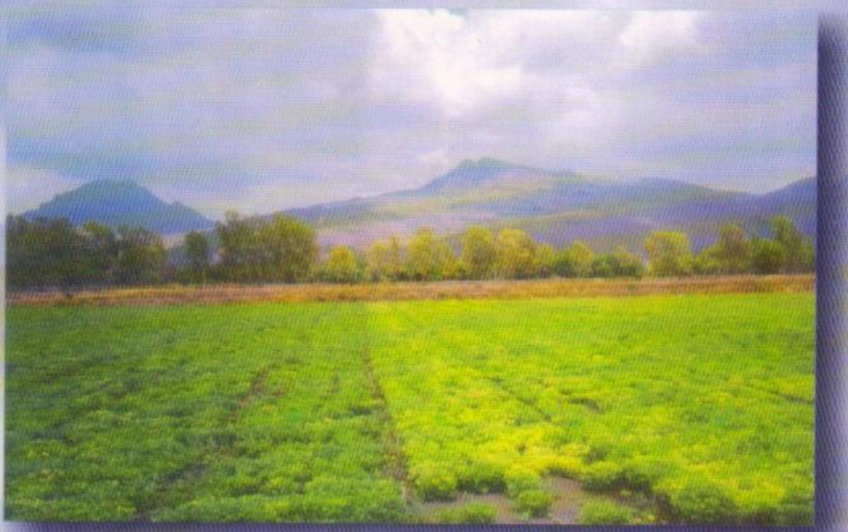
Integrated Nutrient Management in Groundnut

-A Farmer's Manual



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Cover photo	:	groundnut field showing normal and mineral deficient crop
Back page photophoto	:	Groundnut in nutrient blocks- an INM experiment

Preface

Groundnut is an important food legume and oilseed crop of tropical and subtropical areas and cultivated on about 25 million hectare of land in more than 90 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 $ha^{-1.}$ There are fluctuating trends in area and production of groundnut in India, however, it is grown on an area of about 8 million hectare, producing about 8 million tonnes. India has the largest groundnut area 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.

In past 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 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. Also the groundnut, being drought tolerant in nature, suffers from the nutrient deficiencies in semiarid and arid climate, however, in high rainfall areas metal toxicities are the major problem both resulting in low yield. The productivity of groundnut, in India, is still low (approximately 1000 kg ha^{-1}) mainly due to low consumption of fertilizer (4.0 % approx.) inspite of prominent nutrient deficiencies.

Thus, to optimize the production of groundnut, optimization of the mineral nutrition through integrated approach is the key. The visible symptoms are often used to help identify the nutritional disorders, which require a good description and high quality photographs of the symptoms. An integrated approach to plant nutrient management has gained momentum and has become more essential due to the escalating production cost of mineral fertilizers. The residual toxicities of these fertilizers posing problem of environmental pollution, the depletion of essential nutrients due to indiscriminate use of inorganic fertilizers which has a threat to the sustainability of crop production. For sustained groundnut production the modern farming demand efficient and balanced fertilizer use through conjunctive use of organic, inorganic, biofertilizers and crop residue.

Looking to the need of farmers, work in this direction was initiated about 20 years ago at several places in India, the results and recommendations of which are scattered in various journals. In this farmers friendly manual, an effort was made to synthesize the knowledge on nutrient disorders problem of various groundnut growing areas of India and their cost effective solutions for the prevention and correction through integrated approach to enhance the groundnut yield and quality. As most of the time farmer is not able to diagnose the problem in this manual 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.

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 manual. The help received from the mineral nutrition group of this centre specially 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 manual will prove valuable to the farmers for integrated nutrient management of groundnut to increase their yield and quality.

Authors

Contents

1. Introduction

The groundnut is an important oilseeds, as well as food crop ranking 13th among the principal economic crops of the world. It is a poor man's nut and grown in a wide areas of tropical and subtropical region between latitudes 40°S and 40°N under different agro-climatic zones where rainfall during the growing season exceeds 500 mm. The roasted and various preparation of groundnut are used throughout the world. 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. In India though there are fluctuating trends in area and production of groundnut, it is grown on an area of about 8 million hectare, producing about 8 million tones 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. Between the decades of 70s and 80s, there is practically little difference in productivity and the increase in production in India were largely due to the expansion in areas. But in 90s the combination of improved genotypes and nutrient management practices 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 rain fed in dry lands, under low fertility and low input management, under vagaries of the weather conditions.

Though the average yield of groundnut in the world is around 1300 kg ha^{-1}, about 70 % of the world groundnut production occurs in the semi-arid tropics with average yield of around 800 kg ha^{-1} only. Also the groundnut, being drought tolerant in nature and being grown in semi arid region, suffers from the mineral nutrient deficiencies resulting in low yield. This is probably the reason why researchers, and farmers are not able to break the barrier of the stagnated yield in groundnut in semi arid region. However groundnut demands both as oilseed and food is increasing with population pressure.

Optimization of the mineral nutrition through integrated nutrient management with balance doses of all the nutrients is the key way to optimize the production of groundnut, as it is high nutrient requirement crop and being an unpredictable legume, if proper doses of fertilizers are not there, many a times there is either no response of any fertilizer or negative response of a single fertilizer. On contrary, the recently released high yielding groundnut cultivars mine more nutrients from the soil, but the groundnut farmers, in most part of the semi-arid region, use meager nutrient fertilizer following 30-40 years old recommendations and only one or two nutrients resulting in severe mineral nutrient deficiencies. This has resulted in shifting towards the old varieties like TMV 2, AK 12-24, GG 2 and SB XI in low fertility soils where the recently released cultivars fail.

Thus, it is a high time to look into the integrated nutrient management practices of groundnut for achieving high yield and advocate the suitable package of practices for optimization of yield. Looking to the need of farmers, work in this direction was initiated about 20 years ago at several places in India, the results and recommendations of which are scattered in various journals. In this farmers friendly manual, an effort was made to synthesize the knowledge on nutrient disorders problem of various groundnut growing areas of India and their cost effective solutions for the prevention and correction through integrated approach to enhance the groundnut yield and quality.

2. Major groundnut areas and prominent mineral disorders

Groundnut, besides being a premier oilseed crop, is also a valuable high quality protein, in India, and presently grown in about 260 districts in various states. Among the 9 annual oilseeds cultivated in India in about 25 million ha, groundnut share 32% of the total area under oilseeds and contributes 42% of the total oilseed production. Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra are the five major roundnut growing states account for about 85% of the total groundnut area and contribute nearly 85% of the total groundnut production. The Rajasthan, M.P., U.P., Orissa, Punjab and NE are the other states contributing significantly to groundnut production in India. West Bengal, Assam and NE Hill Regions are the potential Non-traditional areas where groundnut is grown in both rainy (uplands/terraces) and post rainy seasons with a productivity anywhere between 2000-4000 kg ha^{-1}. In India, majority of the groundnut area (5.5-6.0 m ha) is under rainfed where productivity fluctuates between 500-1500 kg ha^{-1} depending upon the monsoon. Rabi-summer groundnut, on the other hand is grown in about 1.5-20 m ha under assured moisture condition with a productivity of 2000-3000 kg ha^{-1}.

The major portions of the groundnut growing soils are coastal alluvial (Kutch and Saurashtra of Gujarat) which are medium black calcareous, red and mixed red (A.P., Karnataka, T.N., Rajasthan, U.P. and M.P.), and laterite (Karnataka and Orissa) and alluvial (Indo-gangetic plains of a portion of Punjab Haryana and U.P.). The prominent mineral nutrient deficiencies in the major groundnut growing areas and their causes are given in table 1.

The range of soil is so wide that some are having exceptionally low or excess amount of certain nutrients. The parental material and soil forming processes are the characteristic of the soil, which often determines the nutritional stress problem in soils and many nutrient deficiencies or toxicities can be often predicted from these. 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 lime Ca and Mg high CEC 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 and hence require liming.

Table 1. Major groundnut growing areas, soil types and mineral deficiencies

States and Regions	Soil types	Mineral deficiencies	Causes of Mineral deficiencies
Gujarat (Saurashtra)	Coastal alluvial, medium black calcareous, sandy to clayey	P, S, Fe, Zn and B	Calcareous soil, Low rain fall and excessive irigation
Kutch	Coastal alluvial, Sandy	P, K, S, Zn and B	Sandy soil, low soil fertility, low rain fall and drought
Andhra pradesh	Red and mixed red	N, P, Ca K, and B	Low soil fertility, and drought
Tamil Nadu	Red and mixed red	Ca, N, P, K, and B	Low soil fertility due to leaching
Karnataka	Laterite, red and mixed soils	Ca, Mg, N, P, K, and B	Excess and low rainfall, low soil fertility,
Maharashtra	Black calcareous	P, K, S, Fe, Zn and B	Calcareous soil, low soil fertility,
Orissa	Laterite,	Ca, Mg, N, P, K, and B	Excess and low rainfall, low soil fertility,
Rajasthan	Desert, Red yellow and mixed red`	P, K, S, Fe, Zn and B	Low fertility, sandy and calcareous soil, low rainfall and drought
Punjab and Haryana	Alluvial, alkaline	P, K, S, Fe, and Zn	Salinity, Alkalinity, excess irrigation
Madhya Pradesh and Chhatishgarh	Red and mixed red, Medium black	N, Ca, P, and K,	low soil fertility, and low rainfall
Uttar Pradesh	Alluvial, red and mixed red	Ca, P, K, and B	Salinity, Alkalinity,
Bihar & Jharkhand	Alluvial	Ca, P, K, and B	High rainfall and leaching
Assam & NE	Red, mixed red and laterite soils on Upland, tilla, and foot hill and alluvial in medium land	Ca, Mg, P, K, B and Mo	High rainfall, leaching, crusting erosion and compaction
West Bengal	Alluvial, red, mixed red and laterite soils	Ca, Mg, P, K, B and Mo	High rainfall, leaching, crusting erosion and compaction

Also with long history of cropping, the soil, which was sufficient in nutrients, became depleted and hence the nutrient deficiencies are widespread. In groundnut P, Ca, Zn, Fe and B are most widespread (Table 2) and their rectification may increase upto 70% yield and quality.

Table 2. Mineral deficiencies of groundnut in various states of India.

States	Deficiency (+) and sufficiency (-) of mineral nutrients										
	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	+	+++	+	++	-	++	-	-	-	-	+	+

The severity of deficiency of various nutrients indicated as Mild (+), medium (++), and severe (+++).

3. Major problem soils, causes of mineral disorders and yield losses

a. Problem soils

i. Calcareous and alkaline soils

Soils having pH value above 7 are calcareous and alkaline and about one third of the groundnut, in India, is grown on these soils, where chlorosis is of common occurrence. Most of the calcareous soil is spread in Gujarat, Maharashtra, Karnataka, Rajasthan, a portion of Bihar, Tamil Nadu and Punjab, which are the main groundnut growing belts. These soils are productive mainly due to high Ca and cations, their easy accessibility and the groundnut, due to its high Ca requirement, grow well on these soils. However, because of high availabilities of Ca and Mg, in these soils, and their higher uptake by plant show multi-nutrient deficiencies, which are very difficult to diagnose and rectify timely (plate 10). The chlorosis due to iron and sulpur deficiencies is major problems of calcareous and alkaline soils. Phosphorus and Zn availabilities is often low in calcareous soil.

ii. Acid Soils

The pH less than 6.5 in their surface zones are the acid soils, on which about 70 % of the groundnut, on global level, is grown with an average productivity below 800 kg ha^{-1}. These soils are 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. In India, the groundnut is grown on nearly 2.5 m ha of acid soils mainly in high rainfall areas of Tamil Nadu, Karnataka, Orissa, West Bengal, Bihar, Jharkhand, Chhatishgarh. 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, B and Mo, low water holding capacity, susceptible to crusting erosion and compaction. As these are not easily rectifiable, the concepts of fitting plant to soil may be more economical than the soil rectification.

b. Factor causing mineral disorders

The mineral nutrient disorders in groundnut limit crop production. As it requires all the essential nutrients in balanced proportions, deviation from this results 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 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. On the other hand the mineral toxicity occurs due to excess uptake of particular nutrients leading to blockage of path and absorption of certain essential elements.

