GROWTH AND PRODUCTION OF GROUNDNUT

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Contents

Summary

The groundnut or peanut is one of the important legume crops of tropical and semiarid tropical countries, where it provides a major source of edible oil and vegetable protein. Groundnut kernels contain 47-53% oil and 25-36% protein. The crop is cultivated between 40ºN to 40ºS of the equator. Groundnut is a self pollinated crop whereby flowers are produced above ground and, after fertilization, pegs move towards the soil, and seed-containing pods are formed and developed underneath the soil.

The productivity of groundnuts varies from 3500 kg/ha in the United States of America to 2500 kg/ha in South America, 1600 kg/ha in Asia, and less than 800 kg/ha in Africa. This is due mainly to various abiotic and biotic constraints. Abiotic stresses of prime importance include temperature extremes, drought stress, soil factors such as alkalinity, poor soil fertility and nutrient deficiencies. Groundnuts grow best in light textured sandy

loam soils with neutral pH. Optimum temperature for their growth and development ranges from 28 to 30 ºC; the crop requires about 500-600 mm of well distributed rainfall.

The main yield limiting factors in semiarid regions are drought and high temperature stress. The stages of reproductive development prior to flowering, at flowering and at early pod development, are particularly sensitive to these constraints. Apart from N, P and K, other nutrient deficiencies causing significant yield losses are Ca, Fe and B. Biotic stresses mainly include pests, diseases and weeds. Among insects pests pod borers, aphids and mites are of importance. The most important diseases are leaf spots, rusts and the toxin-producing fungus *Aspergillus*.

1. Origin and Distribution

The cultivated groundnut or peanut (*Arachis hypogaea* L.) originated in South America. The term *Arachis* is derived from the Greek word "arachos", meaning a weed, and *hypogaea*, meaning underground chamber, i.e. in botanical terms, a weed with fruits produced below the soil surface. There are two most common names used for this crop i.e. groundnut or peanut. The term groundnut is used in most countries of Asia, Africa, Europe and Australia, while in North and South America it is commonly referred to as peanut. The term groundnut refers to the pods with seeds that mature underground; the connotation of peanut is because this crop belongs to the leguminous family which includes also other crops such as peas and beans. It is a legume crop and not related to other nuts (e.g. walnut, hazelnut or cashews). The terminology of nut is used due its unusual growing habit where flowers are formed above ground (soil) and after fertilization the gynoecium penetrates the soil and forms pods which contain seeds (kernels). In this manuscript the term groundnut will be used due its wider acceptance.

The earliest archaeological records of groundnuts in cultivation are from Peru, dated 3750-3900 years before present (BP). Groundnuts were widely dispersed through South and Central America by the time Europeans reached the continent, probably by the Arawak Indians. There is archaeological evidence of their existence from Mexico, dated 1300-2200 BP. After European contact, groundnuts were dispersed world-wide. The Peruvian runner type was taken to the Western Pacific, China, Southeast Asia and Madagascar. The Spanish probably introduced the Virginia type to Mexico, via The Philippines, in the sixteenth century. The Portuguese then took it to Africa, and later to India, via Brazil. Virginia types apparently reached the Southeast US with the slave trade. Gibbons *et al*. (1972) noted substantial secondary diversity in Africa and Asia. The types they found and their locations supported these various conjectures regarding dispersal.

2. Taxonomy and Classification

The genus *Arachis* belongs to family *Fabaceae*, subfamily *Papilionaceae*, tribe *Aeschynomeneae*, subtribe *Stylosanthinae*. This genus is morphologically well defined and distinguished from other genera by having a peg and geocarpic reproductive growth. The genus *Arachis* has more than 70 wild species, of which only *Arachis hypogaea* L. is domesticated and commonly cultivated.

