most toxic followed by sodium sulphate and magnesium sulphate (Nautiyal, et al., 1989). Based on the seedling mortality, the groundnut genotype NRCG 7537 was found tolerant while NRCG 5507, 7548, 7356 and 7202 were moderately tolerant to salinity (NRCG 1990-91). Under saline (NaCl) condition the ammonium application showed less absorption of nitrogen than in NO_3 for groundnut (Leidi et al., 1992).

9. Yield Targeting

The diagnosis of mineral disorders symptoms followed by soil and plant analysis is the main basis for the fertilizer recommendation in groundnut crop on a particular soil. Further, these recommendations vary with cultivars as some of the cultivars response very high to fertilizer application whereas a few do not. Plant analyses data given above can be used to help guide future soil test calibration work and agronomic research. The soil analyses provide a base but many a times mislead as the deficiency of the element, showing their adequate concentration in soil, occur in plant. Though the soil samples from various states have been analysed and sufficiency, deficiency and toxicity areas of certain elements have been worked out, these studies are based on the limited soil samples and crop cultivars. Though, the responses of nutrients in groundnut are very high particularly on deficient and marginal soils where water is not a limiting factor, only a few attempts have been made on these aspects but no systematic work has been done to delineate the nutrient deficiency and toxicity areas in India, and recommendations of various nutrients for targeted yield (Singh, 1999a).

The cultivars were developed for ideal condition of soil fertility and pH. But when grown on soil even slightly different from those of originating centers developed mineral deficiency or toxicity problems, which are corrected with soil amendment or foliar application of nutrient. The soil and plant analysis can adequately meet the need of Indian groundnut growers by providing efficient and profitable site specific fertilizer recommendation for increasing crop production. The desired yields only could be achieved with suitable fertilizer applied on soil test-crop response basis. This will enhance the fertilizer efficiency.

The fertilizer doses recommended for rainfed and irrigated groundnut for various states of India, during mid 80’s are given in Table 9. The average recommended doses of N, P and K are 15, 37 and 29 kg ha^{-1}, respectively for rainfed groundnut and 20, 46 and 47 kg ha^{-1}, respectively, for irrigated groundnut. However, due to extensive cropping, the deficiencies are becoming more and more and most of the states, has to revised their recommendations. In the present context 30 kg N, 40 kg P2O5 and 40 kg K2O per hectare for Kharif and 40 Kg N, 50 kg P2O5 and 50 K2O per hectare for Rabi-Summer could be considered as blanket recommendation for groundnut. For secondary macronutrients 500 kg/ha of gypsum, 20 Kg ha^{-1} S and 10 kg ha^{-1} Mg as $MgSO_4$ could be applied. Among the sources, Ammonium sulphate for N and S, SSP for P and S, gypsum for Ca and S, FeSO4 for Fe, ZnSO4 for Zn and Borax for B are the preferred chemical fertilizers.

Table 9 . State-wise recommended doses of fertilizers in both irrigated and rainfed systems (DOR, 1985, ICAR, 1987) and proposed doses to boost yield.

State	Active nutrient (kg ha^{-1})					
	Rainfed			Irrigated		
	N	P	K	N	P	K
Andhra Pradesh	20	40	20	30	60	45
Gujarat	12.5	25	-	25	50	-
Karnataka	15	30	25	25	75	25
Madhya Pradesh	20	40-80	20	-	-	-
Maharashtra	20	40	-	-	-	-
Orissa	8	16	15	-	-	-
Punjab	15	40	25	8	26	24
Rajasthan	20	60	-	20	60	-
Tamil Nadu (Aliar nagar)	11	22	33	22	44	66
Tamil Nadu (Tindivanam)	10	20	45	10	10	75
Uttar Pradesh	15	30	45			
Mean	15	37	29	20	46	47
Proposed Doses	30	40	40	40	50	50

Response of groundnut to fertilizer application, based on 2358 trials conducted on farmer's field has been summarized by Kanwar et al. (1983) where yield response to N application are substantial considering that 1 kg pod can pay for 1 kg N. Depending upon the soil types and situations, the response were to the tune of 5.6 to 16.9 kg pods kg^{-1} N, 3.9 to 11.3 kg pod kg^{-1} P and 3.0 to 9.2 kg pods kg^{-1} NPK. In Tamil Nadu copper application increased 22.9 % oil yield and 6.7 % pod yield and boron increased 5-10% oil yield. The boron deficiency in Tamil Nadu is more common and there is significant response of boron application.