Groundnut grows in an environment facing various climatic conditions and soil types and following factors are responsible for these mineral deficiencies and toxicities:

- 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 environment) preventing absorption of nutrients by plants;
- Changes in soil physico-chemical conditions such as pH and EC;
- Imbalance use of fertilizers;
- Induced deficiency (Al induced P and Ca deficiencies in acid soils and Ca-induced iron-deficiency in calcareous soil);
- Interaction between minerals during uptake and antagonism. Low or excess of any element influence the uptake of other nutrients also that may be synergistic (beneficial) or antagonistic (detrimental) effects. At low levels of K, the Ca and Mg uptake are more in groundnut plat tissues except seeds which decreased with increasing the levels of K. Similarly, the concentrations of K and Mg in plant tissues are high at low levels of Ca and increased with Ca levels;
- Use of intensive nutrient (response) requiring and nutrient in-efficient genotypes;
- Biotic (disease and pests) factors;
- The water availability, light intensities and duration and extreme temperature alter the concentrations of elements;

- The temperature influences the movements, translocation and utilization of elements by plants;
- Increasing light exposure reduces the N, P, K, concentration while shading increases the P, K, Al, Ca, Fe, and Mn concentrations and decreases the Cu, Mg, and Zn concentrations in leaves;
- The humidity influences the rate of transpiration and thus indirectly affects the nutrient content in plants;

Many a time the deficiency symptoms are confused with damage caused by insect-pest, disease, salt stress, water stress, pollution, light and temperature injury and herbicide damage. Toxicity of Al is similar to Ca and P deficiencies and toxicity of Mo or Se is similar to P deficiency. These factors are interrelated and interaction between them, for the absorption and utilization of nutrient by plants, is very complex. However, early detection of nutritional deficiency stress and metal toxicity are important as these stresses might extend to the entire plant if relief of stress is not employed and continuous shortage of a nutrient or nutrients might cause plant death.

c. Yield losses due to mineral deficiencies

Inadequate and imbalance use of nutrient is one of the major factors responsible for low yields in groundnut. India is the world's largest producer of groundnut where nutritional disorders cause yield reductions from 30-70% depending upon the soil types, soil nutrient status and groundnut varieties.

The estimated yield losses in groundnut due to the deficiencies of Fe, Mn, Zn, Cu, B, and Mo in India are 10-22, 8-17, 15-20, 13-15, 16-26 and 13-19 %, respectively. However, the yield losses due to the deficiencies of N, P, K, Ca, S and Mg in are 18, 31, 29, 27, 25 and 30 % indicating that all these are essential for harvesting high yield in India.

Providing the adequate quantity of nutrients can double the production and thus meeting the challenges of the future 20 years. The average worldwide yield increase due to application of calcium in the pegging zone is 24 %. The sulphur and iron deficiencies cause 15-29 and 14-40 % yield losses in calcareous soil world wide.

4. Essential mineral elements and their requirement

Groundnut requires 13 mineral elements for its growth and development. The essential mineral nutrients, based on their requirement by plant, 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. In groundnut, the macronutrients are largely involved in structure of and need more than 10 m mole kg^{-1} of dry wt. of plant, however the micronutrients act as catalytic and regulatory role in enzyme and are required relatively in small quantities less than 10 m mole kg^{-1}. Unlike other plant the groundnut nutrition is unique as the pod develops 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 Groundnut is an exhaustive crop and depending upon the yield, it removes large amount of macro and micronutrients (Table 3). A groundnut crop, with an economic yield of 2.0 to 2.5 t ha^{-1} removes 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, 150-200g Zn, 140-180 g B, 30-40g Cu and 8-10 g Mo which is quiet high and to harvest 5 t ha^{-1} pod in coming 20 years, it will harvest double the amount. Among these Ca, K, P and S Fe and B are involved in the kernel filling and oil synthesis and are always limiting hence need more emphasis.

Table 3. Nutrients removed by groundnut crop.

Pod yield (t ha^{-1})	Total dry matter (t ha^{-1})	Nutrient removed (uptake) by groundnut											
		kg ha^{-1}							g ha^{-1}				
		N	P	K	Ca	S	Mg	Fe	Mn	Zn	Cu	B	Mo
1.0	2.5	120	10	60	50	12	25	1.5	200	150	35	150	8
1.5	3.6	140	12	80	60	15	30	2.0	300	200	50	170	10
2.0	4.5	180	15	100	83	20	43	2.5	350	300	60	250	15
5.0*	10.0	300	40	150	150	40	60	10.0	800	600	100	300	50

* Projected yield and nutrient requirement by 2025

5. Diagnosis of mineral disorders

Visible symptoms, plant and soil analysis, pot 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. Therefore, it is necessary to critically observe and define these deficiency symptoms. The deficiency might be distinguished bases on the plant part that showing symptoms, presence or absence of dead spots and entire leaf or interveinal chlorosis.

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. 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:

- The N, P, K and Mg are redistributed from older to younger leaves and hence their deficiencies 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, and require continuous supply of element for maintaining healthy groundnut crop.
- The S, Zn, Mo and Cu have variable mobility in phloem and their symptoms appear on young as well as old leaves depending upon the factor, however, mostly these deficiencies occur on young leaves first.

Main keys to the visible symptoms of nutritional disorders

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 for the diagnosis. For quick diagnosis of various symptoms in groundnut, broadly these have been grouped under following three sections:

1. Symptoms pronounced on the older or basal leaves and organs

S.N.	Main symptoms	Differentiating symptoms	Mineral disorders
1.1	Symptoms common over the whole plants		
1.1.1	Older leaves mainly pale yellow	Pale to yellowish green chlorosis, starting at the leaf tips and dry up weak and prolonged thin stem	N deficiency
1.1.2	Older leaves green with or without dark yellow 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	
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	Mg deficiency
1.2.2	Older leaves mainly green with purple, red or brown pigmentation or lesions, with or without chlorosis	Older leaves with small dark brown to red-purple lesions resembling spots, green margin along the main veins form a Christmas tree pattern on moderately old leaves	Mn deficiency
		Older leaves with marginal yellow, of leaf tips margines followed by brown or reddish-brown necrosis.	K deficiency
		Older leaves with yellow white or brown margins and necrosis, wilted.	S, Na or Cl toxicities
		Grey to white necrotic lesions	Na toxicity
		Yellow interveinal chlorosis and red-purple lesions on the middle leaves.	Cl toxicity

2. Symptoms pronounced on the younger leaves and organs.

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		
2.1.1.1	Young leaves not wilted without necrotic spots	Young leaves yellowish-green, lemon-yellow or yellowish-white interveinal chlorosis and sharply demarcated green veins	Fe deficiency
		Young leaves with pale yellow or yellowish-green, including veins, veins are more yellow than blade	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	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, mottled area with red-brown interveinal lesions.	Mn deficiency
2.2	Terminal bud die off after of deformations on young leaves starting at the tips or at basal end	Leaves becomes cupped, 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)	Ca deficiency
		Terminal end thickened and stiff, young leaves turn pale green starting at the base, deformed, twisted and stunted, often thickened, right and brittle, shortened internodes, bushy or rosette appearance of the plant.	B deficiency

3. Symptoms prominent on both young and old leaves

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 mottled leaves with incurled margins.	Mo deficiency
		With or without interveinal chlorosis	S deficiency or Al-toxicity induced Fe and Mg deficiencies

b. Plant Analysis

The plant analysis involves a number of steps, sampling, sample preparation, laboratory analysis and interpretation of data and all these must be done carefully. There is a functional relationship between the crop yield and concentration of nutrients in the whole plant or an index tissue and 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. For field grown groundnut, the time of sampling and tissues, for various elements, are given 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 & Zn	Seed at 80 DAE and at harvest

Table 4. The low, sufficient and high nutrient concentrations in groundnut

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

Leaves are the major sink for nutrients accumulation during vegetative stage as a result high nutrient concentration is noticed at 40-60 DAE, but soon as pod development start, the developing pods become the major sink. Thus leaf samples at 40-60 DAE is the correct stage for most of the element, but for phloem-immobile elements Ca and B the seed concentration is the index.

As the critical level is a single value and varies with condition and genotypes, the sufficiency range is better the concept for interpretation of plant analysis in groundnut (Table 4).

c. Soil Analysis

Soil analysis can be used to predict the nutritional status of a soil before crop is planted as there is a functional relationship between the nutrient availability in soil and crop yields. It is assumed that the chemical extractants remove the whole or some part of the plant–available nutrient elements from the soil. The suitable soil extractants for various elements are listed in table 5.

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.

Table 5. Extractants use for soil analysis of nutrients

Nutrients	Extractants	Concentration	pH
N	Alkaline potassium permangnate	0.32 %	
P	Sodium bicarbonate	0.5 M	8.5
K, Ca & Mg	Neutral ammonium acetate	1.0 N	7.0
S	15 % calcium chloride	15 %	
Fe, Mn, Zn & Cu	Diethylene triamine pentacetic acid (DTPA)	0.005M DTPA +0.01M $CaCl_2$ +0.1M Triethanolamine	7.3
B	Hot water	-	-
Mo	Ammonium oxalate		3.3

d. 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.

e. Fertilizer trials

Though it requires large inputs of time and materials, by means of field experiments we can accurately establish the fertilizer requirement. 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. The limitations of field trial is that, only a few elements can be tested at a time.

f. Other diagnostic methods

The deficiencies of various elements show different florescence in light, and the measurement of same can diagnose the various deficiencies in the leaf. The. 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 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 the productivity by appropriate fertilization in groundnut. Biochemical diagnostic technique offers a new avenue for indirectly detecting nutrient status. In groundnut activities of peroxidase, Nitrate reductase and ascorbic acid oxidase serve good indicator for diagnosing Fe, N and Cu deficiencies, respectively.

6. Mineral disorder symptoms and their remedies

a. Nitrogen

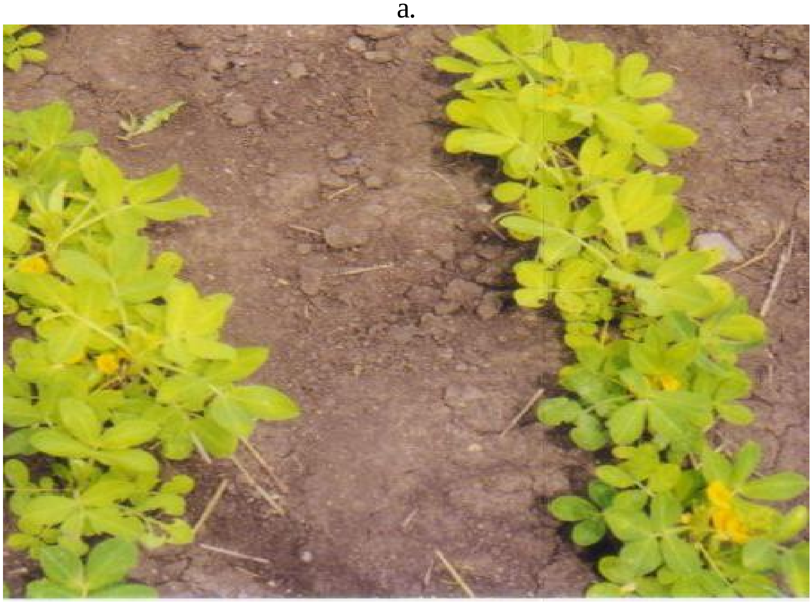
Nitrogen requirement of groundnut is much higher than cereals because of its high protein content, but most of the soils where groundnut is grown are deficient in nitrogen. The fact is that groundnut is capable of meeting its nitrogen requirements both from symbiotic nitrogen fixation (60-80%) by root nodules and soil nitrogen (20-40%). However, the nitrogen supply to groundnut is very crucial and deficiency is observed during early growth stages till 45 DAE and at pod formation stages. During reproductive stage, N is mobilized continuously from leaves to the developing pods and hence deficiency occur at this stage too. For these reasons N must be applied to groundnut at these stages.