The taxonomy of the genus *Arachis* has been well documented and includes 37 named species and a number of undescribed species. The genus has been divided into nine sections i.e., *Arachis, Caulorrhizae, Erectoides, Extranervosae, Heteranthae,* *Procumbentes, Rhizomatosae, Trierectoides* and *Triseminalae*. The section Arachis comprises an annual and perennial diploid ($2n = 20$) and two annual tetraploids ($2n = 4x = 40$). The leaves of *Arachis hypogaea* L. are tetrafoliolate, and plants are typically erect or decumbent and pegs penetrate the soil at an angle of approximately 45°. Most of the earlier classifications of *Arachis hypogaea* L. were based on growth habit, presence or absence of seed dormancy and relative time to maturity. In later classifications, characters such as branching pattern and location of reproductive branches have been included.

Cultivated groundnuts are divided into two large botanical groups, Virginia and Spanish-Valencia, on the basis of branching pattern. There are two basic types of branching "alternate" and "sequential", and cultivar groups within the two branching patterns are considered as subspecies. In the Virginia group, the main stem does not have reproductive axes. Alternating pairs of vegetative and reproductive axes are borne on the cotyledonary laterals and on other $n+1$ branches (where `n' is the main axis, and primary, secondary and tertiary branches are $n+1$, $n+2$ and $n+3$, respectively). This system was termed the `alternate branching pattern'. The first two branches on the n+1 laterals are always vegetative and the alternate branching pattern is repeated in the higher order branches.

In the Spanish-Valencia group, reproductive branches are borne in a continuous series on successive nodes of the cotyledonary and other lateral branches, on which the first branch is always reproductive. Reproductive branches are also borne directly on the main axis at higher nodes. Most $n+2$ and $n+3$ nodes are reproductive.

Subdivision of *Arachis hypogaea* L. holds two subspecies: *A. hypogaea subsp. hypogaea* and *A. hypogaea subsp. fastigiata*. Subspecies *hypogaea* has a central axis that never bears inflorescence and has laterals where vegetative branches alternate regularly with reproductive branches. The inflorescence is simple, seeds show dormancy and plants are late maturing (120 to 150 days depending on temperature and crop density). In general, these types branch profusely and have a runner or spreading bunch habit. In runners (prostrate) the stems trails over the ground, while in spreading bunch, the main stem is erect, while branches trails on the ground. The US market types Virginia and Virginia Runner and the distinct variety *hirsuta* belong to this group.

Arachis hypogaea subsp. fastigiata comprises plants that are always erect, with inflorescence on the central axis, and without a regular pattern in the sequence of reproductive and vegetative branches. The inflorescence is simple or compound, pods are concentrated around the central axis, and seeds do not show dormancy; plants are early maturing (90 to 120 days). In general, these types are sparsely branched and have an erect bunch habit. The US market types Valencia and Spanish belong to this group.

3. Groundnut Production and Productivity

The world groundnut (in shell) harvested area in 2007 (FAO, 2007) was 23.4 million ha with a total production of 34.9 million metric tons (Mt). The total harvested area in 2007 increased by 3.7 million ha when compared to 1990, while production increased by 11.7 million Mt. The world's average productivity in 2007 was about 1490 kg/ha. It is cultivated in as many as 90 countries. Groundnut is therefore an oilseed crop on a global scale.

Groundnuts are predominantly grown in developing countries (Asia and Africa), where the crop finds the appropriate climates for optimum production. About 90% of the total world production comes from this region and about 60% of production comes from the semiarid tropics (SAT). Roughly two-thirds of this is used for oil, making it one of the important sources of vegetable oil, along that of soybean, sunflower and palm oil (*see also : Growth and Production of Soybeans* and *Growth and Production of Oil Palm*).

3.1. Asia

Asia has the largest area of groundnut cultivation in the world contributing to 67% of the total production in 2007. India holds the largest acreage (6.7 million ha) followed by China (4.7 million ha), Indonesia, Myanmar, Pakistan and Thailand. There has been an important increase in harvested area in Asia in the last two decades, mainly in China, Hong Kong, Japan, Korea and Taiwan.