In groundnut very few workers have attempted for yield targeting experiment. The yield targeting field experiments conducted by Kadam et al (1985) in clay soil at Rahuri with 157, 10 and 410, kg ha^{-1} Available N, P, K, respectively indicated highest a return of Rs 47 per rupees of fertilizer applied in 1.5 t ha^{-1} yield target. But, the highest monetary return was observed under 2.0 t ha^{-1} yield target and these all depends upon the soil available N, P, K. However, such experiments need to be conducted in other groundnut growing states.

There is an urgent need to workout the physiologically-based critical value for diagnosis of Ca, S, K, Fe, and B in various plant parts and its correlation with agronomic yield and for making fertilizer recommendation. The absorption of P, Ca and Mg at low and high temperature and phosphorus level, the association of net influx of Ca with efflux of K from the developing groundnut pods. For immobile element particularly of Ca, and B the leaf concentration does not provide the correct nutrient status and demand of pods. Moreover, as the pod also absorbs nutrient from the soil, the nutrient concentration of seed or other plant parts of these elements should be taken as the criteria for the critical levels.

Table 10. Response of groundnut to fertilizer in various soils (Source: Kanwar et.al., 1983).

Soil	Moisture regime	Yield (kg ha^{-1}) without fertilizer	Yield increased (kg per unit NPK)			
			N	P	NP	NPK
Red sandy	Irrigated	1626	12	5.7	6.3	4.6
	Rainfed	1149	7.1	5.6	5.7	5.3
Red loam	Irrigated	2054	15.7	8.6	13.1	9.2
	Rainfed	1468	16.6	9.6	7.8	7.3
Black	Irrigated	1662	12.5	3.9	6.3	5.8
	Rainfed	1260	6.9	4.8	5.1	4.3
Alluvial	Irrigated	1316	7.9	8.8	7.7	6.0
	Rainfed	1065	8.2	8.3	8.1	5.6
Coastal	Irrigated	1983	16.9	11.3	12	7.2
Alluvial	Rainfed	1602	17	9.8	10.7	9.2
Laterite	Rainfed	1215	9.7	8.2	11.8	7.6
Mixed red and brown	Rainfed	967	6.4	3.9	4.4	4.5
	Mean		10.5	6.8	7.6	5. 9

The absorption and mobility for foliar applied nutrients in groundnut are mentioned below:

Absorption			Mobility		
Rapid	Moderate	Slow	Mobile	Partially Mobile	Immobile
Nitrogen, Potassium, Zinc	Calcium, Sulfate, Manganese, Boron	Magnesium, Copper, Iron, Molybdenum	Nitrogen, Potassium, Phosphorus, Sulfate	Zinc, Copper, Manganese, Molybdenum	Iron, Calcium, Boron, Magnesium

Finally only a few scientists on global level are working on the mineral nutrition of groundnut. Still the groundnut crop in most part of the world is grown under low fertility. A group of scientists should work in close collaboration to improve the its nutrition particularly in acid and calcareous soils.

10. References

Adams, J.F., D.L.Hartzog and D.B. Nelson. 1993. Supplemental calcium application on yield, grade and seed quality of runner peanut. Agron. J. 85: 86-93.

Ae, N And T. Otani, 1997. The role of cell wall components from groundnut roots in solublizing sparingly soluble phosphorus in low fertility soils. In Plant Nutrition-For Sustainable Food Production and Environment (T.Ando et al Eds) pp 309-314. Kluwer Academic Publishers, Printed in Japan.