In groundnut, as there is no early senescence of leaves, the yellowing of older leaves which later on die with age of crop is the most common nitrogen deficiency symptom (Plate 1). Besides that the N deficient crop shows weak and prolonged stem. The sufficiency levels of N, in leaves at full bloom stage (45-60 DAE), is in between 3.0-4.5 % and nitrogen deficiency symptom appears when the leaf N concentration falls below 2.2 %. However the critical concentration of N in leaves, at 45-60 DAE, is in between 2.5-3.0 % depending upon genotypes. For optimum yield, the N, P and S ratio should be around 15:1:1 in the 4^{th} leaves from top.

The *Bradyrhizobia* fix atmospheric nitrogen and supplies to the host plant. The Spanish and Valencia bunch groundnut, because of lesser Nitrogen-fixation and crop duration respond more to nitrogen than the Virginia. The virginia cultivars accumulate N at faster rate an and maintain higher N in leaves than the Spanish groundnut. The Native *Bradyrhizobium* are abundant and apparently able to fix adequate N at most of the places in India (except the rice fallows), hence there is no for inoculation with *Bradyrhizobium*, however the efficient strains must be inoculated in low nodulating areas and rice fallows.

Nitrogen needs of groundnut can be met through any available N sources, however, groundnut absorbs mainly nitrate nitrogen and urea, DAP and ammonium sulphate are the main preferred sources. Ammonium sulphate is preferred if deficiency is combined with S. In rainfed groundnut, N should be applied as basal in furrows, however split application is useful during good rain if there is no drought. Nitrogen should be applied in 2-3 splits in irrigated groundnut.

a.



b.

Plate 1. Field view of groundnut crop showing (a) severe N deficiency in early growth stages (15-30 days after emergence, DAE), (b) close view of a nitrogen deficient crop showing pale to yellowish green canopy.

The recommended doses of nitrogen are in between 20-40 kg ha $^{-1}$ for rainfed and 30-50 kg ha^{-1} for irrigated crop. Application of 20 kg N ha^{-1} as basal dose followed by two topdressing of 10 kg N ha^{-1} each at 30 DAE (Days after emergence) and 70 DAE produce highest groundnut pod and increased the efficiency of N fertilizer. Higher amount of N lead to excessive growth and decrease harvest index and pod yield.

b. Phosphorus

On global level, phosphorus is the most deficient element and is restricted to the area not fertilized with P. Most of the Indian soils, where groundnut is grown are deficient in P due to its fixation and low availability. Phosphorus is a component of certain enzymes and proteins, and involved in various energy transfer reactions and genetic informations. It limits N_2^--fixation, plant growth, shelling percentage and oil content and it is very critical at flowering and pod formation stages.

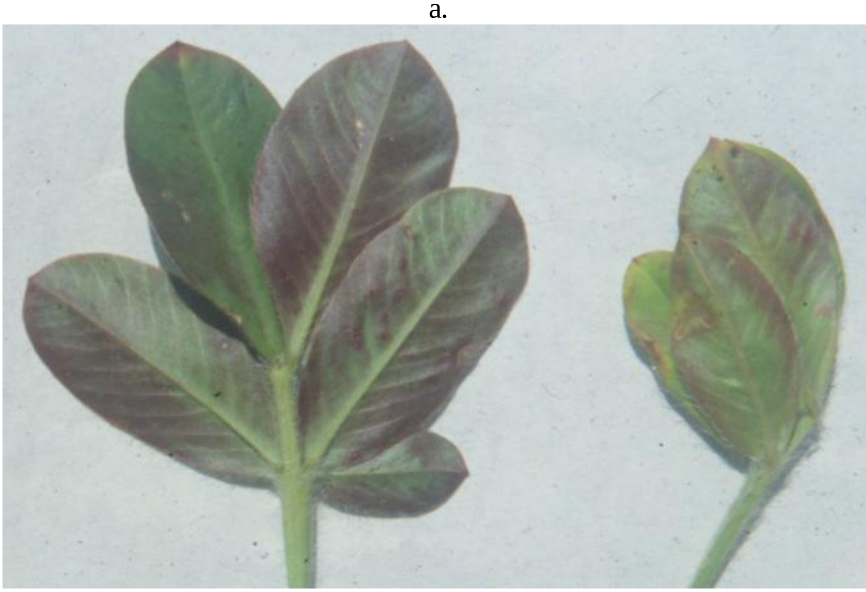
P deficiency causes purpling of leaf margin and stunted growth but more green in colour (Plate 2). The deficiency first occurs on older leaves and later spread to other leaves from the bottom, but it takes minimum of 4 weeks to appear the symptoms on plants. Some older leaves also become orange yellow, then brittle and finally shed.

The critical levels of soil available P, in surface soil, is 10 ppm available P groundnut. Leaf P content, at flowering, is the most standard plant part and age to determine the critical levels which is 0.22 % in Spanish and 0.25 % in Virginia cultivars. The sufficiency level of P, in leaves, is 0.26-0.35 % for Spanish and 0.29-0.50 % for Virginia cultivars at flowering, which declined over the time and is lowest (0.12-0.18 %) at harvest. The sufficiency level of P in seed is 0.4-0.62 %. The P fertilization at flowering and pod formation stages increase shelling percentage, oil yield and nodulation. The recommended doses are 30-40 kg P_2O_5 ha^{-1} during rainy season and 40-60 kg P_2O_5 ha^{-1} during post rainy season. Field application of 20 kg P_2O_5 ha^{-1} as basal and 20 kg P_2O_5 ha^{-1} at 30 DAE as single super phosphate (SSP) is best for maximum pod yield and fertilizer efficiency.

The Ca-P is the chief fraction involved in the P nutrition of groundnut. However, due to transformation of P into unavailable form in soil, the response of P to groundnut is not consistent and following practices need to be adopted:

- Use P-efficient genotypes in acid and calcareous soils.
- Use broad-bed and furrow system of cultivation.
- Single super phosphate is better than triple super phosphate.
- Drilling of P below the seed is a superior to broadcasting.
- Inoculate with efficient cultures of PSM and VAM.

a.



b.

Plate 2. (a) Groundnut crop in sandy soil of northern India showing severe P deficiency in early growth stages (15-45 DAE) with stunted growth, (b) leaf showing purpling of leaf margin and back, a typical symptoms of P deficiency.

c. Sulphur

The sulphur is as important as phosphorus for groundnut as it constitutes methionine and cysteine, increases oil synthesis, nodulation and pod yield and reduces disease incidence. The groundnut grown on coarse-textured sandy soils generally suffers from S deficiency due to leaching of SO_4^{2-} and is severe in Bihar, Gujarat, Punjab, M.P., U.P., Karnataka and A.P.

The S deficiency symptoms are like nitrogen but occur on young leaves and extend to middle showing pale yellow colour with vein showing white (Plate 3). The Fe and S deficiency symptoms appear together. The adequate concentration of S in the leaves is in between 0.2-0.35 % and S deficiency occurs when the leaf concentration falls below 0.17%. The critical level of soil available S is 10 ppm (heat soluble) in the surface layer (0-15 cm) and most of the groundnut growing soils, in India, are deficient in S. Calcareous and red laterite soils are more S deficient and application of 20-30 kg S ha^{-1} is essential.

Generally 20 kg of S ha^{-1} is sufficient for groundnut which can be met through either of gypsum, elemental S, pyrite and phosphogypsum. Plant takes up S mainly as SO_4^{2-} and the sulphur added to soil is subjected to microbial transformation by *Thiobacillus sp*. into SO_4^{2-} before the plants take it up. Application of 1 kg of nutrient S produce 13 kg pod and 4.3 kg oil ha^{-1}. Application of 10 kg S ha^{-1} as basal and 10 kg S ha^{-1} at 40 DAE is best for maximum pod yield with high fertilizer efficiency. The natural deposits of gypsum and pyrites are found in abundance in India and are effective sources of S. Pyrite is a good and cheap sulphur source for calcareous and alkaline soils. The S also shows synergistic effect with K and P on yield and nutrient uptake.

d. Potassium

Potassium is required for translocation of assimilates and involved in maintenance of water status of plant, the turgor pressure of cells and opening and closing of stomata. It increases the availability of metabolic energy for the synthesis of starch and proteins and helps in pod growth and filling. Most of the groundnut growing soils in western parts of India are rich in K, but the eastern parts are poor in K. However, the K deficiency is prominent in Tamil Nadu, Orissa, part of A.P., U.P., Gujarat and Maharashtra due to very high K requirement by groundnut, intensive cropping and very little or no potassium application.

a.

b.

Plate 3. Sulphur deficiency in groundnut, (a) field view of a crop showing S deficiency on young leaves, (b) young leaves showing pale yellow colour with vein showing white, a typical S deficiency.

The K deficiency is more common on the older leaves. Drying up of leaf margin with hallow yellowed margin and necrotic symptoms and reddish coloration of tip of leaves and branches (Plate 4). The stem becomes red by excess storage of starch and leaves light green. Some times, there is interveinal chlorosis. As groundnut roots are highly efficient in obtaining soil K, the sufficiency level of K in soil is above 20 ppm K. The normal K content in leaf is 1.5 % and deficiency occurs below 0.5 %. The soil having less than 150 kg ha^{-1} exchangeable K is deficient in K and has to be fertilized with 50 kg ha^{-1} K_2O ha^{-1}.

The recommended doses of K are 25-50 kg K_2O ha^{-1} for rainy season and 40-75 K_2O ha^{-1} for post rainy season irrigated crop. Large seeded groundnut requires more K than the small seeded one. It should be applied as basal in the furrows. However, top dressing also gives good results.

e. Calcium

Calcium maintains cell integrity and membrane permeability, enhances pollen germination, activates number of enzymes for cell division and takes part in protein synthesis and carbohydrate transfer. In groundnut, Ca is more important as often lack of Ca reduces the yield and quality more than any other element. Early ovule abortion was prevented by adequate calcium supply. The groundnut grown on acid soils having low base saturation show prominent Ca-deficiency for which liming is must.

Calcium is taken up directly from the soil by pods, and inadequate supply results in pods without seeds called "Pops" or blackened plumule inside the seed known as “Black heart”. The plumule damage in seed is due to calcium deficiency. The calcium deficiency in leaf is characterized by development of localized pitted area on lower surface of leaves which later on converts into large necrotic spots (Plate 5). The adequate concentration of Ca in leaves is 1.2-2.0 %, at 50-70 DAE, and the tissue concentration less than 1.2 % is considered low, however, this calcium is immobilized in the leaves. Thus Ca content of seed in groundnut is the alternative and minimum Ca content in seed needed for maximum germination and seedling survival is 400 ppm. The critical levels of soil Ca is 250 ppm (1.25 meq 100 g^{-1} or 560 kg ha^{-1}) in root zone and 600 ppm (3 meq 100 g^{-1}) in pod zone, however the soil Ca more than 2 meq 100 g^{-1} in root zone and more than 4 meq 100 g^{-1} in pod zone is ideal.

The runner genotypes disperse their pods more than bunch genotypes typically providing double the soil volume available for calcium exploitation to pods. The Ca accumulation in pod is also positively correlated with the pod surface area, days required to maturity, and negatively with the pod thickness.

a.

