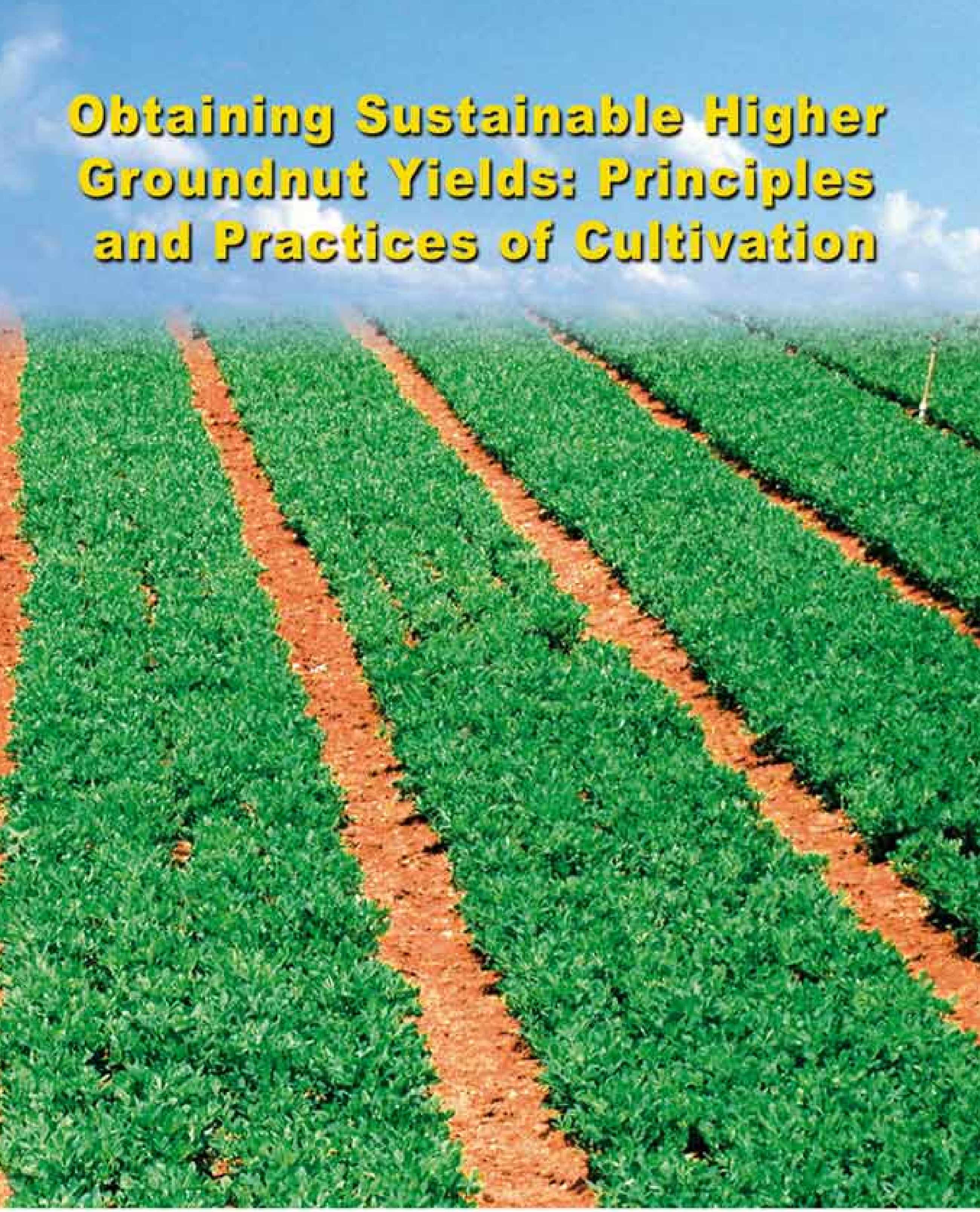
Obtaining Sustainable Higher Groundnut Yields: Principles and Practices of Cultivation



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Abstract

With a few exceptions, groundnut productivity in most developing countries continues to be low. Although many high-yielding varieties have been released, their full potential is not realized in the absence of appropriate crop management practices. General agronomic recommendations are broad based and do not help much because of large variation in soil characteristics and nutrient status and other agroecological factors across groundnut fields. This bulletin discusses the underlying principles of various aspects of crop cultivation to encourage farmers to develop their own package of cultivation practices suitable to their fields and needs. It also provides information on groundnut cultivation under polythene mulch, which has resulted in 20–50% increase in groundnut productivity in China and on a seed production method to build self-reliance in the seed of improved groundnut varieties.

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Contents

Foreword

About 94% of the global groundnut (peanut) production comes from the developing countries. However, their productivity remains low. There is a large variation in groundnut productivity not only among the countries but also among the regions within a country. Groundnut productivity can be enhanced if improved varieties are grown following appropriate cultural practices. However, general agronomic recommendations do not take into account variations in agroclimatic conditions, soils and other factors across groundnut fields, which are often significant. Blanket fertilizer application, in the long run, often results in nutrient imbalance in the soil affecting nutrient use efficiency and productivity adversely. To increase profitability of agriculture, agronomic practices, particularly fertilizer application, will have to be customized for each field. This can be achieved only when underlying principles of various aspects of crop cultivation are fully understood by farmers, extension officials, NGOs and other agencies involved in agricultural development. Insect pests and diseases cause considerable economic losses to the crop. Not only do they reduce the yield but they also affect the quality of produce adversely. With increasing food use of groundnut, it is essential that the produce is of high quality and free from chemical residues and aflatoxins. An integrated approach in the management of diseases and insect pests is required to reduce the cost of production and ensure quality of the produce. In Southeast Asia, groundnut cultivation with polythene mulch is gaining popularity even under rainfed conditions among the farmers. The full retrieval of the polythene film from plants in the case of fodder use and from soil will be essential to ensure the safety of livestock and soil.

Due to low seed multiplication ratio, ensuring availability of good quality seed of improved varieties in required quantities is a huge task in groundnut. No single agency can fulfill this requirement. The seed replacement rate in groundnut remains very low. The farmers are encouraged to develop self-reliance in the seed of improved varieties if they wish to harness the benefits of improved varieties and production technologies.

It is hoped this publication will generate enough interest and awareness among groundnut development and farming community to make the crop more competitive and profitable to farmers.

William D Dar
Director General
ICRISAT

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Introduction

Groundnut (*Arachis hypogaea*), a legume, is a major oilseed crop in the world. It is grown on 24.4 million ha with a total annual production of 35.0 million t and an average productivity of 1.4 t ha^{-1} (FAOSTAT, 2005). Groundnut seeds contain about 48–50% oil and 26–28% protein. Besides, they are also rich source of minerals, vitamins and dietary fiber. The haulms are utilized as fodder and the cake, after extraction of oil, is used in the livestock feed industry. Groundnut shells are used as fuel, as a filler in feed industry, and in making cardboards. Being a leguminous crop, it enriches the soil with nitrogen and is therefore valuable in cropping system. It is simultaneously a food crop and a cash crop, providing smallholder families with dietary protein and high-grade fat as well as cash income from sale in local markets.

A groundnut plant with pods. Inset: 1. Shells 2. A seed 3. A cotyledon with embryo.

Groundnut is largely a smallholder crop, grown under rainfed conditions in semi-arid areas. It is cultivated either as a sole crop or in intercropping and mixed cropping. The mixed cropping is more prevalent in subsistence farming. The low yields in groundnut are primarily due to low inputs, rainfed cultivation of the crop in marginal lands, non-availability of the seed of suitable high yielding varieties, and the occurrence of insect pests and diseases at different stages of the crop. When the crop is grown under high-input conditions with irrigation, yields exceeding 4 t ha^{-1} are not uncommon. Some documented cases of record groundnut yields are 11.2 t ha^{-1} in 0.1 ha plot in Shandong, China; 9.6 t ha^{-1} in large plots in Zimbabwe; and 9.5 t ha^{-1} in 0.2 ha plot (in summer groundnut crop) in Kolhapur, Maharashtra, India.

Asia produces 67.7% of the world's groundnut production from 54.5% of the global area under the crop with an average productivity of 1.8 t ha^{-1}. Although more than 28 countries in Asia grow groundnut, the major producers are India (average productivity 1.0 t ha^{-1}), China (2.9 t ha^{-1}), Indonesia (2.0 t ha^{-1}), Myanmar (1.3 t ha^{-1}) and Vietnam (1.7 t ha^{-1}). During 1991–2004, the average annual growth rate in Asia for area under groundnut was -0.01%, for production 2.97%, and for productivity 2.98% (FAOSTAT, 2005). With a little scope for area expansion in Asia, the major gains in production in future will have to come from increased productivity of the crop. Within Asia, the groundnut productivity varies from 0.6 t ha^{-1} in Sri Lanka to 5.4 t ha^{-1} in Israel. Even within a country, a large variation exists in groundnut productivity. Groundnut yields can be improved substantially if suitable varieties are grown and improved crop husbandry is followed. The recommended agronomic and cultural practices are generally broad-based and apply to an agroecological zone. They do not take into account micro-variations in agroecological conditions, soils, and other factors, which are often significant within a zone. As agronomic practices are location specific, each farmer should develop his/her own package of practices to maximize returns from the farming. This bulletin does not make specific recommendations on groundnut cultivation but by emphasizing underlying principles of various aspects of crop cultivation summarized from different sources, it encourages farmers to develop their own package of practices suiting their agroecological and socioeconomic conditions. It is expected that extension officials, NGOs and other organizations involved in on-farm agricultural research and development will be able to understand and appreciate these principles and communicate them to farmers in the language and manner best understood by them.