Agrawal, S.C. and C.P. Sharma, 1979. Recognising Micronutrient Disorders of Crop Plants on the Basis of Visible Symptoms and Plant Analysis. Botany Department, University of Lucknow, p 72.

AICORPO. 1993. Annual Progress Report, Rabi/Summer groundnut. 1992-93. DOR, Hyderabad, India.

AICORPO. 1996. Annual Progress Report, Rabi/Summer groundnut.1992-93. NRCG, Junagadh, India.

Basu, M.S. and P.S.Reddy. 1989. Technologies for increasing groundnut production. Technical Bulletin, NRCG, Junagadh p. 18.

Bell, M.J., K.J. Middleton, J.P. Thompson, G. Hasch and J. Tatnell. 1988. The role of VAM in phosphorus nutrition of peanuts in oxisols. In: Abstracts of the Symposium. Vesiculant-Arbuscular Mycorrhizae (VAM) in agriculture and horticulture. 12-13 Oct. 1988. Australian Institute of Agricultural Science TOOWOOMBA, Australia.

Bell, R.W., D.G. Edwards, and C.J. Asher (1989): Effect of calcium supply on uptake of calcium and selected mineral nutrients by tropical food legumes in solution culture. Austr. J. Agric. Res., 40, 1003-1013.

Compendium of Peanut Diseases, 2nd Edition 1997. Edited by N. Kokalis-Burelle, D. M. Porter, R. Rodríguez-Kábana, D. H. Smith, P. Subrahmanyam 94 pages; 198 color photographs; 81 black and white photographs and illustrations

Cox. F.R., J.F. Adams and B.B. Tucker. 1982. Liming, fertilization and Mineral nutrition. pp. 139-163. In (H.E. Pettee and C.T. Young eds.). Peanut Science & Technology. American Peanut Research and Education Society Inc. Yoakum, Texas, USA.

Cox, F.R. and P.H. Reid. 1964. Calcium-boron nutrition as related to concealed damage in peanuts. Agron. J. 56: 173-176.

Davis, J.G., G. Weeks , C. K. Kvien and W. D. Branch 1995. Varietal tolerance of zinc toxicity. J. Plant Nutr. 18: 2157-2178.

DOR (Directorate of Oilseed Research). 1985. Groundnut, sesame, niger, sunflower and castor,. Extension Bulletin No.2. Directorate of Oilseed Research , Hyderabad.

Dwivedi, R.S. 1988. Mineral nutrition of groundnut. Metropolitan Book Co. New Delhi, India 135pp.

Dwivedi, R.S. 1989. Potash nutrition in relation to energy partitioning and harvesting efficiency of groundnut (*Arachis hypogaea* L.) under rainfed conditions. Oleagineux 44: 413- 417.

Dwivedi, R.S., Y.C.Joshi, S.N.Saha, A.N. Thakkar and V.G.Koradia. 1987. Modeling of peanut (Arachis hypogaea L.) for higher yield on phosphorus deficient soil. Oleagineux 42: 165-168.

Dwivedi, R. S., Y. Misra and K.K. Srivastava, 1997. Effect of potassium on EDTA-osmoticum, nitrate reductase activity and productivity of groundnut-sugarcane intercropping under water deficit conditions. In Plant Nutrition-For Sustainable Food Production and Environment (T. ando et al Eds) pp 93-94 Kluwer Academic Publishers, Printed in Japan.

Fageria, N.K. (1974): Absorption of magnesium and its influence on the uptake of phosphorus, potassium, and calcium by intact groundnut plant. Plant Soil, 40, 313-320.

Gascho, G. J. and J. G. Davis 1994. Mineral nutrition. In The Groungnut Crop: a scientific basis for improvement (Edt J. Smart) Chapman and Hall, London. pp214-254.

Ghetia, N.R. 1995. Response of Summer groundnut (Arachis hypogaea) to fertiirrigation and methods of irrigation under varying fertility levels. M.Sc. Thesis Department of Agronomy Gujarat Agriculture University. Junagadh.

Golakiya , B. A. and M. S. Patel 1986. Effect of Ccalcium carbonate and boron on yield of groundnut. Indian J. Agric. Sci. 56: 41-44.