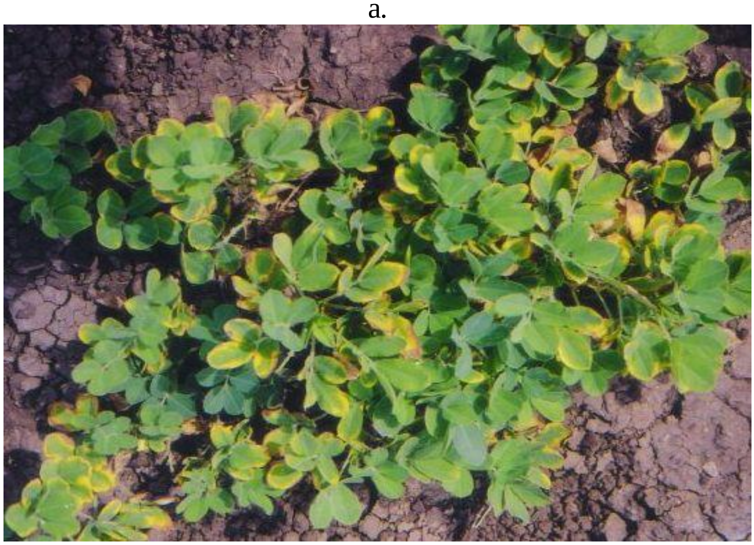


Plate 4. Potassium deficiency symptoms as (a) chlorosis and necrosis in older leaves, starting from the tips and margins of leaves extending towards the center of leaf base, (b) drying up of leaf margin with hallow yellowed margin and necrotic symptoms with reddish coloration of tip and branches.

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, however, for effective use of Ca following practices are recommended:

- The lime-stones (90% $CaCO_3$), dolomites, gypsum, phospho-gypsum, calcium oxide, CAN, Ties and Ca-rich waste products are Ca sources.
- In eastern and north-eastern states of India, invariably apply limeat 1-2 t ha^{-1} or higher depending upon the soil acidity and lime requirement.
- Calcium requirement is greater for pod filling than flowering, and it is greater for flowering than vegetative growth hence shallow incorporation, in the 5-10 cm of soil, of 1000 kg ha^{-1} lime in the furrows before planting or topdressing of 1000 kg ha^{-1} gypsum increases the availability of Ca in the pegging and podding zone.
- In high rainfall areas, lime is better than gypsum as gypsum is leached below pegging zone due to heavy rain, but lime remains in place..
- Excess of Ca produce 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.

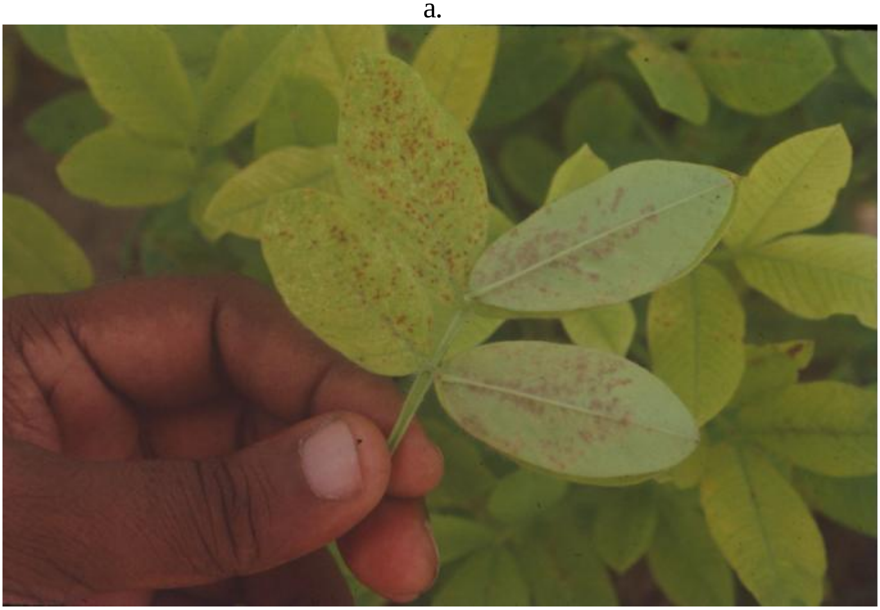
f. Magnesium

Magnesium is a component of chlorophyll and it serves as a cofactor in most of the enzymes that activate phosphorylation processes. The deficiency of Mg is a problem of acid and sandy soils, as under high rainfall it is leached out more easily. Like K the groundnuts are very efficient in extracting Mg from the soil, hence it rarely shows deficiency symptoms. However, the Mg deficiency in groundnut occurs in acid soils of Karnataka, Tamil-Nadu, part of A.P. and Eastern and North Eastern Hill Regions.

In Mg deficient plant interveinal chlorosis of basal leaves starts from leaf margin and advances towards midrib. In acute deficiency, the young leaves are also affected. The Mg deficiency is conducive to the occurrence of “Tikka” disease. The adequate concentration of Mg in leaves, at 50-70 DAE, is 0.30-0.80 % and the critical levels is 0.25 % for Spanish and Valencia cultivars and 0.20 % in Virginia cultivars. The sufficiency level of Mg in soil is 15 ppm for groundnut.

In Mg-deficient soil, though clearcut Mg deficiency are not observed, the hunger sign of Mg deficiency caused upto 25 % yield losses of groundnut where application of 20 kg $MgSO_4$ ha^{-1} is helpful. This also reduces occurrence of tikka disease.

a.



b.

Plate 5. Calcium deficiency in groundnut (a) field showing acute Ca deficiency as chlorosis (control) and healthy crop in limed field in acid soils of NEH, (b) leaf showing localized pitted area a typical symptoms of Ca deficiency.

g. Iron

Among all micronutrients, iron deficiency is most commonly observed in groundnut mainly due to its availability in root zone rather than abundance. It is most severe in calcareous and alkaline soils causing 16-40% yield losses. In groundnut, the Fe-deficiency appears 10-15 days after emergence in the field and remains throughout the cropping season with maximum intensity in between 30-70 DAE.

The Fe deficiency first appears as chlorosis of young rapidly expanding leaves characterized by interveinal chlorosis which later under severe deficiency, the veins also become chlorotic and leaves become white papery (Plate 6). The acute iron deficiency leads to dying of plant in the field. The Fe deficiency is visible when leaf Fe falls below 30 ppm , but the critical limit of Fe is 40 ppm and sufficiency level is 50-300 ppm. The total iron content of leaves, however, many a time may not show differences, and hence active iron (Ferrous iron) is taken as criterion where the chlorotic plants showed less than 12 ppm active Fe. The soil with less than 5 ppm DTPA extractable Fe showed Fe deficiency in groundnut.

Following Fe and S fertilizers, their doses and mode of application are recommended for effective amelioration of iron-chlorosis in groundnut:

Fertilizers	Nutrient doses (kg ha^{-1})	Amount of fertilizers (kg ha^{-1})	Mode of application
Iron sulphate	10-20kg Fe	50-100	Soil, 50% as a basal, 25% at 30 DAE and 25% at 50 DAE,
Fe-EDDHA	5-10 kg Fe	25-50	As above
Iron sulphate	2 kg Fe	10	Foliar sprays of 0.5% aqueous suspension thrice at 30, 50 and 70 DAE.
Iron sulphate	3 kg Fe	15	7.5 kg ha^{-1} as basal in the soil and 7.5 kg ha^{-1} on the foliage (three foliar sprays)
Iron citrate	2-3 kg Fe	9- 13 kg	Three foliar sprays of 0.5% aqueous suspension at 30, 50 and 70 DAE.
Gypsum	20-40 kg S	100-200	Soil, 50% as a basal, 25% at 30 DAE and 25% at 50 DAE,
Phospho-gypsum	20-40 kg S	125-250	As above
Elemental S	20 kg S	20	As above
Pyrite	20 kg Fe	43	As above

a.

b.

Plate 6. Groundnut plants showing (a) Fe-deficiency as interveinal chlorosis of young rapidly expanding leaves, (b) Screening for iron deficiency chlorosis in calcareous soil, with tolerant (green) and susceptible (yellow) genotypes during peak (60-70 DAE) growth stages.

The remedies of Iron-chlorosis are soil and foliar application of iron containing fertilizers and selection of Fe-efficient groundnut varieties. However, to manage iron-chlorosis, following strategies are recommended:

- Grow only identified iron-chlorosis tolerant genotypes.
- Keep the crop free from iron-chlorosis during 30-70 DAE.
- For prevention of iron-chlorosis apply 10-20 kg Fe ha^{-1} either as pyrite, iron sulphate or 10 kg Fe ha^{-1} as FeEDDHA.
- In the standing crop, foliar spray of 0.5% $FeSO_4$ + 0.02% citric acid at 500, 500 and 1000 l ha^{-1} at 30, 50 and 70 DAS, alleviate iron-chlorosis.
- In semi-arid region apply iron-fertilizer through drip.
- Inoculation with *Bradyrhizobium* and *Pseudomonas* also improve iron nutrition and correct iron-chlorosis in calcareous soil.

h. Manganese

The oxidation-reduction process, photosynthesis and oxygen evolution are governed mainly by manganese, besides it activates IAA oxidase and acts as a bridge for ATP and enzyme complex. Several enzymes activated by Mn and Mg can also function instead, but the photosynthesis and regulation of IAA are the highly Mn specific. Without Mn plant accumulates H_2O_2 causing cell damage. Indian soils are rich in Mn, yet the Mn deficiency is common in Punjab, M.P. Karnataka, Rajasthan and Gujarat. The Mn deficiency is a problem of high pH soil as the Mn content is inversely correlated to Ca and Mg levels, but in groundnut the Mn deficiency also occurr on soil pH as low as 5.8. The calcareous soils are Mn deficient owing to immobilization as insoluble MnO_2 at high pH.

The Mn deficiency appears as interveinal chlorosis of younger leaves and continues on older leaves. Chlorosis produces bold pattern of dark green major veins and is distinguishable from iron deficiency by appearance of varied but characteristic necrotic spotting or lesions on the leaf margins (Plate 7a). The critical Mn of soil is in between 3-5 ppm. The sufficiency level of Mn in leaf is 50 to 350 ppm at 50-70 DAE and concentration below 50 ppm is considered low, but the deficiency occurs at leaf Mn below 20 ppm. At low soil pH such as acid laterite soils, the availability of Mn increases to a toxic level producing necrotic pattern on leaves at 200 ppm of extractable soil Mn.

Soil application of 4- 6 kg Mn ha^{-1} as $MnSO_4$, MnO_2, $MnCO_3$, or $MnCl_2$ along with other fertilizers or foliar application of 0.2 % $MnSO_4$ thrice at 30, 50 and 70 DAE at a rate of 500 L ha^{-1} alleviate the Mn deficiency in field.

a.

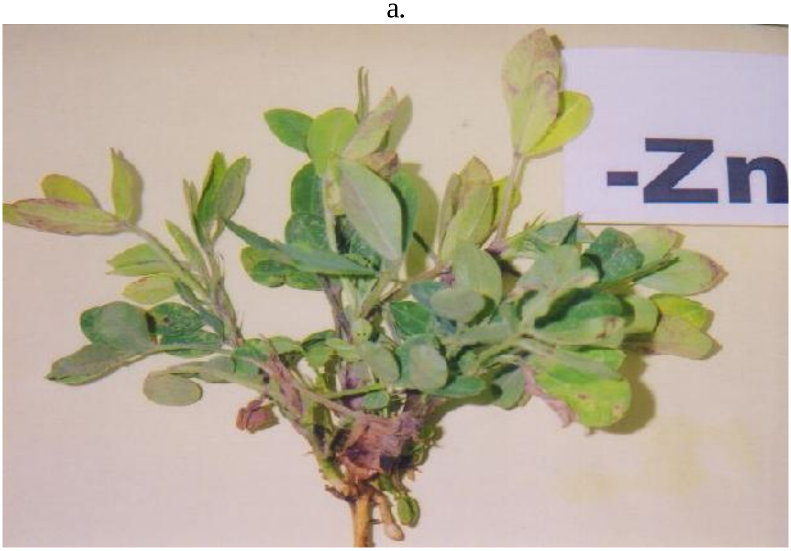


Plate 7. Groundnut plants showing (a) Manganese deficiency as interveinal and intercostal chlorosis of younger leaves with characteristic necrotic spotting or lesions on the leaf margins distinguish this from iron-deficiency, (b) Zn deficiency as interveinal to complete chlorosis in young developing leaves with bronzing and necrosis, and purple pigmentation on the lower surface of leaves and irregular mottling,

i. Zinc

The Zinc is involved in many enzyme systems and carbonic anhydrase is a very specific. Though 50% of the in India soil show Zn deficiency, in groundnut, it is more common in Haryana, M.P., U.P., A.P., Bihar, Punjab, Tamil Nadu and Gujarat in calcareous and alkaline soils that are low in organic carbon, high available P and bulk density.