Crop Season

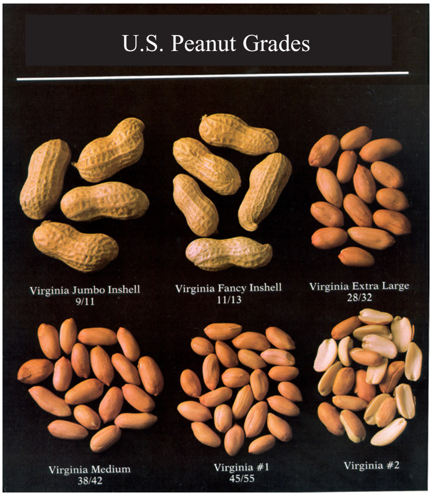
Groundnut is grown commercially throughout the tropical, subtropical and warm temperate regions of the world. In many countries in Asia, multiple crops of groundnut are grown in a year. However, multiple cropping, particularly when the crops overlap, can lead to disease build up in a region. A good example of this is the severity of rust disease in some parts of Tamil

Nadu in India where groundnut crop, due to bimodal rainfall, can be seen at different stages of growth at any given point of time during the year. The optimum air temperature for growth and development of groundnut is between 25^{0}C and 30^{0}C. Temperatures above 35^{0}C are detrimental to groundnut production. The reproductive phase of groundnut is more sensitive than the vegetative phase to heat stress. Under lower temperatures, the germination is delayed and the crop duration prolonged. The delay in germination exposes the seeds to soil pathogen attack for longer duration. Below 17^{0}C, crop growth almost ceases. In places where the crop is grown after winter season, groundnut should not be planted until the average soil temperature at 10 cm is 18^{0}C or greater for a minimum of three consecutive days and favorable air temperatures are forecast. These conditions promote rapid germination and seedling emergence. Soil temperatures above 54^{0}C cause death of embryo in the seed. Depending on the temperature profile of a given location, appropriate sowing time should be decided. In rainfed cultivation, the onset of sowing rains determines the sowing time.

Choice of Variety

During the past three decades, food and confectionery uses of groundnut are increasing globally, and its use in oil and animal feed is declining. With increased availability of cheaper alternatives such as soybean, rapeseed, mustard and palm oil, the use of groundnut for edible oil even in those countries where groundnut oil is popular is declining. Considering the changing pattern of utilization, it is important to grow groundnut, wherever possible, as a food crop to capitalize on its increasing demand for food and confectionery uses. This will require a change not only in the choice of varieties to be grown, but also in crop husbandry, as in food and confectionery uses quality and food safety aspects of the produce become extremely important.

Based on their pod/seed size and shape, the groundnut varieties in the US market are classified as follows: Virginia Jumbo In-shell (Count per ounce: 9–11, 1 Ounce = 28.3 g), Virginia Fancy In-shell (Count per ounce: 11–13), Virginia Extra Large Shelled (Count per ounce: 28–32), Virginia Medium Shelled (Count per ounce: 38–42), Virginia # 1 Shelled (Count per ounce: 45–55), Runner Jumbo Shelled (Count per ounce: 38–42), Runner Medium Shelled (Count per ounce: 40–50), Runner # 1 Shelled (Count per ounce: 60–70), Spanish Jumbo Shelled (Count per ounce: 60–70) and Spanish # 1 (Count per ounce: 70–80). Seeds of Virginia types are elongated and that of



Count per ounce.
Source: Anonymous, 1984. USA Peanuts. National Peanut Council, Washington,USA.

Runner and Spanish types roundish. Virginia pods and seeds are consumed as roasted pods or salted nuts for direct consumption. Runner Shelled are used mostly for peanut butter and candy and Spanish in candies and other confections. For boiled nuts, 3–4 seeded Valencia types are preferred.

To ensure high quality of produce, a high-input system of crop husbandry is needed. Wherever this is not feasible, the crop should be grown for oil purpose taking precautions to minimize aflatoxin contamination of the produce that will ensure proper utilization of the cake in feed industry. In rainfed agriculture, it is essential that the duration of the selected variety matches with the duration of plant extractable water in the soil. Thus, besides agroclimatic conditions, soil type, prevailing biotic and abiotic stresses, the nature of the use of produce and the market demand will be important determinants of the choice of variety to be grown by a farmer. In multiple cropping situation (very common in East and Southeast Asia) or when the crop is grown on residual soil moisture (prevalent in South Asia), short-duration varieties make a better choice. Very often, groundnut varieties interact with cropping seasons. For maximum returns, this necessitates selection of season-specific varieties. Varieties with little or no interaction with seasons can be grown in any cropping season throughout the year. They, however, may not necessarily give maximum returns. The genetic potential of the chosen groundnut variety and its cultural management determine the productivity and quality of the produce. Efficient management of the variety x cultural management interactions brings in stability to productivity. Local varieties/landraces, besides being low yielding, are relatively less responsive to improved management conditions.

Unlike other crops (such as soybean, barley and oats), the varietal mixtures in groundnut have not shown any advantage over the highest yielding variety in the mixture. In rainfed cultivation, strip cropping of two varieties differing in duration in the same field may reduce the risk of crop loss due to unpredictable nature of rainfall. However, this has to be verified.

Selection of Field and Land Preparation

The ideal groundnut soil is well drained, light colored, with either sand, loamy sand, or sandy loam texture. The right soil for groundnut should not ribbon out but fall apart easily when moist soil is rubbed between index finger and thumb. The produce from such soils is clean and bright. Groundnut after groundnut in the same field is not advisable as it builds up leaf spots and other soil-borne diseases and nematodes. Ideally, groundnut should be rotated with a cereal crop and should come back to the same field after two years. Groundnut can make effective use of residual fertilizers left over from the previous crop(s). A proper crop rotation can result in higher yields and in substantial savings in disease control and fertilizer requirements. There should be no stubbles/crop residues from the previous crop in the field. Un-decomposed crop residues promote *Sclerotium rolfsii* (stem rot causing fungus) attack on the crop. Conservation tillage (no-tillage, minimum tillage, reduced tillage and strip tillage) does not consistently produce yields equal to the conventional tillage. Very deep ploughing encourages pod formation in deeper layers of soil rendering harvest more difficult. Fine tilth

Groundnut sown on ridges.

Groundnut sown on raised bed and furrow system.

Groundnut sown on flat bed.

with a depth of 15–20 cm is required for this crop. Groundnut is sown on flat bed or ridges or raised beds separated by furrows. In addition to higher yields, sowing on raised beds with 0.4–0.8% slope is beneficial as it allows easy drainage of excess water, avoids compaction of seedbeds and facilitates field operations as all traffic is restricted to furrows. The width of the raised bed varies depending upon soil type, irrigation system in use (in case of irrigated crop) and available equipment for land preparation and bed formation.

Seed Preparation

Depending upon the seed mass, 100–150 kg seed ha^{-1} is generally required to maintain optimum plant population (see the following section on Sowing and Optimum Plant Population). It is preferable to use Certified seed each year. Groundnut being a self-pollinated crop, the good quality seeds obtained from the previous crop can also be used. After harvest, true to type high yielding plants with healthy pods should be bulked together to form the seed stock for the next season. However, in the case of self saved seed, it is important to purchase Certified seed at regular intervals, preferably every 3–4 years, to maintain varietal integrity, which could otherwise breakdown due to mechanical mixture and/or allotetraploid nature of the crop. Pods should be shelled one week before sowing. If shelled seeds are kept for a long time, they may lose viability, and will be vulnerable to storage pests and other damage if not stored properly. Only healthy, good quality and fully mature seeds free from damage, discoloration and fungal infection should be selected for sowing purposes. It is advisable to grade the seeds before seed treatment. Medium-sized seeds should be used for sowing purposes. Large-sized seeds can be used for food at home or sold on the local market. If they are used for sowing purposes, they take longer to germinate and emerge. Undersized and shriveled seeds should be discarded. It is important to determine germination percentage in the seed lot before sowing to adjust the seed rate and also to detect the presence of postharvest seed dormancy. The seed should have more than 85% germination.