More than 25% of the groundnut area harvested in the world is in India followed by 20% in China. However, China is the largest producer of groundnut and accounts for 37% of world production, followed by India with 22%. The average productivity of groundnut in Asia is 1739 kg/ha.

In India the important groundnut growing states are Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra, Madhya Pradesh, Uttar Pradesh, and Rajasthan. The crop is grown in all three seasons: rainy, post-rainy, and during summer months. It is mostly cultivated under rain fed conditions; only about 10-15% of the cropping area is irrigated.

3.2. Africa

In Africa, groundnut is grown mainly in Nigeria, Sudan, Senegal, Chad, Ghana, Congo, and Niger. In 2007, the total harvested area in Africa was 9.04 million ha with a total production of 8.7 million Mt. The average productivity in this region is 964 kg/ha, which is poor when compared to the US and other developed countries where it is close to 3500 kg/ha. Average productivity is 1720 kg/ha in Nigeria, 500 kg/ha in Sudan, and close to 700 kg/ha in Senegal. For a long time groundnut was the main export product of Senegal and The Gambia.

3.3. North America

In 2007, the total harvested area in the US was 0.57 million ha, with a total production of 1.6 million Mt. The average productivity of this region is 3508 kg/ha, which is about 2000 kg/ha above the world average. Production is mainly concentrated in three major geographic areas: the Southeast, which includes Alabama, Florida, Georgia, and South Carolina; the Southwest, which includes New Mexico, Oklahoma, Texas; and Virginia-Carolina, which includes North Carolina and Virginia. The largest single area in the US is found in Georgia, followed by North Carolina and Alabama.

3.4. South America

The major countries growing groundnut in South America are Argentina, Brazil, Paraguay, Ecuador and Bolivia. The crop is cultivated over an area of 0.39 million ha, with a total production of 1.02 million Mt in 2007. The average productivity of this region is 2595 kg/ha. Argentina is the major groundnut growing country in the region, contributing to more than 70% of area and production. The SAT growing region in this continent is in Brazil, located between 19° and 25° South.

3.5. Europe

In 2007, the total European production amounted to 8,910 Mt, which comes from a harvest area of 10,506 ha with an average productivity of 843 kg/ha. The major groundnut growing country is Greece, followed by Spain, Portugal, and Hungary. There has been a significant variability in the total groundnut area harvested in this region in the last two decades. It increased from 12,718 ha in 1980 to 17,849 ha in 1990, and then decreased again to 11,080 ha in 2007.

4. Utilization

Groundnut is an important subsistence food crop throughout the tropics. It is mainly grown for the kernels and the edible oil and meal derived from them, and the vegetative residue. Groundnut kernels typically contain 47-53% oil and 25-36% protein; they also contain about 10-15% carbohydrate and are rich in P; they are also a good source of vitamins B and E.

Groundnuts are used in various forms, which include groundnut oil, roasted, and salted groundnut, boiled or raw groundnut or as paste popularly known as groundnut (or peanut) butter. The tender leaves are used in certain parts of West Africa as a vegetable in soups. Groundnut oil is the most important product of the crop, which is used for both domestic and industrial purposes. About 75% of the world groundnut production is used in extraction of edible oil.

Groundnut oil is the cheapest and most extensively used vegetable oil in India. It is used mainly for cooking, for margarine and vegetable ghee, salads, for deep-frying, for shortening in pastries and bread, for pharmaceutical and cosmetic products, as a lubricant and emulsion for insecticides and as a fuel for diesel engines. The press cake containing 40-50% protein is used mainly as a high-protein livestock feed and as a fertilizer.

The dry pericarp of the mature pods (known as shells or husks) is used for fuel, as a soil conditioner, filler in fertilizers and feeds, or is processed as substitute for cork or hardboard or composting with the aid of lignin decomposing bacteria. The foliage of the crop also serves as silage and forage. With the recent thrust on bioenergy, possibilities are being tested for using groundnut as a bio-diesel crop, because groundnut produces more oil per hectare than any other food crop.