The Zn deficient plant show irregular mottling in upper leaves with yellow-ivory interveinal chlorosis reducing size of young leaves which are some times clustered or borne very closely (Plate 7b). 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. Leaf tissue less than 20 ppm Zn shows deficiency and soil DTPA extractable Zn below 1.2 ppm reduced groundnut yield. However the critical levels in soil is 0.5 ppm DTPA extractable Zn.

The deficiency of Zn can easily be corrected by adding inorganic sources and zinc containing fertilizers such as $ZnSO_4$, ZnO at of 2- 4 kg Zn ha^{-1}. Soil application of $ZnSO_4$ is most common. Foliar application of 0.2% Zinc sulphate recover zinc deficiency in field. The Maximum response of Zn application is reported in A P, Bihar and Gujarat. Application of Zn through drip irrigation was more beneficial than its soil application.

j. Copper

Being a constituent of chloroplast, protein, plastocyanin, and enzymes cytochrome oxidase, ascorbic acid oxidase and polyphenol oxidase, copper participates in protein and carbohydrate metabolism and nitrogen fixation. It is also involved in the de-saturation and hydroxylation of fatty acids. The Cu deficiency is a major problem of organic and acid soils and occurs in UP, Gujarat, Kerala, Punjab and Tamil Nadu.

In copper deficient groundnut plant, the young leaves are curled. The plant becomes stunted, rosettes, interveinal crinkling and marginal wilting occur due to weakness of cell wall, but not due to water stress. The entire leaf becomes cupped and leaflet margins turn upwards. The pigments in flower decrease. The critical concentration of Cu in soil is 0.2 ppm and the groundnut shows deficiency at leaf Cu below 5 ppm.

As fungicide, Cu is commonly applied, hence it takes care as nutrient also. Application of 2 kg Cu ha^{-1} as $CuSO_4$, CuS and bordeaux mixture in the soil along with other fertilizers alleviate Cu deficiency. However it is advisable to apply 2-6 kg Cu ha^{-1} as $CuSO_4$ 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. Application of $CuSO_4$, as seed dressing is more beneficial. In the standing groundnut crop, foliar spray of 0.1% copper sulphate effectively controls Cu deficiency.

k. Boron

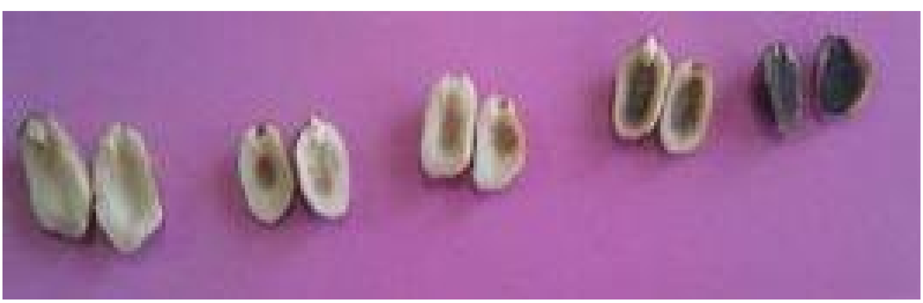
Boron facilitates translocation of sugar and fat synthesis and is important for RNA synthesis, cell division, differentiation and pollen viability and germination. The B deficiency occurs in neutral to alkaline and highly weathered soils and factors influencing the B deficiency are low soil organics, humic gley, moderate to heavy rainfall, dry weather, low light intensity and low soil B. The B deficiency, in groundnut, is more common in Tamil Nadu, Karnataka and AP, however, the hunger sign of B is alarming in Gujarat, Maharashtra, Bihar and part of U.P and response of B are very common.

The B is transported primarily in xylem and is relatively immobile in phloem and hence its deficiency occurs on the growing points. The symptoms are death of the stem apex, regeneration from the lateral bud, malformation of the leaf vein, chlorosis, necrosis of basal margins in rapidly expanding leaves. However, these symptoms are rarely observed in field grown groundnut, even on B deficient soils. The deficiency of B causes low filling of pod resulting in low shelling and the most common B deficiency symptom is hollow-heart of kernel in which the inner faces of the cotyledons are depressed and discolored reducing the quality of seed (Plate 8b). 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 sufficiency level of B in soil is 0.35-0.5 ppm hot water soluble B and B deficiency occurred at less than 0.2 ppm B, however, the critical limits of B vary from 0.2-0.4 ppm. The critical B level in leaf is 20 ppm, but clearcut deficiency symptoms observed only at below 15 ppm.

In B deficient soils, application of 1 kg ha^{-1} B as borax, boric acid or any other sources recover the deficiency, increase the number and proportion of large seeds. As there is a threat of B deficiency and the diagnosis of B requires specific symptoms and only seed are the criteria, soil application of 1.0 kg B ha^{-1}, either as basal or at 20-30 days after emergence, is recommended for production of well-filled and quality seeds of groundnut. In calcareous soil pod yield was highest at Ca: B ratio 200:300.

a.



b.

Plate 8. (a) Groundnut, plant showing severe Mo deficiency as yellowing of old and young leaves, with curled leaf margin, (b) Boron deficieny in seed 'hollow heart' of groundnut.

The B is required in small quantity and application of more than 10 kg ha^{-1} B shows toxicity symptoms in leaves as 5 ppm of B in the soil is toxic to the plant. The B-toxicity causes leaves curling with scorching, leaflets tips become yellow, interveinal chlorosis followed by necrosis, the chlorotic area golden yellow at margin.

I. Molybdenum

In groundnut, molybdenum is essential for nitrogen fixation, nitrogenase and nitrate reductase enzymes. The Mo deficiency disrupts nitrogen metabolism and shows nitrogen deficiency as Mo deficient plants do not show nodule. The factors influencing Mo deficiency are low soil Mo, acid organics, high free Fe. Though Mo availability increases with pH, the deficiencies are quite likely to occur on soil with high pH also.

The Mo deficiency results in reduction of chlorophyll in the leaves first in older leaves and then progress towards the younger until plant die (Plate 8a). The leaves show bright yellow, green interveinal chlorotic mottling, at later stages, leaf margin curled and leaves collapse. The deficiency has largely been reported in acid soils. The critical limit of Mo is 0.04 ppm in soil and 0.2 ppm in leaves.

Application of 0.5-1 kg ha^{-1} ammonium or sodium molybdate with seed or fertilizer or foliar application of 0.01% sodium molybdate alleviates Mo deficiency in groundnut and its application is vital in acid soils. However soil Mo above 1 ppm is toxic to groundnut as the range of sufficiency and toxicity is narrow.

7. Integrated Nutrient management practices

Integration of various nutrient management practices is the only solution to overcome the problem of nutrient deficiencies and toxicities in groundnut as no single method of correction work in isolation. It has become more essential due to the escalating production cost of mineral fertilizers, their residual toxicities posing problem of environmental pollution, the depletion of essential nutrients due to indiscriminate use of inorganic fertilizers and threat to the sustainability of crop production.

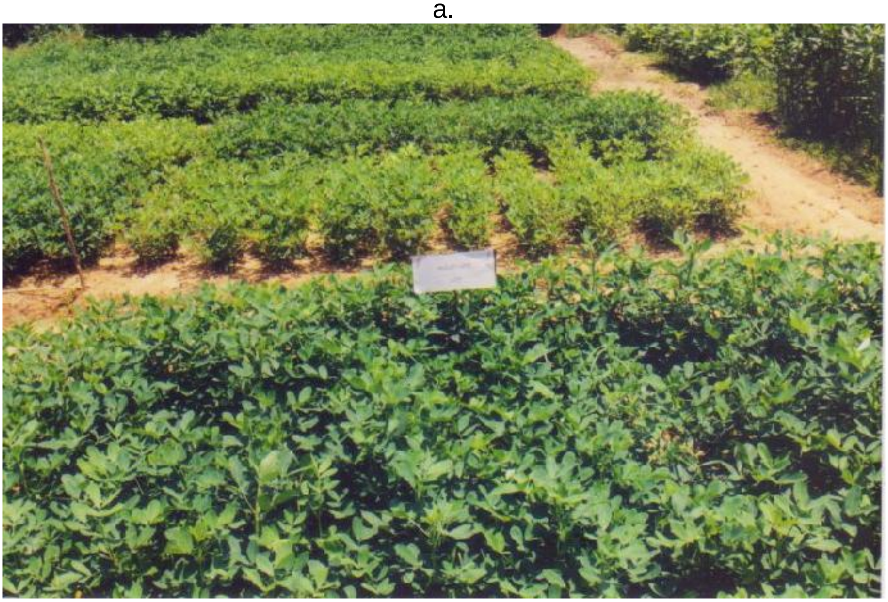
For sustained groundnut production, the modern farming demand efficient and balanced fertilizer use through conjunctive use of organic, inorganic, biofertilizers, efficient crop genotypes and crop residue (Plates 9, 10, & 11). Some of the commonly used measures are summarized in Table 6. This require meticulous planning at farmer level as it is a major decision in groundnut cultivation. Several inputs are required to implement the entire INM package the various components of which are are discussed separately in this chapter.

a. Liming and Ca fertilizers

As the calcium requirement of groundnut is very high and it is grown on a wide range of soils, the liming or gypsum application is must. Liming ($CaCO_3$) and gypsum application is most economical and easy to adopt by groundnut farmers as the return per rupee invested on lime and gypsum is twice when applied as fertilizer in furrows. The calcareous soils of Gujarat, Maharashtra, Karnataka and Rajasthan are most suitable for groundnut cultivation mainly due to its high Ca and cation contents and their easy accessibility by pods, good soil aeration and peg penetration due to looseness of soil, where no liming is required. But, in the rest part of India wherever groundnut is grown, either liming or gypsum application is most essential.

The acid soils, due to high rainfall and leaching, are deficient in Ca, S and Mg with low base and cation exchange capacity (CEC) and require liming to bring the soil to neutral and productive (Plate 5a). The Lime requirements (LR) of acid soils in India varies from 3.0-30 t ha^{-1} depending upon the texture, pH and organic matter content, however, application of 2-2.5 t ha^{-1} lime in furrow is good enough. The CEC is the capacity of the soil's (clay mineral and organic matter) providing negative site to bind exchangeable bases such as K, Na, Ca, Mg besides Fe, Mn, Al, Cu and Co etc and more the base saturation better the

a.



b.

Plate 9. (a) healthy Groundnut crop inoculated with *Bradyrhizobium* (right) and a N deficient crop without inoculation (left) in acid soil, (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 of NEH.