Groundnut seed can be infected by several fungal pathogens and attacked by insect pests while germinating. In order to protect the seed and establish good plant stand, the seed should be treated before sowing with one or the combination of the following or locally recommended chemicals: Fungicides – Captan (1.5 g) + Thiram (1.5 g) kg^{-1} seed or Carbendazim 2.0 g kg^{-1} seed or Mancozeb 2.0 g kg^{-1} seed for soilborne fungi, and Insecticides – Imidacloprid

2 mL kg^{-1}seed for sucking pests and Chlorpyriphos 20 EC 12.5 mL kg^{-1} seed for white grubs in endemic areas. The seed should be treated first with liquid chemicals followed by powder/dust chemicals. Treatment with Imidacloprid also helps to reduce incidence of virus diseases such as peanut bud necrosis and peanut stem necrosis in the early stages of the crop. Seed treatment or seed biopriming with *Trichoderma viride* or *T. harzianum* (antagonistic fungi) also helps in managing seed and soilborne diseases of groundnut.

Virginia varieties have postharvest seed dormancy, which may last up to 5–6 months in some cases. If such varieties are to be sown immediately after harvest, the postharvest seed dormancy must be broken. The seeds should be thinly spread over a tarpaulin or plastic sheet and sprayed thoroughly 2–3 times with Etherel (5 mL in 1 L water) and air dried just before sowing.

Advantages of *Bradyrhizobium* seed inoculation in groundnut are not clearly established. However, in newly cleared fields where native *Bradyrhizobia* are in low number or ineffective, rice fallows, fields where legumes have not been grown for the last four years and fields with low fertility and eroded soils, the *Bradyrhizobium* seed inoculation may assist in achieving higher pod yields. Where *Bradyrhizobium* strain is not compatible with fungicide and insecticide used in seed treatment, it can be applied in sowing rows following slurry method of application. It is necessary to use good quality *Bradyrhizobium* inoculum for positive results.

In North Vietnam, farmers sow pre-germinated (with protruding radicle) seeds for the spring season crop. In spite of the prevailing low temperatures and cold winds at the time of sowing, this practice results in quicker seedling emergence and a perfect plant stand. The maturity is also hastened due to early seedling emergence. However, it is essential to have a good tilth and enough soil moisture or irrigation soon after sowing to support seedling growth. Seeds are pre-germinated by soaking them for 4–6 h in luke warm water and then, storing them in cloth bags overnight at a warm place in the house (near the oven in the kitchen). The next morning, seeds have emerging radicle and are ready for sowing. The non-germinating seeds are discarded. The sprouted seeds are hand sown and covered with soil immediately after sowing. Recently, seed priming is receiving attention in India and Vietnam. In seed priming, seeds are soaked for 8 h in water and then dried to their original water content. A primed seed will only germinate if it takes up additional moisture from the soil after sowing. Apart from swelling slightly and weighing more, a primed seed can be treated in the same way as a non-primed seed.

Sowing and Optimum Plant Population

In groundnut, the cost of seed is one of the major components of the cost of cultivation. Every effort should be made to ensure germination and emergence of each seed sown. Once the seedbeds are ready and the optimum conditions for rapid germination and emergence prevail, seeds can be drilled using a tractor or animal drawn groundnut planter/seed drill or dibbled manually. Machine planting results in faster sowing, quicker emergence and uniform plant stand as it provides better seed-soil contact and uniform sowing depth and better seed coverage with soil. In manual sowing, care should be taken to ensure optimum sowing depth and proper seed coverage by the soil. The practice of sowing behind the plough should be discouraged as it results in uneven plant stand and non-uniform sowing depth. The desirable sowing depth is around 5 cm. Deeper sowing results in delayed emergence, elongated hypocotyl, poor root and shoot development, poor nodulation and decreased nitrogen fixation and consequently lower yields. In the case of shallow sowing, the field should be frequently irrigated to avoid drying of germinating seeds to ensure optimum germination and plant stand. Once the sowing rains are received in rainfed cultivation, it is essential to complete sowing operation in the shortest possible time. Any delay may result in lower germination due to moisture loss from the top soil. In many countries, 2–3 seeds are dropped at each hill in manual sowing. If optimum plant stand is assured with high germination of seed lot, this practice may not be necessary as it increases the quantity of seed required for sowing. It is advisable to determine seed germination of the seed lot 3–4 days before sowing and then, adjust the seed quantity for sowing accordingly. While determining the quantity of seed to be sown, it is better to add 5–10% more seed to compensate for the failure of viable seeds to emerge. Preferably

Manual sowing of groundnut.

Tractor-drawn machine sowing of groundnut.

one seed per hill should be sown. The optimum plant stand remains the key to higher yields in groundnut. Groundnut prefers an even spacing. The higher is the plant population in a groundnut field, the higher is the pod yield if diseases and insect pests do not limit it. However, after a certain level, the higher plant population becomes uneconomic due to increased cost of seed. The optimum plant population depends upon the growth habit of the variety grown and nature of crop cultivation (irrigated or rainfed, fertility level, etc). For varieties with spreading or semi-spreading growth habit, it is lower than that required for varieties with erect growth habit. A lower plant population is kept in rainfed cultivation to avoid inter-plant competition for soil moisture in case of prolonged dry spells. The optimum plant population varies from country to country and from region to region within a country. As a consequence, the optimum row spacing will depend on the variety, nature of crop cultivation and machinery available for sowing. However, the aim should be to obtain full ground cover as quickly as possible. A wider row spacing leaving uncovered ground proliferates thrips/aphids, which can carry virus inoculum (peanut bud necrosis, peanut stem necrosis, peanut mottle and peanut stripe diseases) and promotes weed growth. The row spacing varies from as low as 20 cm to as high as 100 cm, and within row spacing from 7.5 cm to 15 cm in different countries. Under irrigated conditions, the row spacing can be reduced provided it does not affect ease of cultural operations. For varieties with erect growth habit, a narrower row spacing is required. In most Asian countries, the row spacing varies between 30 cm and 45 cm and within the row spacing between 10 cm and 15 cm depending upon the growth habit of the variety. It is important to find out the optimum plant population with inter- and intra-row spacing for the selected variety at one's location from extension officials or other sources. Farmers may also undertake their own research to determine the best population for the variety of their choice for their fields. In India, 'paired row sowing' in Gujarat and 'cris-cross sowing' in rice fallows have sown yield advantage over the conventional pattern of sowing.

Gap filling, if not done within the first 10 days of sowing, is of no use. In the case of delayed gap filling, the new plants are not able to attain normal growth and produce practically no pods.

Intercropping/Crop Rotation

Intercropping/mixed cropping is often practiced in rainfed semi-commercial and subsistence agriculture as an assurance against crop failures. Crops of differing duration grown simultaneously in a field in an appropriate row arrangement can often produce more than the individual crop grown separately. Besides better utilization of light, water, and nutrient resources, it also helps to minimize disease and pest incidence. Because of their differing duration, if one crop fails due to drought at critical stages, the other crop has a chance to survive and contribute to the productivity of the system. Groundnut is intercropped generally with cereals such as maize, sorghum and pearl millet. Lately, groundnut and pigeonpea (both legumes) intercropping has become popular in Gujarat and Andhra Pradesh in India as this cropping system, besides adding to the stability and productivity of the system, also provides pigeonpea stalks which are used as fuel. It is essential to grow suitable combination of varieties of intercrops to derive the maximum benefit of the system. Similarly, the management practices should be cropping system-based instead of sole crops.

When manuring and fertilization is done regularly and insect pests and diseases are effectively controlled, continuous cropping of groundnut has not led to reduction in yield. But good rotation of crops helps to maintain soil fertility, improves organic matter and physical structure of soil and reduces disease inoculum and insect pest population in the soil. As groundnut responds well to residual fertility, it is desirable to rotate it with other well fertilized crops particularly cereals. In Southeast Asia, groundnut-rice rotation is very common. In North India, efforts are being made to popularize groundnut cultivation in the spring/ summer season after harvest of potato to increase cropping intensity and productivity of the high-input cropping system.

Groundnut-pigeonpea intercropping.

Fertilizers and Amendments

Fertilizer application is one of many important production practices needed to harvest optimum groundnut yields in a sustainable manner. A comprehensive fertilization strategy, complete from soil testing before sowing through trouble shooting later in the cropping season, is recommended. The balanced use of fertilizers is essential to increase groundnut productivity. The basics of the fertilization strategy are:

Soil test

Soils from fields to be sown with groundnut must be analyzed for determining the status of macronutrients and micronutrients. Soil samples should be collected from several places in the field at plough depth. These samples should be bulked and mixed thoroughly to draw a representative sample of the field for analysis.

Build soil phosphorus (P) and potassium (K) to medium or high level

Groundnut responds to residual soil fertility better than the direct application of fertilizers. Therefore, building soil P and K levels to at least the medium range should assure adequate P and K nutrition. If P and K fertilizers are needed, they should be turned deep before sowing to keep them out of the pegging zone where they can interfere with calcium uptake. It is better to fertilize the preceding crop well to build up residual fertility for the following groundnut crop.

Maintain ideal soil pH

Ideally the soil pH should be maintained in the 6.0–6.3 range. Soil pH greatly affects the availability of nutrients to plants, especially P and micronutrients. The nitrogen fixation process is also dependent on proper soil pH.