Hartzook, A. 1975. Lime induced iron chlorosis in groundnut: Treatment and Prevention. FAO Plant Protection Bull. 23:1-3.

ICAR. 1987 a. Fertilizer use in groundnut. Technologies for better crops. 30: ICAR, New Delhi, India, 7 p.

ICAR. 1987 b. Use of micronutrient in groundnut. Technologies for better crops. 31: ICAR, New Delhi, India, 11 p.

ICRISAT. 1990. Annual Report, 1989. ICRISAT, Patancheru, A.P. 502 324, India.

Jain, R.C., D.P.Nema, R. Khandwe and R. Thakar. 1990. Effect of phosphorus and potassium on yield, nutrient uptake, protein and oil contents of groundnut (Arachis hypogaea). Indian J.Agric.Sci. 60: 559-561.

Jones, Jr J.B., B. Wolf and H.A. Mills (1991). Plant Analysis Handbook. Micro-Macro Publishing Inc. Georgia, U.S.A., 213 pp.

Jurkevitch, E.,V.Hadar and Y.Chen 1988. Involvement of bacterial sideuphores in the remedy of lime-induced chlorosis in peanut. Soil Sci. Soc. Am.J. 52: 1032-1037.

Kadam, J.R.,K.R. Sonar and N. D. Patil. 1985. Studies on fertilizer use based on soil test and yield target in kharif groundnut. Fert. New (Sept.): 25-27.

Kanwar, J.S., H.L. Nijhawan, and S.K Raheja 1983. Groundnut Nutrition and Fertilizer Responses in India.ICAR New Delhi 185 P.

Keerati-Kasikeran,P. And Panya, P. 1988. Effect of boron on yield of groundnut cultivar in Tainan 9. In proceedings of the 7th Thailand National Groundnut Meeting. Pattaya Chonburi Thailand pp 384-389.

Lund, Z.F. and L.W. Murdock. 1978. Effect of sulphur on early growth of plants. Sulphur in Agriculture 2: 6-8.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. 2nd ed. 889p. Academic Press, New York.

Mengel, K. and E.A. Kirkby (1987): Principal of plant nutrition, Fourth edition. International Potash Institute, Berne, Switzerland.

Nambiar, P.T.C. 1990. Nitrogen nutrition of groundnut in Alfisols. Information bulletin No.30, ICRISAT, Patancheru, A.P., 502 324, India.

Nautiyal, P.C., V.Ravindra and Y.C.Joshi. 1989. Germination and early seedling growth of some groundnut (Arachis hypogaea L.) cultivars under salt stress. Indian J. Plant Physiol. 32: 251-253.

NRCG, 1991. Annual Report 1990-91. National Research Centre for groundnut (ICAR), Junagadh.

O'Hara, G.W., M.S.Dilworter, N,Boonkerd and P. Parkpian. 1988. Iron-deficiency specially limits nodule development in peanut inoculated with Bradyrhizobium sp. New Phytol. 108: 51-57.

Pande, D., S.N. Mishra and S. C. Padhi.1971. Response of groundnut varieties to varying levels of fertility. Indian J. Agronomy 16: 249-250.

Papastylianou, I. 1990. Effectiveness of iron chelates and FeSO4 for correcting iron chlorosis of peanut on calcareous soil. J. Plant Nutr. 13: 555-566.

Papastylianou, I. 1993a. Timing and rate of iron chelate application to correct chlorosis of peanut. J. Plant Nutr. 16: 1193-1203.

Papastylianou, I. 1993b. Interaction of iron chelate and nitrogen fixation in peanuts grown on calcareous soil. J. Plant Nutr. 16: 1205-1213.

Parkar, M.B., T.P. Gaines, M.E.Walker, C.O. Plank and J.G. Davis- Carter. 1990. Soil Zinc and pH effects on leaf zinc and the interaction on leaf calcium and zinc on zinc toxicity of peanut. Common Soil Sci. Plant Anal. 21: 2319-2332.