Table 6. Methods of correcting various nutrient deficiencies

Nutrients	Corrective Measures
Nitrogen	Application of N fertilizer and organic matter to soil, use of N-efficient cultivars.
Phosphorus	Application of P fertilizers and PSM, AM and P-efficient cultivars, amendments to maintain soil pH near neutral in acidic soils.
Potassium	Application of crop residue and potassium fertilizers
Calcium	Liming ($CaCO_3$) of acid soils; addition of gypsum or other soluble calcium source where lime is not required
Magnesium	Soil application of dolomite, magnesium sulfate or nitrate
Sulfur	Soil application of pyrite, ammonium sulfate; single super phosphate; gypsum or elemental sulfur.
Zinc	Soil and foliar (0.2%) application of zinc sulfate.
Iron	Soil application of Fe-EDDHA or iron sulphate, foliar spray of 0.5 % iron sulfate + 0.02% citric acids, use of Fe-efficient cultivars
Copper	Soil or seed application of copper source of fertilizer or foliar spray of 0.1-0.2% solution of copper sulfate
Boron	Soil application of borax, boric acid or any other B sources, 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% ammonium molybdate.
Manganese	Soil application of Mn sources, foliar application of 0.2% manganese sulfate

soil fertility. Liming increases solubility of Fe and Al phosphates and helps to retain phosphates in Ca-phosphates form.

The press mud a waste of sugar factory and basic slag from paper and other factories are the other liming materials. The sludge of paper mill with 60-80% $CaCO_3$ and press-mud, with 13 % organic matter and 42% Ca, are effective ameliorant. Basic slag contained as much P_2O_5 as SSP. The leaves of local tree species (teak, mahua,) with high Ca can be used as mulch in acid soil.

b. Chemical Fertilizers

Various fertilizers and manures used in groundnut and their nutrient contents are given in table 7 and their doses for rainfed and irrigated groundnut for various states of India, in Table 8. The average recommended doses of N, P and K are 20, 40 and 40 kg ha^{-1}, respectively for rainfed groundnut and 25, 50

a.

b.

Plate 10. (a) Multinutrient deficiencies in field grown groundnut in calcareous soil and (b) a luxuriant crop at optimum INM practices in acid soil of NEH region.

and 50 kg ha^{-1}, respectively, for irrigated groundnut. However, due to extensive cropping, the deficiencies are becoming more and more. In the present context 30 kg N, 40 kg P_2O_5 and 40 kg K_2O per hectare for rainfed *kharif* and 40 Kg N, 50 kg P_2O_5 and 50 K_2O per hectare for irrigated rabi-summer must be applied for maximum yield. For secondary macronutrients 500-1000 kg ha^{-1} of gypsum, 20 kg ha^{-1} S as Elemental sulphur and 10 kg ha^{-1} Mg as magnesium sulphate is applied. Among the sources, Ammonium sulphate for N and S, SSP for P and S, gypsum for Ca and S. The recommendation of micronutrients are location specific, however, the iron-sulphate for Fe, zinc sulphate for Zn and Borax for B are the preferred chemical fertilizers and must be applied as these deficiencies are of common occurrence in groundnut throughout India.

i. Fertiliser selection and Balanced doses

Use of balanced doses of efficient fertilizers is the most essential part of the chemical fertilization in groundnut. If not balanced, its adoption will never give the best possible yield and profit and many a time there is negative effects especially in case of P fertilizers. Before recommending a fertilizer, it is essential to know, which nutrients to use and how much, which fertiliser to choose and how and when to apply. For best response of P and S, in various soils, following integration are recommended base on the duration of groundnut cultivars:

		Duration and habit group of Groundnut cultivars	
Soil reaction	Sulphur deficiency	Short (110 days Spanish and Valencia)	Medium to long (More than 110 days Virginia)
Acidic	Yes	SSP or SSP + Rock P mix or SSP + FYM mix	SSP + Rock P, Rock P + FYM & AS for N + S or APS
	No	Any P or mixture having 30-50 % water soluble P- source (WSP)	Rock P + FYM or 30 % WSP
Near Neutral	Yes	SSP* or APS or any high WSP source with AS or gypsum for S	Rock P + SSP, APS or source with 50-70 % WSP with gypsumor AS for S
	No	Any high WSP	Rock-P + FYM or any source with 30-60% WSP
Alkaline	Yes	SSP or APS or any water soluble P with AS or gypsum for S	SSP, APS or 30-70 % WSP with AS or gypsum for S
	No	Any source with over 80 % WSP	Any source with 30-70 % WSP

a.

Plate 11. (a) Integrated nutrient management using combination of fertilizers, manures and groundnut genotypes and (b) efficient nutrient application through drip.

Table 7. Fertilizers and manures used in groundnut and their nutrient contents

Fertilisers and Manures	Nutrient content (%)				
	N	P_2O_5	K_2O	S	Others
Ammonium sulphate (AS)	21	0	0	24	-
Calcium Amm. Nitrate (CAN)	25	0	0	0	Ca
Urea	46	0	0	0	-
Ammonium Polyphosphate (liquid)	10	34	0	-	-
Mono Ammonium Phosphate	11	52	0	-	-
Mono Potassium Phosphate	0	52	34	0	-
Single Super phosphate (SSP)	0	16	0	12	20% Ca
Boronated SSP	0	16	0	12	20%Ca, 0.18% B
Potassium Chloride (MOP)	0	0	60	-	40 % Cl
Potassium Sulphate (SOP)	0	0	50	18	-
Potassium Magnesium Sulphate	0	0	22	22	11 % Mg
Diammonium Phosphate (DAP)	18	46	0	1	-
Urea Amm. Phosphate (UAP)	20-28	20-28	0	-	-
Amm. Phos. Sulphate (APS)	16-20	20	0	15	-
Nitrophosphate	20-23	20-23	0	-	-
NPK Complex	12	32	16	-	-
Rock Phosphate	-	18-20	-	-	Ca
Gypsum (Agriculture grade)	-	-	-	13	16-19 % Ca
Phospho-gypsum	-	-	-	16	21 % Ca
Pyrites (Agriculture grade)	-	-	-	22	20 % Fe
Magnesium Sulphate	-	-	-	13	16 % MgO
Borax	-	-	-	-	10. 5 % B
Boric Acid				-	17 % B
SOLUBOR	-	-	-	-	19 % B
Iron Sulphate	-	-	-	12	19 % Fe
Fe-EDTA	-	-	-	-	12 % Fe
Manganese sulphate	-	-	-	15	30.5 % Mn
Zinc Sulphate	-	-	-	11-16	21- 33 % Zn
Chelated Zinc as Zn-EDTA	-	-	-	-	12 % Zn
Copper sulphate	-	-	-	13	24 % Cu
Cu-EDTA	-	-	-	-	9-13 % Cu
Ammonium molybdate	-	-	-		54 % Mo
Sodium molybdate	-	-	-		39 % Mo
Farmyard manure (FYM)	0.5	0.2	0.5	-	-
Rural compost	0.6	0.5	0.9	-	-
Urban compost	1.5	1.0	1.5	-	-
Oil cakes	5-7	1-2	1-1.5	-	-
Sludge of paper mill	5.8	3.2	0.6		60 % $CaCO_3$

Table 8. Fertilizer doses to maximize yield in major groundnut growing states.

State	Active nutrient (kg ha^{-1})						FYM (t ha^{-1})	Gypsum (kg ha^{-1})	Lime (kg ha^{-1})
	Rainfed			Irrigated					
	N	P_2O_5	K_2O	N	P_2O_5	K_2O			
Andhra Pradesh	20	40	20	30	40	50	10	500	
Gujarat	20	40	40	40	50	50	5		
Karnataka	25	50	40	25	75	40		500	
Madhya Pradesh	20	40	40	20	80	80	10	500	
Maharashtra	20	40	-	25	50	-			
Orissa	20	50	40	25	50	50	5		1000
Punjab	20	40	40	40	50	50			
Rajasthan	15	60	-	20	60	-			
Tamil Nadu	20	40	40	22	44	66	10	500	
Uttar Pradesh	20	40	45	40	50	40			
WB and NE States	40	50	40	40	50	40			2000
Mean	20	40	40	25	50	50			

As no two fertilizers are alike, selection of the right one is an important step towards getting the best out of money spent on it :

- The fertilizers of different brands are much alike, but fertilisers without any brand differ in the amount of nutrients, solubility and cost per unit nutrient.
- Choice of the right fertilizer needs some basic knowledge of the differences between products and how they behave in different soils and cultivars.
- Ignorance, shortcuts and over simplification does not work. For example, a product priced at Rs 150/ bag is not automatically "cheaper" than one at Rs 200/ bag. One has to see the type and amount of nutrients in the two products for a valid comparison.

Technical recommendations generally confine to rates of nutrient application per unit area and only in some cases advocate specific products in case of N, P and K. The recommendations are often given in for the micronutrient fertilizers such as zinc sulphate, borax etc.

ii. Fertilizer calculations

The general formula for converting the amount of a nutrient recommended into the quantities of fertilizer required is:

$$\text{kg fertiliser needed} = \frac{\text{kg nutrient needed}}{\text{\% Nutrient in the fertiliser}} \times 100$$

For example, if 40 kg N ha^{-1}, and it is to be given through urea, then:

$$\text{urea needed} = \frac{40}{46} \times 100 = 87 \text{ kg urea or 1 bags + 37 kg (one bag =50 kg)}$$

This formula can be used for any nutrient through a straight fertiliser. The recommended doses of commonly used nutrients and their corresponding fertilizer doses are given in table 9 and the mode of application of micronutrient fertilizers in table 10.

In groundnut generally NP or NPK mixtures, ammonium sulphate and muriate of potash are used. The NP complex such as DAP is available but is not of 1:1 ratio hence use it to provide P_2O_5 first. DAP needed for 45 kg P_2O_5 = 45/46 x100 = 98 kg or 100 kg DAP which will also give 18 kg N. In this case the remaining 27 kg N (45-18) will have to be given through a straight N fertiliser. It can not be given through DAP because it will result in too much of P application. Two forms of zinc sulphate, heptahydrate with 21 % Zn and monohydrate with 33 % Zn are available and both are equally effective.

iii. Efficient fertilizer application techniques

Soil, foliar, seed dressing and drip application of fertilizers are the main application methods. After a product has been selected it has to be used at the right time and in the right way. Generally the split application is better than all as basal. The various mode of application are given in table.

Often farmers need to mix together fertilizers before application, due to differences in chemical and physical properties, not all fertilizers can be mixed. Following points need to remember:

- It is advisable to mix the micronutrient fertilizers with macronutrients.
- Urea can be mixed with most fertilizers just before application, but such mixtures should not be stored.
- MOP and SOP can be mixed with most fertilizers but their mixtures with urea cannot be stored.
- Super phosphates should not be mixed with lime, slag or rock P.

iv. Economics of Fertilizer use

The economics of fertilizer and manure use is essential because it should not just increase crop yield but the increase should be large enough to pay for its cost and give some profit as well. The economics of fertilizer use indicate, whether or not fertilizer use is profitable, the amount of profit or loss, the optimum dose, the rate of return (value of crop per rupee spent on fertilizer) and the effect of different factors on profitability of using fertilizer.

Table 9. Fertilizer calculations for groundnut

Fertilizer	Percent nutrient	Doses (kg ha^{-1})	Amount of fertilizer (ha^{-1})	Mode of application
Urea	46 % N	40 kg N	40/46x100= 87 kg urea	50 % as basal + 25 % each at 30 & 50 DAE
Ammonium Sulphate	21 % N	40 kg N	40/21 x 100 = 190 kg	-do-
DAP	46 % P_2O_5 and 18 % N	45 kg P_2O_5	45/46 x100 = 98 kg kg	50 % as basal + 50% at 30DAE
MOP	60 % K_2O	50 kg K_2O	50/60 x100 = 83 kg MOP	-do-
Ferrous sulphate	20 % Fe and 15 % S	10 kg Fe	10/20 x100 = 50 kg $FeSO_4$	50 % as basal + 50% at 30DAE
Zinc sulphate	21 % Zn	5 kg Zn	5/21 x100 = 24 kg	Basal in furrows
Manganese sulphate	30.5 % Mn and 15 % S	10 kg Mn	10/30.5 x100 = 33 kg	Basal in furrows
Copper sulphate	24 % Cu and 13 % S	5 kg Cu	5/24 x100 = 20.8 kg	Basal in furrows or seed dressing
Borax Sodium tetra-borate ($Na_2B_4O_7.10H_2O$)	10.5 % B.	2 kg B	2/10.5 x 100 = 19 kg	Basal in furrows
Boric acid (H_3BO_3.)	17 %, B	2 kg B	2/17 x 100 = 12 kg	Basal in furrows
Ammonium molybdate	52 % Mo	0.5 kg Mo	0.5 /52 x100 =1 kg	Seed dressing

Under good management practices, the return per rupee invested on fertilizer and manure varies from Rs 2 to 5. However, the fertilizer and manure use in groundnut is acceptable if each rupee spent on it produces crop worth Rs. 2 or more under low risk (irrigated) condition.