Provide calcium (Ca) to pegging zone

Ca is essential for pod and seed development. It is most commonly deficient for groundnut in non-calcareous soils. Having adequate quantities of Ca present in the top 8–10 cm of soil, available for direct absorption by developing pegs and pods, is an absolute must for producing high quality groundnut yields. Adequate Ca supply to the pods also helps to reduce infection by *Aspergillus flavus* and other pod rot causing fungi.

Troubleshoot for suspected problems

Both nodulation and soil pH should be checked during the growing season if nitrogen deficiency (indicated by 'yellowing') is suspected. A routine tissue sample can be taken prior to or at flowering from the upper mature leaves to check if N, P, K, Ca, Mg, S, Mn, Fe, B, Cu, Zn, and Mo are in a sufficient range where yield will not be limited.

Nutrient Requirement for High Yields

The amounts of nutrients removed from the field by groundnut pods and vines are presented in Tables 1 and 2.

Depending upon the targeted yield levels, the required quantities of the nutrients should be made available to the crop. Achieving very high yields under rainfed conditions may not be feasible due to soil moisture limitations.

Nitrogen (N)

Under most conditions enough N is fixed through symbiotic relations with the native *Bradyrhizobium* spp. to avoid deficiency throughout the plant's

Table 1. Estimated nutrients required to produce selected pod yields of groundnut.

Pod yield					(in kg ha^{-1})*					
(t ha^{-1})	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B
1	58	5	18	11	9	4	2	0.09	0.08	0.05
2	117	10	36	23	18	9	4	0.19	0.16	0.11
3	174	15	54	34	27	13	6	0.29	0.24	0.16
4	232	20	73	45	36	18	8	0.38	0.32	0.22
5	290	25	91	56	45	22	10	0.48	0.41	0.27
6	348	30	109	68	54	26	12	0.58	0.49	0.33
7	406	35	126	77	63	30	14	0.68	0.56	0.38
8	464	40	144	88	72	34	16	0.78	0.64	0.44
9	522	45	162	99	81	38	18	0.88	0.72	0.49
10	580	50	180	110	90	42	20	0.98	0.80	0.54

* – Calculation based on Sahrawat, KL, Srinivas Rao, B and Nambiar, PTC. 1988. Plant and Soil 109:291–293.

Table 2. Nutrient uptake/removal in groundnuts.

	Yield	(in kg ha^{-1})					
Plant part	(t ha^{-1})	N	P	K	Ca	Mg	S
Pods	3	120	11	18	13	9	7
Vines	5	72	11	48	64	16	8
	Total	192	22	66	77	25	15

Source: Gascho, GJ.1992. Groundnut (Peanut), Chapter 5.2 *in* IFA World Fertilizer Use Manual, eds. DJ Halliday, ME Trenkel and W Wichmann, International Fertilizer Industry Association, Paris.

life cycle. However, under certain conditions, N deficiency can occur. These include poor and eroded soils, lack of or inefficient *Bradyrhizobium* in the soil, drought, and high temperatures. In many countries, N is applied to the crop and the rate ranges between 10 to 30 kg N ha^{-1}. In areas of high intensity rains, split application of N may be beneficial in light soils. In some studies, foliar application of N at the time of podding also resulted in increased yield. However, N application is not recommended in the USA.

Phosphorus (P)

On a global scale, P may be the most deficient element for groundnut. In general, P deficiency in groundnut can be easily corrected by application of P fertilizers since the crop is grown in sandy soils with low amounts of clays. In such soils P fixation is not a problem. But in calcareous sandy soils, P fixation can lead to P deficiency in spite of P fertilization. Soil P levels required for groundnut are often lower than those required for other crops.

Potassium (K)

K is needed by groundnut from early stage of its growth to maturity. Considerable amount of K is taken by the crop but most of the Indian soils are rich in K. Groundnut does not respond to application of K unless available K in the soil is very low. There is mutual antagonistic effect on the uptake of K, Ca and Mg. The proportion of K:Ca:Mg is more important than the total amount of any one of them. A high concentration of K in the pod zone is harmful because it affects pod quality, especially at low levels of Ca. The suggested proportions in the literature are 4:4:2 and 4:2:0. The latter was reported from studies on sandy loam soils under rainfed and irrigated conditions in Tirupati, Andhra Pradesh, India.

Calcium (Ca)

The 30-day period following pegging is most critical for Ca supply. If a soil pH adjustment is recommended by the soil test, lime may be used to provide both pH adjustment and Ca to the pegging zone. However, lime must be applied and incorporated to a shallow depth immediately after deep ploughing to allow enough time for the Ca in lime to dissolve and get into soil solution. Where lime is not needed, calcium sulfate (gypsum or land plaster) should be applied when needed. This need for additional Ca is best determined by taking a 'pegging zone soil test'. Regardless of the soil test Ca level, gypsum should be applied to all large-seeded groundnut and groundnut seed crop. The peak flowering stage of the crop is the best time to apply gypsum to the soil. It should not fall on the foliage as it may cause scorching of leaves. The gypsum application should be followed by light inter-cultivation or last hand weeding to ensure its incorporation into the soil. Groundnut produced under Ca-deficient conditions exhibits poorer germination than those produced with an adequate Ca supply. Lack of sufficient soil moisture in the top 8–10 cm zone during the pod and seed developmental period can result in Ca deficiency as Ca is not replenished in the soil solution. It is important to ensure sufficient moisture supply in the podding zone for the development of well-filled pods.

Concentrations of other cations in the soil, particularly K and Mg, can influence Ca uptake and thereby affect groundnut yield and quality. The optimum Ca/K ratio in the groundnut pegging zone topsoil is about 10. The optimum Ca/Mg ratio for obtaining maximum percentage of sound mature kernels is 24 to 28.

Magnesium (Mg)

Little response is reported for application of Mg to groundnut. Responses occur at very low soil test levels most likely on deep excessively drained sandy soils. Some soils retain greater concentration of Mg in the subsoil than in the surface horizon. The deep root pattern of groundnut allows plant to forage deeply for Mg as well as for other nutrients.

Sulfur (S)

Application of gypsum provides adequate S to the crop. Sulfur deficiency is most likely on very sandy soils, which possess little anion exchange capacity. Deficiency of S affects terminal growth, restricts root growth and new leaves become pale green or yellow.

Sulphur-deficiency symptoms in groundnut.

Micronutrient Amendments

The single most important consideration in proper availability of micronutrients for plants is soil pH. Most micronutrients are more likely to be deficient at high pH, particularly in calcareous soils. Groundnut soils in southern India are generally deficient in B, S and Zn.

Boron (B)

B is an essential micronutrient that is necessary for proper flowering and podding. The B deficiency causes less intense flowering, prolongs flowering period and affects seed development resulting in a discolored cavity (hollow heart) on the inner face of the cotyledons. Severe B deficiency causes leaf to turn deep green, terminal leaves to become small and deformed, reduced internodal length and production of secondary branches making the plant appear stumpy and short. Application of borax to the soil at a rate of 3–4 kg ha^{-1} usually overcomes the symptoms with a good residual effect that lasts for several seasons. The deficiency can also be corrected by spraying 0.1% borax early in the season to assure uptake before flowering. Over application of B can cause toxicity in plants.

Discolored cavities in groundnut seed due to B-deficiency.

Iron (Fe)

Fe-deficiency symptoms in groundnut.

Fe deficiency can be a serious problem in calcareous soils. Plants suffering from Fe-deficiency show interveinal chlorosis (beginning on the youngest leaves) followed by chlorosis of the entire leaf (whitish-yellow) and brown spots leading to marginal chlorosis. It slows down the plant growth and results in poor nodulation. Iron chlorosis can be alleviated by applying 10 kg ha^{-1} ferrous sulphate to the soil or spraying the affected crop with 0.5% ferrous sulphate + 0.2% urea. If required, the spray can be repeated at 10–14 days interval.

Zinc (Zn)

Zn-deficiency symptoms in groundnut.

Zn deficiency can be observed when the crop is grown in high pH soils. It is wide spread in sandy and sandy-loam soils in India. Plants affected by Zn-deficiency appear stunted with reduced internodal length, new leaves develop slowly and terminal leaflets are small, thickened and dark green in color. Basal application of 10–20 kg ha^{-1} zinc sulphate once in three years to the soil where groundnut is grown continuously can rectify the deficiency.

Manganese (Mn)

Mn deficiency occurs in soils inherently low in this nutrient, especially if they have been limed more than necessary. Mn deficiency causes interveinal chlorosis with symptoms ranging from mild (light green leaves with the regions immediately adjacent to the veins and the veins themselves remaining green) to severe (entire interveinal area chlorotic). Foliar Mn application can correct Mn deficiency more rapidly than soil Mn application.

Mn-deficiency symptoms in groundnut.

Other Amendments

Application (8–10 t ha^{-1}) of farmyard and other (compost and cattle and sheep penning) organic manures is a common practice in Asia. However, the rate of application and its frequency depend upon the local availability of the organic manures. Application of the organic matter improves the structure and reduces compaction and crusting of the soil. It also improves nodulation and enhances the availability of P to the crop. Farmers in India also apply tank silt 15–25 t ha^{-1} once in three years mainly to increase water-holding capacity of the soil. Introducing green manuring in crop rotation also helps in increasing the organic matter content of the soil.