Pasricha, N.S. Aulakh, M. S., Bahl G.S.. and Baddesha,H.S. 1987. Nutritional requirement of oilseed and Pulse crops in Punjab (1975-1996) Res. Bull 15. Punjab Agric. University Ludhiana pp 92.

Patel, M.S and Kanzaria M.V.1985. Factors affecting response of groundnut to P fertilizer in medium black calcareous soil of Saurashtra. Fer. News 30(3) : 31-36.

Prasad, M.V.R. 1993. Genetic enhancement of groundnut for higher productivity based on canopy development. Oilseeds Research and Development in India: Status and Strategies. Extended summaries of National Seminar 2-5 August 1993, DOR, Hyderabad,India p. 2-5.

Ramachandrappa, B.K and Kulkarni, K.R. 1992. Response of groundnut to ca sources and saturation levels in two soil. J. Oilseed Res. 9(1) : 80-86.

Ravichandran, V. K. Sivasubramanian, P and Natarajaratham, N. 1991. Fertilization to groundnut. Fert,. news. 36(2): 12-34

Sahu, S.K., Mitra, G.N. and Miswhra, U.K. (1991). Groundnut responses to sulphur application in Orissa. Indian Farming 41 (1): 2-3.

Samdur, M.Y., A.L. Singh, R.K. Mathur, P. Manivel, , B. M. Chikani, H.K. Gor and M. A. Khan 2000. Field evaluation of Chlorophyll meter for screening groundnut (*Arachis hypogaea* L.) genotypes tolerant of iron-deficiency chlorosis. Current Science, 79(2):211-214.

Savani, R.P., M.S.Patel and G.S.Sutaria. 1991. Influence of sulphuric acid on the availability of applied phosphorus to groundnut in calcareous soils. J.Indian Soc.Soil Sci. 39:798-800.

Singh, A.L. 1994a. Screening of groundnut cultivars for tolerance to lime-induced iron-chlorosis. In Plant productivity under environment stress, Karan Singh and S.S.Purohit (edt.). Agrobotanical Publishers, Bikaner, India pp.289-294.

Singh, A.L. 1994b . Micronutrient nutrition and crop productivity in groundnut. In Plant productivity under environment stress, Karan Singh and S.S.Purohit (edt.). Agrobotanical Publishers, Bikaner, India pp.67-72.

Singh A. L. 1999a. Mineral Nutrition of Groundnut. In Advances in Plant Physiology (Ed. A. Hemantranjan), Vol II pp. 161-200. Scientific Publishers (India), Jodhpur, India.

Singh A. L. 1999b. Sulphur Nutrition of Oilseed Crops. In: Advances in Plant Physiology (Ed. A. Hemantranjan), Vol II. pp. 201-226. Scientific Publisher (India), Jodhpur, India.

Singh, A.L. 2000. Mechanism of Tolerance and Crop Production in acid Soils. In: Advances in Plant Physiology Vol III Plant Physiology, Biochemistry and Plant Molecular Biology in 2000 (Ed. A. Hemantranjan), Vol II. pp. 353-394. Scientific Publisher (India), Jodhpur, India.

Singh, A. L., 2000. Potassium, calcium and boron fertilization of bold-seeded groundnut in calcareous soil. In: Proceedings of the GAU-PRII-IPI National Symposium on Balanced Nutrition of Groundnut and other Field Crops Grown in Calcareous Soils of India., 19-22 Sept. 2000.(B.A. Golakiya, J. D. Gundalia, S. K. Bansal. And Patricia Imas edt) Vol. 2. pp 199-204. Gujarat Agricultural University, Junagadh.

Singh, A. L, 2001. Yield losses in groundnut due to micronutrient deficiencies in calcareous soils of India. In: Plant-nutrition: Food security and Sustainability of Agro-ecosystems through basic and Applied Research. (Eds. Horst W.J., Schenk M.K., Burkert A., Claassen N., Flessa H., Frommer W.B. Goldbach H., Olfs H.W., Romheld V. (eds).), pp 838-839. Proceedings of the 14th International Plant Nutrition Colloquium, Hannover, Germany 27th July- 3rd August 2001. Kluwer Academic Publisher, Dordrecht; Netherlands.