C. Organic manures and mulching

The role of organic carbon is the most important in Indian agriculture. Addition of organic matter, increases the physico-chemical properties by loosening the soil, increases fertility and enhances well-filled pod and sound

Table 10. Effective rates and method of micronutrient application in groundnut

Details of the micronutrient fertilizers/ chemical used		Rate and mode of application			Time and amount of fertilizer application
Chemical name and their formulae	% micro-nutrient	Rate nutrient ($kgha^{-1}$)	Mode of application	Amount of fertilizer ($kg\ ha^{-1}$)	
Iron sulphate ($FeSO_{4.}$ 7H O)	20 % Fe	3 kg Fe	Soil	15	5 kg each at basal, and 30 and 50 DAE
		3 kg Fe	Foliar(0.5 %aq. sol.)	15	1000 L each at 30, 50 and 70 DAE
			Drip	15	5 kg each at 30, 50 and 70 DAE
Zinc sulphate ($ZnSO_{4.}$ H_2O)	22 % Zn	2 kg Zn	Soil	9	3 kg each at basal, and 30 and 50 DAE
		2 kg Zn	Foliar (0.2 % aq.)	9	1000 L each at 30, 50 and 70 DAE
		2 kg Zn	Drip	9	3 kg each at 30, 50 and 70 DAE
Boric acid (H_3 $BO_{3.}$)	17 % B	1 kg B	Soil	6	2 kg each at basal, and 30 and 50 DAE
		1 kg B	Drip	6	2 kg each at 30, 50 and 70 DAE

mature seeds in all the soils. In acid soil it immobilize Al^{3+} ions by forming chelates and reducing the harmful effect of aluminium, and in calcareous soil it reduces the Fe, Zn and P deficiencies. The absence of organic matter results in high hematite and soil compactness in acid soils causing poor pod filling.

Various organic materials used in groundnut are compiled in table 11. Organic fertilizers always show its superiority over inorganic one and decomposed farm yard manure (FYM) at 10 t ha^{-1} alone double the groundnut productivity in any soil at any time with the responses are always superior than that of 40:60:40 kg ha^{-1} NPK fertilizers. The FYM, cakes of oilseeds and neem, biogas slurry, waste of peanut and cotton and mulching with local plant materials are the promising organic in western India and slurry from cow, rabbit and pig sheds, poultry manure and mulching with local plant materials, *Gliricidia* and subabul green leaf in NEH and eastern part of India and based upon the availability, any one of these could be used. However for immediate response FYM and cakes are the best. An INM practice including application of lime (2t/ha) or FYM (10 t/ha), half NPK doses (20: 25:25) and inoculation of PSM and *Bradyrhizobium* is recommended for Acid soils (Plate 10b).

Table 11. Organic manures, mulching materials and biofertilizers, their rates and effective used in groundnut

Name	Rate of application	Mode of application
Compost	FYM, 10 t ha^{-1}	Basal
	Cowdung (10 t ha^{-1})	Basal
	Vermicompost (5 t ha^{-1})	Basal
Oil seed cake	Mustard cake 1000 kg ha^{-1}	Basal
	Caster Cakes 1000 kg ha^{-1}	Basal
Cakes of caster and neem (3: 1 ratio)	750 kg/ha caster cake + 250 kg/ha neem cake)	Basal
Neem cake	500 kg/ha	Basal
Slurry	40,000 litre/ha biogas slurry (Cow dung) (4 t ha^{-1}dry wt.)	50% each at 30 & 50 DAS
	Rabbit slurry (20 tha^{-1} wet wt)	As above
Briquet of peanut shell and cotton waste	10 t ha^{-1}	Basal
Green manuring	Green manuring of Mungbean	Turned
Mulching with fresh material	Wild sorghum (20 t ha^{-1} fr. wt.)	Spread in between the plant rows at 20 DAS
	Gliricidia green leaf (10 t ha^{-1})	Half at time of planting and half 30DAE
	Subabul green leaf (10 t ha^{-1})	As above
	Ambrossia a weed (20 t ha^{-1} f.wt)	As above
Bun method of Farming	*insitu* application of green biomass (20 t ha^{-1})	As above
Biofertilizers (PSM + *Bradyrhizobium)*	500 ml ha^{-1} culture solution of PSM, *Bradyrhizobium* and PGPR each	Culture solution applied in the furrows at the time of sowing

d. Bio-fertilizers

Greater emphasis should be paid to the use of bradyrhizobium, phosphorus solublizing microorganisms (PSM) and plant growth promoting rhizobacteria (PGPR) biofertilizers as the cost of chemical fertilizers is increasing. *Bradyrhizobium* forms root nodules in groundnut, which fix 100-300 kg N ha^{-1} $crop^{-1}$, and for a successful inoculation a concentration of 10^6-10^8 cells ml^{-1}

of effective *Bradyrhizobium* is needed. An excellent response of *Bradyrhizobium* and PSM in groundnut is noticed in eastern and NEH states of India, with green canopy, where stunted growth with chlorotic leaves, poor nodulation and N and P deficiency symptoms is most common (plate 9).

Groundnut forms symbiotic association with certain zygomycetous fungi known as arbuscular mycorrhiza (AM) such as *Gigaspora calospora*, *Glomus mosseae*, *Glomus fasciculatus* and *Glomus macrocarpus* are known to augment plant phosphorus (P) uptake ability from soils deficient in this element. As groundnut roots show extensive AM colonization, inoculation with either of these resulted in growth stimulation and higher P uptake.

The *Bradyrhizobium* can be applied directly to seeds, but when groundnut seeds are coated with fungicides, applying a slurry of peat based inoculum in the seed furrows is most common. However the best way is to mix the *Bradyrhizobium* and PSM inoculum with water to form a suspension and apply the same in the furrows before the seed is sown. The effective *Bradyrhizobium* strains are: NC 92, IGR 6 and IGR 40 TAL 1000 and TNAU 14 which are recommended for their inoculation. The effective PSMs are *Bacillus polymyxa, B. circulans, Pseudomonas striata, Penicillium, digitatum,* and *Aspergillus, awamorii.* The effective PGPR for groundnut are as PGPR1, PGPR2 and PGPR4 which are strains of *Pseudomonas fluorescens.* These biofertilizer packets are available in the market. Field inoculations are always beneficial, but once proper soil population is established re-inoculation is not required.

e. Other amendments and Intercultural practices

Root aeration is most important in groundnut as it is sensitive to flooding and compaction. Flood irrigation aggravates problem of root aeration and respiration, inhibiting root growth and altering nutrient availabilities and metabolic functions. Plants becomes chlorotic due to mineral deficiencies caused by inability of roots to take up these. Broad-bed furrow method is beneficial especially where water stagnation during rainy season is a problem. The furrow made in system helps to drain of excess water thus improves the micro-environment especially aeration in the field.

Cultivation of groundnut in set-furrows is a common practice in Saurashtra region of Gujarat where it 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. Silt or sand are also mixed in furrows, for growing groundnut, during the field preparation to alter the soil physical condition suited for groundnut crop.

The farmers of the coastal belt of Sheel area of Mangrol in Saurashtra has been harvesting 4-5 t ha^{-1} pod yield of groundnut for the past 20 years and has won several state level awards for realizing high yield continuously for several years, in Gujarat. The main production factors and package of practices being followed are:

- The soils of the field are sandy to sandy loam red, yellow and black colour. The climate is humid and wind blow at a fast speed.
- The farmers grow the spreading varieties GG 10, GG 11, Sangadi etc
- The farmers in this area apply 3-4 tractor trolleys of the tonch (murrhum) per bigha (90-100 t ha^{-1}), which contains mostly calcium and also apply 3-4 trolleys of the seashore sand per bigha in the field, which contains mostly seashells. This helps in increasing the porosity of soil, water holding capacity and releasing the available Ca. These all finally helps in increasing the size of pod and yield.
- DAP is most widely used fertilizer applied @ 25 kg $bigha^{-1}$ (150 kg ha^{-1})
- As the incidence of iron-chlorosis is very high very high in the region, farmer use 3-4 spray of iron sulphate + 0.02 % citric acid at an interval of 10-15 days from 30 days onwards.

f. Cropping Systems

To maximize the nutrient use and to increase the cropping intensity and productivity, the groundnut is also grown as intercrop and sequence crop. In this approach two to three crops are grown in sequence or as intercrop. In crop sequence a crop, which is highly responsive to fertilizer and tolerant of soil acidity or alkalinity, is included as a first crop in rotation. Rice is a main component of acid soil cropping system and groundnut very much fit in the system as second crops as it is medium response. In north eastern region, groundnut can be successfully adapted as a companion crop with upland rice and maize.

The short duration semi-dwarf rice, maize, pigeon pea and cultivars are fit for intercropping with high yielding groundnut varieties. Groundnut is intercropped with base crop like maize in 2:2 rows ratio and upland rice (4:2 rows ratio). Adoption of sequential cropping with rice some times involves risk of partial or complete failure of groundnut crop grown after rice. Thus improvement of soil health through incorporation of a crop residue or FYM is essential before taking groundnut crop. The fertilizer doses for important cropping sequences are given in table 12.

The profitable and nutrient responsive crop sequences and intercrops are listed below:

Crop sequences	**Intercropping**
Groundnut-groundnut	Groundnut + Pigeonpea
Groundnut-chickpea	Groundnut + Castor
Groundnut-safflower	Groundnut + Sunflower
Groundnut-sesame	Groundnut + Sesame
Rice-groundnut	Rice + Groundnut (4:2)
Rice-potato-groundnut	Groundnut + Maize (1:1)
Rice - mustard-groundnut	Groundnut + Pigeon pea (5:1)
Maize - groundnut	Groundnut + Chili (2:2)
Groundnut – Mustard	Maize + Groundnut (2:2) – Mustard
Groundnut – Radish	Maize + Groundnut (2:2) – Radish
Groundnut – Potato	Rice + Groundnut (4:2) – Mustard
Groundnut-fodder maize	Rice + Groundnut (4:2) – Radish

Table 12: Fertilizer doses for important cropping sequences

Crop sequences	States/regions	NPK doses (kg/ha)	
		Groundnut	Sequence crop
Groundnut- mustard	Rajasthan, M.P., Punjab	20:30:30 + 20 kg S	80:40:40
Groundnut-wheat	Gujarat (Saurashtra)	20:40:25	120:60:0
	Maharashtra (Digraj)	20:30:0 + 2500 kg FYM	120:60:60
	A. P. (Jagtial)	20:20:10 + 500 kg FYM	60:60:40
Groundnut-rice	Orissa, A.P., Karnataka	20:30:30 + *Bradyrhizobium*	80:50:50
Groundnut-sunflower	Gujarat	20:40:40	20:20:0
	A. P.	20:40:20	40:60:40
	Tamil Nadu	11:22:33	40:60:40

g. Selection of nutrient efficient genotypes

Acid and alkali are the two major problem soils causing most of the nutritional disorders in groundnut. As these are not easily rectifiable the concepts of fitting genotypes to soil may be more economical than the soil rectification. This can be easily achieved by screening groundnut genotypes tolerant to these adversities. For acid soils there is need to grow P, Ca, K, B and Mo efficient genotypes which are also tolerant to Al and Fe toxicity. However, for calcareous soil, our strategy should be to screen for P, Fe, Mn and Zn and B efficient cultivars. Some of the nutrient efficient genotypes are listed in table 13 which may be used in low fertility nutrient deficient soils.