Use of Growth Regulators

The use of chemical growth regulators on groundnut to suppress vegetative growth, achieve higher yield and improve pod quality have met with varying degree of success. But their use in groundnut is very common in China and Vietnam. The following are based on the recommendations in the Chinese literature.

Dinocap (DPC)

It inhibits stem growth, enhances root development and branching and increases pod yield by increasing pod number per plant. The early flowering stage is the best time to apply 80 parts per million (ppm) DPC as foliar spray.

Paclobutrazol (P 333)

If groundnut plants in highly fertile soils grow more vigorously than expected, foliar application of P 333 at 60 ppm is recommended around 25–30 days after the first flowering. Its application reduces stem growth and increases pod number per plant, pod and seed mass and pod yield.

Fosamine

Fosamine strongly inhibits the growth of aerial parts and flowering of groundnut. Its effect lasts for longer duration. Foliar application of 500 ppm is recommended at late pod forming stage to reduce late forming flowers. However, the seeds from fosamine-treated groundnut have poor germination and produce abnormal seedlings. Therefore, they should not be used as seeds to grow the next crop.

2,3,6-trichlorobenzoic acid (TCBA)

It inhibits growth of the aerial parts and late ineffective flowers. It should be sprayed (250 ppm) at peak or late peak flowering stage. Once the effect of the chemical wanes, the plant may grow more rapidly. Response to TCBA application (increase in yield) varies with the genotypes. It gives good results with large-seeded varieties of medium- and long-duration. Its effect on Spanish varieties is very little.

P 333 is the more commonly used growth regulator. It has given positive response in Vietnam also. In the USA, Kylar 85 [1.2 kg ha^{-1} of powder formulation, 85% active ingredient (a.i.) in 38 L of water] is recommended for arresting excessive vegetative growth. It can also be applied in split doses. However, growth promoters are no substitute for good crop husbandry. Their maximum positive response is realized only when all other factors contributing to crop production are optimum.

Earthing-up

Earthing-up (mounting the soil around the plants to allow late formed pegs to enter soil) is a common groundnut cultivation practice in South Asia. There is no consistent evidence to support this practice in the field. On the contrary, it may reduce yield and affect the quality of the produce under certain conditions. The groundnut leaves buried in the soil during earthing-up may promote *S. rolfsii* growth (stem rot causing fungus). While waiting for the late formed pods to mature, earlier set ones may sprout in case of lack of dormancy or the

Sprouting of earlier set seeds/pods due to earthing-up in groundnut.

peg attachment may weaken resulting in their loss into the soil at the time of harvest. Some farmers roll a drum or run a plank over a standing crop to bend stem and branches to allow late formed pegs to enter the soil. Like earthing-up, these practices also have no evidence in their support.

Weed Control

Groundnut is highly sensitive to weed competition up to 45 days after emergence. Application of pre-emergence herbicide such as Pendimethalin@1.0–1.5 kg a.i. ha^{-1} as spray or Fluchloralin @ 1.0–1.5 kg a.i. ha^{-1} as preplant soil incorporation followed by 1–2 hand weedings, as and when needed, effectively reduce the weed competition. The amount of water required for spraying varies from 1000–1500 L ha^{-1}. The last hand weeding can follow the gypsum placement in the field. It is important to keep groundnut field weed-free even at later period because weeds interfere with harvesting and cause pod loss into the soil.

Inter-cultivation also helps to control weeds. In a rainfed crop, it loosens the surface soil and facilitates infiltration of rainwater. However, the inter-cultivation should not be carried out after the ground cover is obtained as it would damage the vines and disturb the pegs entering soil.

Water Management

Although groundnut requires relatively less water, it cannot tolerate moisture stress at flowering, pegging, pod and seed formation stages. The seed formation stage is the most sensitive stage for moisture stress. The exact water requirement for groundnut crop depends on the soil type and climatic conditions of a given locality. The water requirement of groundnut in different types of soil varies from 420 mm to 820 mm in India. Generally, 600–650 mm of water is sufficient. Quality of irrigation water can affect groundnut productivity. Limits for saline water for groundnut are EC (Electrical Conductivity) < 4.0 mmhos cm^{-1} and RSC (Residual Sodium Carbonate) < 2 meq L^{-1}. Groundnut can tolerate moisture stress in the early vegetative phase. At many places, farmers subject groundnut crop to moisture stress soon after the emergence for 2–3 weeks and then resume regular irrigation to induce profuse flowering and uniform maturity. It also results in higher yields. At pegging and pod and seed development stages, light but frequent irrigation is required. Flood irrigation, commonly practiced in case of flat sowing in South Asia, is not a good method of irrigation as it

Sprinkler irrigation in groundnut.

wastes water, results in overwatering and trampling of plants in the field by persons engaged in irrigation. Among various irrigation methods, sprinkler method of irrigation is found more efficient and beneficial to groundnut.

In rainfed agriculture, it is essential that duration of the selected variety matches with the duration of plant extractable water available in the soil. In the case of groundnut, it is important that the topsoil remains moist at the time of pegging to facilitate their entry into the soil and during the pod and seed development. Every effort should be made to conserve and harvest rainwater. It can be used in irrigating the field at the time of pegging and pod and seed development stages. Besides increasing yield, the absence of moisture stress at the time of pod and seed development will also discourage pod and seed invasion by *A. flavus* and subsequent aflatoxin production.

Groundnut does not tolerate standing water in the field. Standing water even for 4–6 hours in the field can damage the crop. Groundnut fields should be well drained. Planting on raised beds or ridges facilitates drainage.

Plant Protection

Several diseases and insect pests attack groundnut crop at different stages of growth. Diseases and insect pests of major economic importance are discussed in the following section.

Use of resistant cultivars and cultural, chemical and biological control options are available to manage diseases and insect pests. But no single option for a given insect pest or disease may be adequate for maximizing the economic returns. An integrated insect pest management (IPM) and integrated disease management (IDM) encompassing various approaches is required to effectively and safely contain the damage. Chemical sprays should be need-based and appropriate safety precautions should be taken while applying them. These include use of protective clothing, hand gloves, nose mask and goggles while applying the chemical, washing hands and face thoroughly after application, and destroying and safely disposing the empty chemical containers after use.

Seed and seedling diseases

Seed and seedling diseases are best managed by appropriate chemical seed treatment, following crop rotation and other field sanitation practices including summer ploughing. Chemical treatment of soil for controlling these diseases is expensive. Some varietal differences in susceptibility to these pathogens are reported, but they rarely express under field conditions. Common seed and seedling diseases are pre-emergence seed and seedling rot (*Aspergillus niger*, *A. flavus*, *Macrophomina phaseolina*, *S. rolfsii*, *Rhizoctonia solani*, *Rhizopus* spp., *Penicillium* spp., *Pythium* spp. and *Fusarium* spp.), *Aspergillus* crown rot (*A. niger*), yellow mold (*A. flavus*), diplodia collar rot (*Lasiodiplodia theobromae*) and rhizoctonia damping-off (*R. solani*). These diseases can be managed by treating seeds with seed dressing fungicides or *T. viride* and *T. harzianum* (see Seed Preparation section for details). *T. viride* or *T. harzianum* can also be applied into the soil after multiplying them in farmyard manure and neem or castor bean cake powder mixture. The soil should be wet at the time of application. They can also be applied as soil drench by dissolving them in water. Soil application of *T. viride* and *T. harzianum* may also help to reduce *A. flavus* infection of groundnut pods.

Foliar fungal diseases

Among the foliar fungal diseases, early leaf spot (C*ercospora arachidicola*), late leaf spot (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*) are distributed worldwide and cause significant pod and haulm yield loss besides adversely affecting their quality. Late leaf spot and rust usually occur together.

Early leaf spot

Early leaf spot lesions, often surrounded by a yellow hallow, are sub-circular, dark brown on the upper leaflet surface where most sporulation occurs and lighter shade of brown on the lower leaflet surface.

Early leaf spot symptoms in groundnut.

Late leaf spot

Late leaf spot lesions are nearly circular and darker than those of early leaf spot. On the lower leaflet surface where most of the sporulation occurs, the lesions are black and slightly rough in appearance.

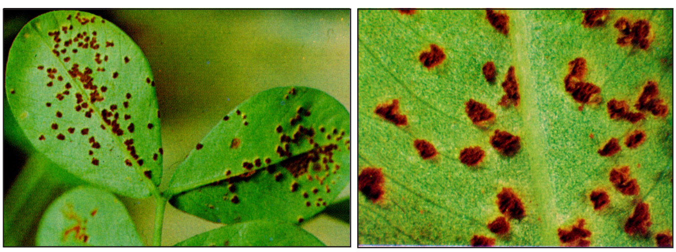
When the attack is severe, both early- and late-leaf spot cause severe premature defoliation.

Late leaf spot symptoms in groundnut.

Rust

Rust pustules are orange colored and appear on the lower surface of leaflets. On rupturing, they release masses of reddish-brown spores. In contrast to the rapid defoliation associated with leafspots, leaves infected with rust become necrotic and dry up, but tend to remain attached to the plant.