Singh, A.L. 2002. Macronutrient stresses and interaction of nutrients in plants. In Physiology Of Abiotic Stresses In Plants (Eds R.S. Dwivedi and P. Dwivedi), pp Oxford IBH Publishers, New Delhi, India. (in press)

Singh A. L. 2002. Effect of macro- and micro-nutrients on yield and pod filling of bold-seeded groundnut. In: K. K. Vora, Karan Singh and Arvind Kumar (Eds) Production and Developmental Plant Physiology, pp 381-86 Pointer publishers Jaipur, India.

Singh, A. L. 2001. Comparison of seed dressing and soil application of macro- and micro-nutrients in groundnut in calcareous soil. pp. 124-129. In: "Plant Physiological Paradigm For Fostering Agro- and Biotechnology and Augumenting Environmental Productivity" (Eds R. S. Dwivedi and V. K. Singh) proceeding of National Seminar organized by ISPP/IISR at Lucknow, India 7-9 Nov. 2000. Indian society for Plant physiology, New Delhi India.

Singh, A.L. 2003. Potassium influences kernel filling of large–seeded groundnut in calcareous soil. J. Potassium Research 18: 47-52

Singh, A. L., Ajai and Vidya Chaudhari. 2001. Drip irrigation- a potential system for micronutrient application in groundnut in semi-arid region. pp 501-507. In: Micro-irrigation (Eds H. P. Singh, S. P. Kaushish, Ashwani Kumar, T. S. Murthy and J. C. Samuel), a proceeding of the International Conference on Micro and Sprinkler Irrigation Systems, 8-10 February 2000, Jain irrigation Hills Jalgaon, India. Published by Central Board of Irrigation and Power, New Delhi, India.

Singh, A.L. M. S. Basu and N. B. Singh, 2003. Iron deficiency chlorosis and its management in groundnut. National Research center for groundnut (ICAR), Junagadh India p 30

Singh, A.L. and Vidya Chaudhari, 1991. Screening of groundnut cultivars tolerant to iron chorosis. Indian Journal of Agricultural Sciences. 61:(12).

Singh, A.L. and V. Chaudhari (1992): Enzymatic studies in relation to micronutrient deficiencies and toxicities in groundnut. Plant Physiol. Biochem., 19, 107-109.

Singh, A.L. and Vidya Chaudhari, 1993a. Screening of groundnut germplasm collection and selection of genotypes tolerant of lime-induced iron-chlorosis. J. Agric. Sci. Camb.121:205-111.

Singh, A.L. and Vidya Chauadhari. 1993 b. Root peroxidase activity as an indicator of iron chlorosis in groundnut. Groundnut News 5(1): 6.

Singh,A.L. and Vidya Chaudhari, 1995. Source and mode of sulphur application on groundnut productivity. J. Plant Nutr. 18: 2739-2759.

Singh,A.L. and Vidya Chaudhari, 1996a. Interaction of sulphur with phosphorus and potassium in groundnut nutrition in calcareous soil. Indian J. Plant Physiology New Ser. 1: 21- 27.

Singh,A.L. and Vidya Chaudhari, 1996b. Use of zincated and boronated superphosphate and mycorrhizae in groundnutnutrition in calcareous soil. Indian J. oilseeds Res. 13: 61-65.

Singh, A. L. and V. Chaudhari, 2000. Manifestation of iron-deficiency chlorosis in 102 Indian groundnut cultivars in calcareous soil. In: Proceedings of the GAU-PRII-IPI National Symposium on Balanced Nutrition of Groundnut and other Field Crops Grown in Calcareous Soils of India., 19-22 Sept. 2000, (B.A. Golakiya, J.D. Gundalia, S.K. Bansal. And Patricia Imas eds) Vol. 2 pp. 78-83, Gujarat Agricultural University, Junagadh, India.