Table 13. Nutrient efficient and in-efficient genotypes

Nutrient	Efficient	In-efficient
N	JL 24, GG 2, GG 20,GG 7, Fe ESG 8, GAUG 10, TAG 24	SB 11, J11, VRI 3,
P	GG 5, GG 20, TKG 19A, TAG 24, Fe ESG 8, 10, NRCG Acc 1308, 3498, and SP 250A	VRI 3, PBS 16003, 20012 and 18057
P and Ca	TKG 19A, GG 20, ICGS 76, ICGV 86590, ICG 813, 1001, 1021, 1048, 1056, 1064, 1355, 3606, 10964,11183. ICGV 80338, ICGV-88348, ICG (FDRS)-40, ICG (FDRS)-50	ICG 2120, 4407, 6727, 6855, 7288, 7600, 7787, 7821, 10580, 11748.
K	GG 20, GG7, JL 24, GG2	
Ca	ICGHNG 88448, and, NRCG 6155, 5513 and 7599 FeESG 10	NRCG 6155 7417 NRCG 7472 and 162
S	NRCG 2588 and 1306 FeESG 10	NRCG 3498 and 4659
Fe	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, GG 20, NRCGs 389, 1308, 2588, 3498, 5513, 6450, 6820, 7027, 7258, 7267, 7417, 7607, 7599	VRI 3, ICGS 11, ICGS 44, ICGS 65, Chico, Robut 33-1, GAUG 1, Kadiri 2, TG 3, Co 1, ICGV 87276, NRCGs 7472, 162, NCAc 17090

Most of the nutrient efficient genotypes are high yielding too and hence recommended to grow. For example the Fe-efficient one may be grown in the area where problem of iron chlorosis is very serious, the Fe-inefficient genotypes, however can be grown in Fe-toxic areas of acid soils.

h. Polythene Mulch Technology

Use polythene mulch for rabi groundnut, where crop face winter and temperature goes below 15°C most of the time, enhances yield per unit area. The IPCL mulch film of 7-8 micron was tested in Meghalaya, Manipur and Assam where excellent results were obtained. The crop showd 10-12 days earlier germination and groundnut cultivar JL 24 produced 2193 kg ha^{-1} pod yield with polythene mulch as against only 175 kg ha^{-1} in control. In medium black-cotton soils of Maharashtra, Shri JB Gunde, an innovative farmer using polythene mulch on Broad Bed-and-Furrow (BBF) planting recorded 5.0-7.0 t pod yield ha^{-1} for 2 consecutive summer season as against 2.6 t ha^{-1} in non-mulched in the groundnut varieties TG 26, ICGS 11 and TAG 24.

Polythene show better soil-moisture conservation and temperature balance capacity in soil, which results in higher nutrient availability due to change in microclimate and micro flora, number and weight of pods, kernel weight and thus higher pod yield. The PMG can be adopted in the rice fallow residual moisture situation in Orissa, Tamil Nadu, Assam, West Bengal and low temperature areas of Punjab, UP and north eastern states during rabi summer.

i. Management of biotic and abiotic stresses

Proper nutrition is must to maintain a healthy crop as the nutrients help the crop grow well and provide the resistance to sustain against the disease, pests and abiotic stresses. Some of the tips for maintaining healthy crops are:

- Though, during drought the uptake of most of the minerals is restricted, application of Ca and K and S is beneficial. Gypsum helps the drought management by delaying the wilting and senescence of leaves.
- During cold season when the nutrient uptake and growth are reduced, application of N helps the crop grow well.
- Application of Mg and Fe reduce the incidence of Tikka and rust diseases.
- The role of Cu and S in disease management is well known and application of S reduces rust and leaf spots. The elemental S or copper sulphate when mixed with the seed act as a seed dresser and also as fungicides.
- Greater Ca and B is required for large seeded groundnut as improper nutrition of these causes cracking of pods and seed inviting the soil fungi especially *Aspergillus*, *flavus* to attack and develop aflatoxin.
- Application of Ca increased the thickness of seed coat leading to decrease in seed infection by *Aspergillus* spp., *Penicillium spp.* and *Rhizopus* spp.

8. Yield targeting and quality

The yield and quality determines the economic value of groundnut, 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 potential yield of groundnut is more than 15 t ha^{-1} and with good management practices a few farmers of Dharwad and Sholapur region are being harvesting 5-6 t ha^{-1} groundnut pods. A village in Mangrol area of Saurashtra regularly harvest 4000 kg ha^{-1} pods for the past 20 years. But the average yield of groundnut, in India, is around 1000 kg ha^{-1} clearly indicating that there is tremendous scope to increase the groundnut yield through precision farming and nutrient and agronomic management.

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 responses of nutrients to groundnut are very high on deficient and marginal soils, but limited systematic work has been done on these aspects. The desired yields only could be achieved with suitable fertilizer applied on soil test-crop response basis. This will enhance the fertilizer efficiency. According the groundnut yield can be targeted.

As the groundnut is much remunerative crop 1 kg pod can easily pay for 1 kg of most of the macronutrient. Depending upon the situation and soil types the response in term of pod production of groundnut are given below, accordingly the yield can be targeted as:

Nutrients	Response of nutrient on groundnut (kg pods kg^{-1} Nutrient)			
	1.0-2.0 t ha^{-1}	2.0-3.0 t ha^{-1}	3.0-4.0 t ha^{-1}	4.0-5.0 t ha^{-1}
N	6 -17	5-15	5-12	4-8
P	5 -14	6-12	4-10	3-8
K	8-12	8-10	7-10	5-8
Ca	10-25	10-20	8-15	6-10
S	9-13	8-12	7-10	5-8
Mg	5-10	4-8	3-6	3-5
NPK	4-9	3-9	2-8	2-6

Thus two distinct strategies need to be followed:

- Fertilize the soil deficient in the nutrient to avoid yield losses.
- Fertilize the crop to achieve the targeted yield.

In field, the yield target of 5-6 t ha^{-1} can easily be achieved, but the highest return is obtained in yield target of 2.0- 3.0 t ha^{-1}. However, all these depend mainly upon the soil available macro and micronutrients and its external application. A groundnut crop, with an economic yield of 2.0 to 2.5 t ha^{-1} removes 160-180 kg N, 20-25 kg P, 80-100 kg K, 60-80 kg Ca, 15-20 kg S, 30-45 kg Mg, 2-3 kg Fe, 300-400 g Mn, 150-200g Zn, 140-180 g B, 30-40g Cu and 10-15 g Mo. Thus to feed the new population towards 2020 we have to produce an average yield of 4-5 t ha^{-1} pod (i.e. 8-10 t ha^{-1} total biomass) for which will remove 300 kg N, 40 kg P, 150 kg k, 150 kg Ca, 40 kg S, 60 kg Mg, 10 kg Fe, 0.8 kg Mn, 0.6 kg Zn, 100 g Cu, 300 g B and 50 g Mo majority of which has to be applied through external sources.

The biological limitations for low yields in groundnut are to conversion of photosynthates to lipids. Unless the groundnut is provided with extra input, this crop is not expected to produce the same high yield as in case of cereals. As the groundnut is much remunerative crop, the fertilizer response in groundnut need not be compared with those of cereals because of the large differences in the energy or market values. These responses varied with states to states and soil types.

Fertilizers can influence quality, either indirectly by improving plant health, especially resistance to adverse climatic factors, diseases and pests; or directly, by increasing the content of essential and beneficial organic and mineral nutrients in seed and fodder. There are two separate aspects of quality :

- Market value, depending on easily recognizable external characteristics such sedd size and filling, content of oil, protein and sugar, etc.
- Nutritional value, comprising palatability (taste and smell, difficult to categorize), content of the many important organic and mineral nutritional constituents, and absence of undesirable or dangerous toxic substances.

Both of these could be increased by use of balanced and combination of organic and inorganic fertilizers in groundnut.

9. Major recommendations

- It is necessary to maintain expertise in the diagnosis and treatment of nutrient deficiencies through visual symptoms, among the farmers and consultation with groundnut scientists for plant and soil analyses.
- The Fe, P, Ca and S deficiencies are major problem of groundnut for which nutrient efficient cultivars must be used.
- Application of organic manures and lime or gypsum takes care of most of the nutritional disorders and hence must be applied.
- On low pH soil liming is must, however on neutral and alkaline soils gypsum is applied. For effective absorption, these must be applied in soil near pod zone. Depending upon the Ca level of soil, lime and gypsum application from 500-1000 kg ha^{-1} is sufficient. Double the rates of gypsum to all large-seeded peanuts, regardless of Ca soil test.
- The P deficiency is main problem throughout India causing low pod filling where application of 40 kg ha^{-1} P_2O_5 is recommended. Rock phosphate, is a cheap source of P, which may be used in acid soil, however for calcareous soil SSP is best.
- As P fertilizer is limiting, the P-efficient genotypes should be used which has superior ability to solubilise and take up P from soils with low P.
- In nitrogen deficient soils, application of 20 kg N ha^{-1} as basal dose followed by two top dressing of 10 kg N ha^{-1} each at 30 DAE and 70 DAE is useful.
- Inoculation with *Bradyrhizobium* and PSM is most essential
- Sulphur deficiency is the most common problem of groundnut and soil application of 20 kg ha^{-1} S in two splits of 10 kg S ha^{-1} as basal and 10 kg S ha^{-1} at 40 DAE either as pyrite, or as elemental S is most effective.
- The bold-seeded groundnut require higher amount of nutrients and farmers are advised to apply 1000 kg ha^{-1} gypsum or 2 t ha^{-1} lime, 50 kg ha^{-1} K2O and 2 kg ha^{-1} B.
- Apply K and Ca for production of quality seed and aflatoxin free groundnut.

- An INM practice including application of lime (2t ha^{-1}) or FYM (10 t ha^{-1}), half NPK doses (20: 25:25) and inoculation of PSM and *Bradyrhizobium* is recommended for Acid soils.
- Lime-induced iron deficiency chlorosis is a major problem of groundnut in calcareous and alkaline soils which can be ameliorated by growing iron-efficient genotypes and soil application of 50 kg ha^{-1} iron sulphate or 45 kg ha^{-1} pyrite.
- Foliar application of 0.5 % iron sulphate + 0.02 % citric acid thrice at 30, 50 and 70 DAE alleviate iron-chlorosis in the standing crop in the field.
- Three foliar sprays of 500, 500 and 1000 L ha^{-1} aqueous solution containing 0.5 % iron sulphate, 0.2 % zinc sulphate, at 30, 50 and 70 DAE, respectively is recommended for alleviating Fe and Zn deficiencies in the standing crop.
- The boron deficiency is problem of Tamil Nadu, Karnataka AP and Gujarat where 1 kg B ha^{-1} must be applied along with NPK fertilizers.
- Application of soluble or liquid fertilizer through drip irrigation increases fertilizer use efficiency and yield of groundnut in semi-arid region. This may be used wherever facility exist.
- Frequent foliar sprays are recommended for correcting Fe- and Zn deficiencies. Foliar spraying is most effective, and the risk of scorch is minimized, if the spray droplets do not dry too rapidly, hence spray is recommended on cloudy days and in the early morning or late afternoon.
- For maximum nutrient absorption maintain the soil loose and airy through 3-4 intercultural practices hoeing and watering during first 70 days.
- For maximum response and quality produce, maintain healthy crop throughout following optimum integrated crop management practices.

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