The spores of early- and late-leaf spot causing fungi can survive for years in soil. Therefore, it is essential to remove all groundnut plant debris from the field and follow deep ploughing. Crop rotation with other crops also helps in reducing the inoculum in the soil. These diseases can also spread through airborne



Rust symptoms in groundnut.

inoculum coming from other infected fields. As rust spores do not survive for long under ambient conditions (not more than 30 days under ambient conditions in South India), its inoculum is mostly airborne and comes from

ICGV 86590, a rust and leaf spot resistant variety.

other infected fields. Generally, these diseases start appearing on the lower leaves from 30–35 days after sowing in humid regions and spread rapidly under favorable weather conditions. If they are not managed properly at the initial stage, the crop losses could be severe (50–60%). Effective chemical control measures are available for these diseases (Chlorothalonil 75 WP 1 kg ha^{-1} for combined occurrence of leaf spots and rust, Carbendazim 50 WP 500 g ha^{-1} or Mancozeb 50 WP 1 kg for both leaf spots and Calixin 250 mL for rust alone). The chemical control measures should start soon after the appearance of disease symptoms. The spray schedule varies depending upon the agroclimatic conditions and severity of the diseases. Number of sprays can be reduced by following integrated disease management practices. In USA and other developed countries, farmers follow weather-based disease management advisory to optimize chemical use and increase its effectiveness. In many countries, rust resistant and leaf spots tolerant varieties have been released. In disease endemic areas, resistant/tolerant varieties together with limited chemical control provide best economic returns. In the case of severe premature defoliation, it is advisable to harvest the crop early.

Virus diseases

Peanut bud necrosis disease (PBND) caused by peanut bud necrosis virus (PBNV) and transmitted by thrips in South Asia, and peanut stripe virus disease (PStVD) caused by peanut stripe virus (PStV) and transmitted by aphids in East and Southeast Asia are the major virus diseases in Asia.

Border cropping with maize in groundnut. Inset: PSND symptoms in groundnut.

Recently, peanut stem necrosis disease (PSND), caused by tobacco streak virus (TSV) and transmitted by thrips, is gaining importance in Andhra Pradesh and Karnataka in India. Both PBNV and TSV are not seed borne but PStV is. Therefore, it is essential to use virus free seed in the case of the latter. In addition to growing field tolerant varieties (for PBND and PSND, no tolerance is available for PStVD), field sanitation and cultural management offer best solution to contain these diseases. The management practices include timely sowing, optimum plant population, effective control of vectors and intercropping and border cropping with fast growing tall cereal crops. Removal of alternate weed hosts of the virus and the vector during off-season helps in reducing the initial inoculum of the disease. Chemical seed treatment offers protection against sucking pests and helps to reduce disease incidence in early stages of the crop. Intercropping and border cropping act as barrier to the vector.

Bacterial wilt disease

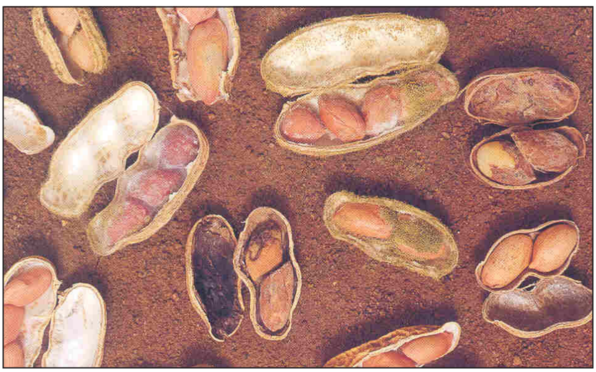
Bacterial wilt (*Ralstonia solanacearum*) is a soilborne disease confined mostly to East and Southeast Asia and some parts of Africa. Many high yielding, bacterial wilt resistant varieties are available which should be grown in infected fields.

Bacterial wilt symptoms in groundnut. Inset: a wilted groundnut plant.

Crop rotation with rice in lowlands and with sweet potato, sugarcane, barley, wheat, maize, sorghum and cotton in uplands also helps to reduce the disease incidence. Rice cultivation for three or more years in infected field can even eradicate the disease.

Aflatoxin contamination

Aflatoxins are secondary metabolites produced in groundnut seeds by *A. flavus* and *A. parasiticus*. These fungi (soil-borne and air-borne) get access to seeds through microscopic cracks in pod wall and seed coat, mechanical injury to pods during intercultural operations and harvesting, and insect and nematode damage to pods. Aflatoxins are carcinogenic, lower the body's normal immune response and impair growth in children. In poultry and livestock, they can cause feed refusal, loss of weight, reduced egg production and contamination of milk. Poultry and livestock fed on infected groundnut cake or haulms with infected under-developed pods pass on the toxins to their products including milk. In international trade, there are very strict upper limits sets for aflatoxins. The European Union has set the upper limit of 2 $\mu g\ kg^{-1}$of seed for aflatoxin B_1. In Asia, *A. flavus* infection is more prevalent. The fungus infection can occur in the field when the pods and seeds are developing (preharvest infection), during drying and curing after harvest and in storage (postharvest infection). Moisture stress at pod and seed development stage predisposes them for *A. flavus* infection in the field. The rainfed groundnut is more vulnerable to fungal infection in the field. Postharvest infection is serious under wet and humid conditions.



Groundnut seeds infected with A. flavus.

Improved varieties with tolerance/resistance to seed colonization by *A. flavus* and aflatoxin production are available but their resistance is not absolute. Growing tolerant varieties and following cultural management practices can minimize the problem to a large extent. In addition to good crop husbandry, the following precautions should also be taken to contain the problem of aflatoxin contamination:

- Provide light but frequent irrigation, if available, during pod and seed development stages
- Avoid mechanical damage to the pods during weeding, harvesting and curing, threshing and storage
- Harvest the crop as soon as it matures (in case of severe drought, the crop should be harvested early)
- Dry the pods to lower the moisture content below 8%
- Do not mix the gleanings (pods left into soil at the time of harvesting) with main produce
- Remove damaged and under developed pods from the produce
- Store groundnut in-shell and at low temperature, low humidity and in moisture-free conditions

Sucking insect pests

Sucking insects such as jassids (*Empoasca kerri*), aphids (*Aphis craccivora*) and thrips (*Scirtothrips dorsalis, Thrips palmi, Frankliniella schultzei* and *Caliothrips indicus*) are common in all areas. The economic importance of these sucking insects as direct pests is less than their role as vectors of virus diseases.

Effective chemical control measures are available to control these insect pests. However, indiscriminate use of chemicals should be avoided and they should be applied based on economic threshold levels. Seed treatment with Imidacloprid @ 2 mL kg^{-1}seed provides protection for almost a month against sucking pests. Rains or sprinkler irrigation also help to wash down these insect pests. However, if dry conditions prevail, their severity may increase.

Aphids

When all the terminal buds are infested with aphids particularly in a young crop, the weather is dry and no ladybirds, syrphids, or lacewings (natural predators) are present, Dimethoate @ 200-250 mL a.i. ha^{-1} should be sprayed.

Aphids on a groundnut terminal.

Thrips

Thrips damage on groundnut leaves. Inset: An adult thrip.

If more than five thrips per terminal leaf (folded) are observed before 20 days after emergence (DAE), Imidacloprid @ 20 mL a.i. ha^{-1} or Dimethoate @ 200–250 mL a.i. ha^{-1} should be sprayed. Thereafter, it is not necessary to control thrips. Several cultivars resistant to thrips are available.

Jassids

Hopper burn in groundnut foliage. Inset: An adult Jassid.

If more than 10% of the total leaves show 'hopper burn' ('V' shaped yellowing at the leaf tip) before 30 DAE, Imidacloprid @ 20 mL a.i. ha^{-1} or Dimethoate @ 100–200 mL a.i. ha^{-1} should be sprayed. There is no need to control this insect pest thereafter.

Foliage feeding insect pests

Groundnut can tolerate considerable defoliation without causing any economic loss. However, the indiscriminate use of insecticides can cause pest outbreaks to inflict severe crop losses. Tobacco caterpillar (*Spodoptera litura*),

Tobacco caterpillar.

Red hairy caterpillar.

Gram pod borer.

red hairy caterpillar *(Amsacta albistriga)*, gram pod borer (*Helicoverpa armigera)*, and leaf miner *(Aproaerema modicella)* are of prime importance among the defoliators.

Tobacco caterpillar, gram pod borer and red hairy caterpillar

These defoliators inflict economic losses only when the foliage damage exceeds 25%, or if one or more larvae per plant are observed during the first 50 DAE. Defoliation can be ignored once the crop passes the vegetative phase (>50 DAE). The IPM strategies to reduce the incidence of these pests include (1) growing sunflower or castor bean on borders or as intercrop, (2) destroying the egg masses by hand on groundnut and trap crops, (3) encouraging larvae predation by birds by providing perches, and (4) application of insect pathogens such as nuclear polyhedrosis virus (NPV). Under moderate levels of attack, only NPV or neem seed extract should be applied. Insecticide application (Indoxacarb 20 mL a.i. ha^{-1} or Spirosad 45 mL a.i. ha^{-1} or Endosulfan @ 350 mL a.i. ha^{-1}, Monocrotophos @ 300 mL a.i. ha^{-1} or Fenvalerate @ 100 mL a.i. ha^{-1}) is recommended only as a last resort when there is an absolute necessity.