Singh, A.L. and D.Dayal, (1992): Foliar application of iron for recovering groundnut plants from lime-induced iron deficiency chlorosis and accompanying losses in yields. J. Plant Nutr., 15: 1421-1433.

Singh,A.L. and Y.C. Joshi, 1993. Comparative studies on the chlorophyll content, growth, N uptake and yield of groundnut varieties of different habit groups. Oleagineux 48: 27-34.

Singh A. L. and Y. C. Joshi, 1997. Prevention and correction of iron-deficiency chlorosis of groundnut in India. In Plant Nutrition-For Sustainable Food Production and Environment (T. Ando et al Eds) pp 271-272. Kluwer Academic Publishers, Printed in Japan.

Singh, A. L. and Y.C. Joshi , 2001. Dynamics of sulphur, iron and magnesium and their nutrition in groundnut in calcareous soils of India. In: Balanced Nutrition of Groundnut and other Field Crops Grown in Calcareous Soils of India (eds N. S. Pasricha, S. K. Bansal and B. A. Golakiya) pp. 103-122. Proce National Symposium held by PRI, IPI and GAU during Sept. 19-22, 2000 at Gujarat Agril. University, Junagadh, India. Published by Potash Res. Institute of India, Gurgaon, India.

Singh, A.L., Y.C.Joshi and V.G.Koradia. 1987. Assessment of yield losses caused by iron chlorosis in groundnut. pp. 20-21. In: Micronutrient stresses on crop plants: Physiological and genetical approaches to control them. Proceeding of National Symposimposium, 16-18 Dec. 1987. MPAU, Rahuri & Food and Agril. Department of Atomic Energy, India.

Singh, A.L., Y.C. Joshi, Vidya Chaudhari, and P.V. Zala, 1990a. Effect of different sources of iron and sulphur on leaf chlorosis nutrient uptake and yield of groundnut. Fertilizer Research 24: 85-96.

Singh, A.L., Y.C. Joshi and Vidya Chaudhari and P.V. Zala (1990b) Effect of different sources of iron and sulphur on nutrient concentration of groundnut. Fert. Res., 24, 97-103.

Singh, A.L., Vidya Chaudhari and V.G. Koradia, (1991a). Foliar nutrition of nitrogen and phosphorus in groundnut. In D.N. Tyagi et al. (editors) Physiological Strategies for Crop Improvement: Proceedings of the International Conference of Plant Physiology. pp. 129-133. B.H.U., Varanasi, India.

Singh, A.L., Y.C. Joshi, Devi Dayal and J.B.Misra 1991b. Application of different sources of sulphur in groundnut. In Proceedings of the National Seminar on Sulphur in Agriculture. In R.Siddharmappa P.K.Vijaya Chaudahry and

L.Susheela Devi; (edts.) University of Agricultural Science Bangalore and Fertilizer and Chemicals Travancore Limited. Cochin India. pp.76-81.

Singh, A.L., Vidya Chaudhari and V.G.Koradia. 1993. Spray schedule of multimicronutrients to overcome chlorosis in groundnut. Indian J.Plant Physiol. 36: 36-40.

Singh, A. L., Vidya Chaudhari, V.G. Koradia and P.V. Zala, 1995. Effect of excess irrigation and iron and sulphur fertilizers on the chlorosis, dry matter production, yield and nutrient uptake by groundnut in calcareous soil. Agrochimica 39: 184-198.

Supakamnerd, N., B. Dell and R. W. Bell (1990): Diagnosis of sulphur deficiency in peanut (Arachis hypogaea) by plant analysis. In : M.L. Van Beusichem (Editor) Plant Nutrition- Physiology and application. Proceedings of the XIth International Plant Nutrition Colloquium 30 July -4 August 1989, Wageningen, Netherland Kluwer Academic Publishers, Dordrecht pp.791-795.

Takkar, P.N., I.M. Chhibba and S.K.Mehta. 1989. Twenty years of coordinate research on micronutrients in soils and plants. IISS Bulletin No.1, Indian Institute of Soil Science, Bhopal, India.