Groundnut leaf miner

Leaf miner larva inside the miner. Inset: A leaf miner adult.

Chemical control (Dimethoate @ 200–250 mL a.i. ha^{-1} or Monocrotophos@ 150–200 mL a.i. ha^{-1}) is recommended if five or more active larvae $plant^{-1}$ are found before 30 DAE, 10 larvae $plant^{-1}$ between 30–50 DAE, or 15 larvae $plant^{-1}$ at 51 DAE or later. The role of natural enemies must be considered before resorting to chemical control. For instance, if more than 50% of the larvae are parasitized (the parasites can be seen as minute white specks, no more than 1 mm long, attached to the outside of the leaf miner larvae), the chemical spray should be suspended while closely monitoring the development of the pest population.

Soil insect pests

Many insects feed on roots and pods. Root feeders cause sudden death of plants. In the case of pod borers, the damage is detected when the crop is harvested. It is not easy to manage them as they are sporadic and extremely difficult to detect before the damage is done.

White grubs

The two most important species of white grubs in India are *lachnosterna consanguinea* and *L. serrata*. The former is common in light soils in northern and western India and the latter is found throughout the country. In endemic areas, soil application (Thimet 10 G or Carbofuran 3 G @ 1 kg a.i. ha^{-1} just before sowing in seed furrows) or seed treatment (Chlorphyriphos 20 EC @ 12.5 mL kg^{-1} seed) with chemicals can provide effective control of white grubs.

A white grub larva in the soil.

Nematodes

In certain areas/fields plant parasitic nematodes can be a major threat to groundnut cultivation. The important diseases caused by nematodes in groundnut include root knot (caused by *Meloidogyne arenaria* and *M. hapla*), root lesion (caused by *Pratylenchus brachyurus*) and Kalahasti malady (caused by *Tylenchorhynchus brevilineatus*). In the case of Kalahasti malady, resistant cultivars are available in India. Crop rotation with non-hosts can be effective in reducing the damage to groundnut crop. Deep ploughing and cultivation with polythene mulch can also help in reducing the nematode

Groundnut pods infested with T. brevilineatus.

Galls on roots and pods caused by M. arenaria.

population in the soil. In developed countries, nematicides are used to control diseases caused by nematodes.

Harvesting

Because of indeterminate growth habit, the pod maturity in a groundnut plant is not uniform. If one waits for all the pods in a plant to mature, the seeds in already mature pods start to sprout due to lack of seed dormancy (in case of Spanish or Valencia varieties) or over mature pods due to weakening of peg are lost in the soil at the time of harvesting. It is very important to determine the right time for harvesting as early harvesting like late harvesting could result also in economic loss. There are several biochemical (Optical Density of Oil, Arginine Maturity Index, Methanol Extract and Maturity Protein Marker) and physical (Kernel Density, Internal Pericarp Color, Seed Hull Maturity Index and Hull Scrap) methods proposed to determine the time of harvesting. Each method has some deficiencies. The easiest and most practical method is the Internal Pericarp Color. Darkening of internal surface of pericarp is directly related with seed maturity. By uprooting a couple of plants from different places of the field and observing the inside of a pod for pericarp darkening can help to decide on time of harvesting. When 75–80% pods in case of Spanish and Valencia varieties and 70–75% pods in case of Virginia varieties show internal pericarp darkening, the crop is ready for harvest. In case of severe disease pressure, it is advisable to harvest the crop early. In rainfed cultivation, early cessation of rains may cause forced maturity. In such situations, it is better to harvest the crop as soon as possible as any delay in harvesting may harden the soil making the harvest difficult.

Darkening of internal pericarp in a groundnut pod – a sign of pod maturity.

Although commercial groundnut combines are available, the crop in Asia is harvested generally by uprooting the plants manually. In some cases, animal drawn digger, which cuts the roots of the plants below the podding zone, is also used. It is followed by manual lifting of the plants.

Drying and Curing

At the time of harvesting, groundnut pods contain about 35% moisture, which must be brought below 10% to prevent molding and heating in storage. Proper drying (removal of moisture from the produce to a point at which the moisture content of the produce comes into equilibrium with the moisture of the surrounding air) and curing (the total process of moisture removal and flavor and texture development in bringing the produce into storable condition) of the harvested produce is essential to ensure its high quality of the produce. Depending upon the size of holdings and the cropping season, the practice of drying and curing may vary. The harvested plants are well shaken to dislodge the soil from pods and kept inverted in the rows (pods facing upwards) for 2–3 days in the field before threshing. The soil on the pods slows down drying and provides favorable conditions for fungal growth. In the postrainy season, when higher temperatures prevail at the time of harvesting, the harvested plants are assembled in the field in circular heaps with pods facing inside to avoid their direct exposure to the sun. After 2–3 days of drying in the field, the pods are threshed. Both mechanical and manual threshing is practiced. In manual threshing, haulms for fodder use are preserved better. The threshed pods are sun dried for 3–4 days to bring down the moisture content below 10%. In the postrainy season, when the prevailing temperatures are high, shade drying of pods is recommended to maintain seed viability for a longer period. Drying under high temperature (49^0C and above at the drying floor) causes the loss of seed viability. In the case of smallholdings, the harvested plants are taken home for drying and curing. It is important to remove all damaged, rotted and sprouted pods from the harvested produce as they reduce the quality of produce and serve as a source of diseases and insect pests in the storage.

Harvested plants in inverted windrows for drying.

Harvested plants in circular heaps for field drying.

Storage (only for seed purpose)

Under unfavorable conditions, groundnut seed (shelled groundnut) loses viability quickly. If seeds are to be stored, they should be stored under low storage temperature conditions. In general, the lower the temperature, the longer is the expected storage life of the seeds. The seed quality can be maintained at least a year at temperatures of 1 to 5^{0}C and moisture content of 7% or lower. The relative humidity in the storage should be between 65% and 70%. High moisture in groundnut seeds causes more deterioration than any other single factor. However, it may not be possible to provide such storage conditions for the seed by small farmers. Instead of groundnut seed, they can store groundnut pods. Only undamaged, well-dried pods (about 5% moisture content) should be stored to avoid fungal and insect pests attack in the storage. Below 9% moisture content, the pathogens become inactive. The pods should be stored in polythene lined gunny bags or in some other safe storage structure in a well-ventilated and rodent free room. The bags should not come in contact with the floor or walls and no more than 10 bags should be stacked together.

Pod and seed damage by storage insect pest.

In case of pest outbreak in storage, the bags should be covered with polythene sheet and fumigated with Celphos (tablets) @ 3 g bag^{-1} (40 kg bag). The polythene sheet should remain as cover for 4–5 days. The fumigator should use protective clothing, hand gloves, nose mask and goggles. Fresh air should be allowed in for some time by keeping the windows and door open before entering the store 4–5 days after fumigation.

Appendixes

Appendix 1. Groundnut Cultivation under Polythene Mulch

Introduction of polythene mulch from Japan in 1978 and its use in groundnut cultivation has revolutionized the groundnut production in China. This practice alone has increased groundnut yields by 20–50%. Currently, more than 20% of the groundnut crop in China is raised with polythene mulch. With the adoption of new high yielding varieties and improved production technology with polythene mulch in the country, the average productivity has increased from 1.21 t ha^{-1} in the 1970s to 2.9 t ha^{-1} in 2000s. The following information is adapted from English and Chinese literature published by the Chinese scientists.

Advantages of polythene mulch

- Suitable for all cropping seasons in all kinds of soils. Helps to extend crop cultivation into non-traditional areas by influencing soil temperature.
- In addition to pod yield and proportion of well-filled pods, the cultivation with polythene mulch increases oil and protein contents and improves oleic to linoleic fatty acid ratio in seeds
- The crop can be sown under lower temperatures (mean soil temperature over five days in the top five cm soil 12.5^0C and above) and it matures early giving opportunity to increase cropping intensity
- Requires fewer irrigations and suffers less insect pest damage as compared with non-mulched crop
- Provides better weed control (herbicide impregnated films are also available)

Disadvantages of polythene mulch

- More labor intensive and requires higher initial investment
- Full retrieval of polythene film is difficult. Film sticking to haulms would make them unfit for fodder use and that left in the soil may cause environmental pollution (now photo degradable films are also available)
- Viability of seeds produced with polythene mulch is lower than that of produced without mulch

Factors that result in high yield with polythene mulch

Soil temperature

As the transparent polythene film has above 80% sunlight transmittance, it raises the soil temperature due to heat entrapment. The increased accumulated temperature shortens the crop duration and increases the pod yield. On the other hand, during the hot season, the polythene film protects the soil from direct sunlight, and its impermeability to hot air ensures optimum temperature for the middle growth phase of groundnut.

Groundnut plants emerging through holes in polythene mulch.

A groundnut crop grown with polythene mulch.

Soil moisture

Polythene mulch prevents soil evaporation, which accounts for 25–50% of the total quantity of water used in crop production. It helps retain soil moisture. During heavy rains, the polythene film retards soil erosion and rapid infiltration of rainwater into the soil. Optimum soil moisture ensures good emergence and seedling growth.

Soil structure

As the soil under polythene mulch remains undisturbed during the cropping period, it maintains higher porosity resulting in better root growth and nodulation.

Soil micro-organisms

The population of micro-organisms (fungi, actinomycetes, ammonifiers, nitrogen fixing bacteria and nutrient solubilizing bacteria) in the soil goes up significantly under polythene mulch, which accelerates the decomposition and transformation of organic matter leading to increasing levels of available nutrients in the soil.

Micro-climate

During the middle growing stage, the reflection of sunlight by polythene film increases illumination between rows. The accumulated soil temperature is more and the wind speed between the rows is faster. Faster wind speeds favor air exchange and CO_2 movement. All these factors increase photosynthetic efficiency.

Cultivation practices

Selection of polythene film

Although a film with thickness varying between 0.004 mm and 0.014 mm can be used for mulching, the thickness of 0.007 mm is optimum and economic. The film should have light transmittance $\geq$ 70% and elasticity $\geq$ 100%. The width of the film will depend on the width of the seedbed and the type of variety to be grown (small-seeded or large-seeded). It can vary between 750 mm and 900 mm.

Land preparation and fertilizer application

Deep tillage must be carried out for polythene mulching. The field should be prepared thoroughly before seedbed formation. The fertilizer requirement under mulched conditions is higher than that of the non-mulched conditions because of the higher yields obtained under the former. In a comparable situation, the target yield in mulched conditions will be 30% higher than under non-mulched conditions. The farmyard manure should be applied at the time of land preparation and the inorganic fertilizers at the time of seedbed formation.

Seedbed formation

The 50–60 cm wide beds (for planting two rows) alternated with 30 cm furrows are made 4–6 days before sowing, either by a bed-former drawn by tractor or manually. The beds should be 11–12 cm high with both sides vertical and the surface smooth without clods or pebbles, so that the film hugs the soil surface and is not dislodged by strong winds.

Polythene mulching

Mulching can be done either before or after sowing. Before laying the polythene film over the bed, appropriate herbicide should be sprayed over the bed surface. The film can be laid manually or by a mulching machine drawn by a power tiller. The polythene film should be well stretched over the bed surface and buried on either side of the bed.

Sowing after mulching

Holes, 3–4 cm deep, are made at desired spacing with a hole-maker. Two seeds are placed in each hole and covered with soil. If soil moisture is low, some water is poured in the hole and seeds are covered with moist soil. Some additional soil is also placed over the hole to cover the edges of polythene film.

Sowing before mulching

Normal sowing with two seeds per hill is carried out in rows 30–40 cm apart on bed surface followed by mulching. As the soil cracks due to emerging seedlings, holes of 4–5 cm diameter are made over the crack in the film and the hole is covered with moist soil to facilitate emergence of seedlings through the holes in polythene film. Any delay in making the holes after soil cracking could result in heat injury to emerging seedlings.

Good quality, uniform sized seeds with > 98% germination should be used in sowing after appropriate chemical seed treatment. The seedlings and young plants should be inspected regularly to ensure that all emerging lateral branches are over the film. In case some seeds fail to germinate, the gaps should be filled in early, preferably with sprouted seeds.

Cultural management

Shallow hoeing should be done in furrows as and when required to keep them weed free and encourage water infiltration and moisture conservation. Irrigation should be given in furrows when long dry spell occurs at moisture sensitive stages such as peak flowering, pegging and podding. Appropriate plant protection measures and other cultural treatments should be followed as and when required.

Harvesting

The crop with polythene mulch matures 7–10 days earlier than the non-mulched crop. The pod maturity is relatively uniform under the former. When 90% of the pods mature, the crop should be harvested. During harvesting, all film should be retrieved from soil and plants for recycling to avoid environmental pollution.

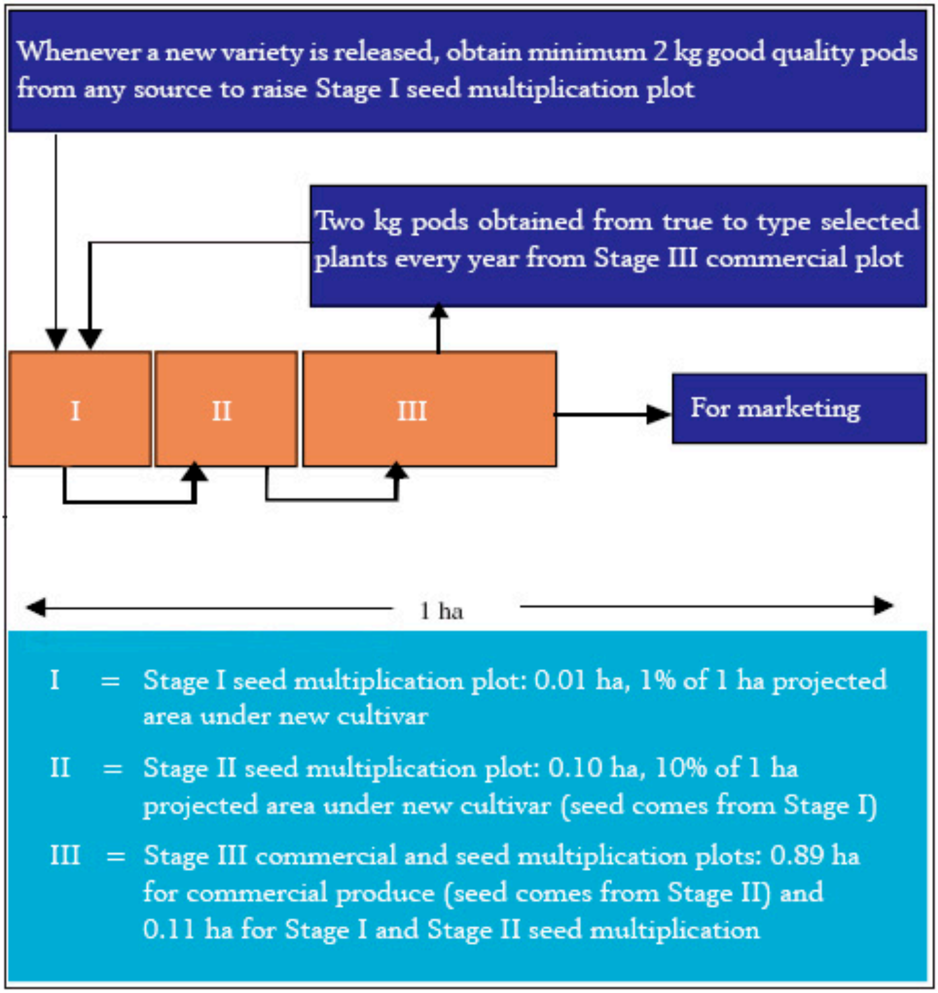
The National Research Centre for Groundnut, ICAR, Junagadh is also promoting polythene mulch technology in groundnut cultivation under *rabi*/ summer, low temperature and rice fallows/residual soil moisture conditions in India. In demonstrations conducted during 1997–1999 in Goa, Gujarat, Maharashtra, Orissa, Rajasthan and West Bengal, the pod yield advantage under polythene mulch ranged between 20% and 45% and the benefit cost ratio varied from 1:2.5 to 1:2.7.

Appendix 2. Building Self-Reliance in Seed of Improved Groundnut Varieties

Non-availability of the seed of improved varieties is a major constraint in groundnut production in most of the groundnut growing countries. Of the 1.5 million t annual requirement of Certified seed of groundnut in India, the public sector seed producing agencies are able to provide only 0.065 million t. There remains a severe shortage of Certified seed of groundnut forcing farmers either to save their own seeds or to meet their seed requirements at the time of sowing from local markets, which often sell nondescript or mixed varieties. The vertical seed replacement rate for groundnut in India is about 6%, leaving vast opportunity for old varieties to dominate the groundnut varietal scenario in the country. The private sector seed producing agencies show little interest in groundnut seed production due to reasons such as low seed multiplication ratio, bulky nature of the produce, quick loss of seed viability, high cost of transportation, low profit margin, and self-pollinating nature of the crop (absence of hybrids). Unless farmers produce their own seed of improved varieties, they are likely to stay with old varieties for a long time thus suffering loss in groundnut productivity.

The PKV method of groundnut seed production (Deshmukh SN, Satpute GN, Dabre WM and Deshmukh RG. 2001. International *Arachis* Newsletter 21: 23-24) suggests a scheme which farmers can adopt to produce their own seed of improved groundnut varieties. Starting with 2 kg pure seed (pods) of a new variety, sufficient seed for 1 ha can be produced in two seasons. After the third season, seed production chain becomes self-sustaining.

Schematic presentation of PKV method of seed production by farmers



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About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a nonprofit, non-political organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT's mission is to help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture. ICRISAT belongs to the Alliance of Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR).

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