Takkar, P.N., M.S. Mann and N.S.Randhawa. 1975. Effect of direct and residual available zinc on yield, zinc content and its uptake by wheat and groundnut crop J.Indian Soc. Soil. Sci. 23: 91-95.

Tandon, H.L.S.1990. Fertilizer recommendations for oilseed crops. A guide book, FDCO, New Delhi.

Tandon, H.L.S. 1991a. Sulphur Research and Agriculture Production in India 3rd edition FDCO, New Delhi ,India.

Vose P. B. 1982. Iron nutrition in plants : A world overview. J. Plant Nutr. 5: 233-249.

Walkar, M.E., T.P. Gaines and M. B. Parker 1989. Potassium, magnesium and irrigation effects on peanuts grown on two soils. Commun. Soil Sci. Plant Anal. 20: 101-1032.

Williams, J. H. 1979. The physiology of groundnuts (Arachis hypogea L. cv. Egret). II. Nitrogen accumulation and distribution. Rodesian J. Agr. Res. 17: 49-55.

Zharare, G. E., C. J. Asher and F. P. C. Blamey , 1997. Net influx of calcium and efflux of potassium in groundnut pods grown in solution culture. In Plant Nutrition-For Sustainable Food Production and Environment (T. Ando et al Eds) pp 177-178. Kluwer Academic Publishers, Printed in Japan.

Zuo, Yuan Mei, Zhang FuSuo, Li XiaoLin, Cao YiPing, Zuo YM, Zhang FS, Li XL, Cao YP 2000. Studies on the improvement in iron nutrition of peanut by intercropping with maize on a calcareous soil. Plant and Soil. 220: 13-25.

About the Authors

Dr Amrit Lal Singh is currently working as a Senior Scientist in Plant Physiology at the, National Research Centre for Groundnut, ICAR, Junagadh. Dr. Singh obtained his M.Sc. (Botany) from Banaras Hindu University, Varanasi and Ph.D. in Botany from Utkal Univ. Bhubaneshwar. He worked on the biological nitrogen fixation by Azolla-Anabaena complex and blue green algal biofertilizers and successfully demonstrated their use in rice. Dr Singh, joined ICAR as an ARS Scientist in Plant Physiology, two decade ago and since then working on the various aspects of groundnut physiology with special reference to mineral nutrition in problem soils of both western and north-eastern India. He is the life member of more than a dozen of scientific societies and published more than 100 research papers in the national and international journals of repute. He has also contributed 15 review articles and book chapters and two technology bulletins.

Dr. Mukti Sadhan Basu is currently working as Director, National Research center for groundnut (ICAR) at Junagadh. Dr. **Basu** had his Ph.D degree in Plant Breeding and Genetics from University of Calcutta. He worked on Jute for more than 10 years and on groundnut for more than 20 years. He was the Project coordinator-groundnut for a period of more than 10 years (1988-2000) and contributed significantly to the growth and productivity of groundnut in India. He has served as Indian Leader of the International projects on water use efficiency by ACIAR, Australia and ICAR, India, and UNDP project on promotion of aflatoxin risk free groundnut as food crop for sustained nutritional security. He has published more than 100 research papers in the national and international journals and about 20 technical bulletins on various aspects of groundnut, besides several book chapters.

Dr. N.B. Singh is currently working as Assistant Director General (Oilseeds & Pulses) at the ICAR, New Delhi. Dr. Singh has a Ph.D degree in Plant Breeding from the reputed University of Minnesota, USA. He served Rajendra Agricultural University, Pusa (Bihar) as Professor of Plant Breeding for more than one decade. As distinguished Professor he has served International Crops Research Institute for Semi- Arid Tropics (ICRISAT), Hyderabad as visiting Scientist for more than three years. He has contributed a number of research papers in the area of oilseed and pulse crops improvement in national and international journals of repute. Also he has edited a number of books on oilseeds and pulses. He has long experience of working at ICAR, New Delhi as Assistant Director General of Pulses and Oilseeds. He is a widely recognized scientist for his contributions for improvement of both pulses and oilseeds crops in India.