5. Growth and Development of Groundnut

5.1. Growth Stages

The growth stages of groundnut plants based on visual observations of vegetative and reproductive growth have been described and defined by Boote (1982). This widely adopted system describes a series of vegetative (V) and reproductive stages (R), and all stages are discrete population-based events which are mostly determined by field observations (Table 1). Different reproductive stages of groundnut are shown in Figure 1.

Table 1. Growth stage descriptors for groundnut (Boote, 1982).

5.2. Seedling and Vegetative Growth

The groundnut seed consists of two cotyledons, a hypocotyl, epicotyl, and radicle. All primordial leaves, which the seedling will develop within the first few days after germination, are present in the seed. There may be 4-5 leaf primordia in the embryo of seed; five are well developed in large seeds and four in small ones. Germination is epigeal, the cotyledons become green soon after emergence. The seedling consists of cotyledons, vegetative axes, and the main axis. The hypocotyl is white and is easily distinguished during the early stages of growth, but becomes indistinguishable from the root as the plant matures.

Figure 1. Reproductive stages of groundnut showing (a) appearance of first flower, R1; (b) pegging, R2; (c) podding, R3; (d) full pod, R4; (e) starting of seeding, R5; (f) full seed, R6; (g) mature seed, R7; and (h) harvest maturity, R8.

Groundnuts take about 3-5 days for germination and emergence from the soil at 30° C. The radicle emerges within 24 h or earlier for vigorous Spanish types and within 36 to 48 h in Virginia types. The primary root system is tap-rooted but many lateral roots also appear about 3 days after germination. Roots are concentrated in the 5 to 35 cm zone below the soil surface, but penetrate the profile to a depth of 135 cm. Groundnut roots do not have typical root hairs, but rather tufts of hair, which are produced in the root axils.

During the first few days the developing seedlings are dependent on assimilates stored in cotyledons. After 5-10 days, depending upon cultivar and environmental conditions, the seedling grows autotrophically and is capable of absorbing minerals via the roots whilst the epicotyl is exposed to light and capable of photosynthesis. Stems are angular, green or pigmented and are initially solid, but as the plants grow they tend to become somewhat hollow. The main stem develops from a terminal bud of the epicotyl and two opposite cotyledonary laterals grow at soil level. The main stem can be upright or prostrate and from 12 to 35 cm long or may exceed 1m in runner types.

The early vegetative growth stage is mainly concerned with mainstem elongation and leaf production, whereas the formation of lateral branches dominates later growth. Mainstem leaves account for >50% of the leaf area of plants for the first 35 days, but at 90 days they account only for 10%. After flowering, dry matter accumulation is mainly in the reproductive structures.

The growth and branching patterns differ between subspecies and botanical types. Subspecies *hypogaea* has alternating pairs of vegetative and reproductive nodes, while subspecies *fastigiata* has a sequential pattern of reproductive nodes.

5.3. Reproductive Growth and Maturity

Groundnut cultivars typically flower (R1) about 25 to 30 days after sowing, depending on cultivar and climatic conditions. The flowering pattern varies within and between botanical types. The Spanish types flower relatively early and have a broader first flowering peak whereas the Virginia types are later flowering and have multiple flowering peaks. Cultivars within the subspecies also vary in their flowering patterns. Flowers are borne in the axils of leaves (Figure 2a), usually with three flowers per inflorescence.

Figure 2. Groundnut flowering (a), formation of pegs (b), and penetration of peg into the soil (c). (Courtesy Dr. J. Beasley, University of Georgia, USA).

Generally one bud per inflorescence reaches anthesis on a given day, but occasionally two or more buds may open on the same day. Flower color varies from yellow to orange to dark orange and rarely to white. The style is contained within a calyx tube (hypanthium). The bud is 6-10mm long 24 h before anthesis and, during the day, the hypanthium elongates slowly and the bud attains a length of 10-20 mm. During the night, elongation of the hypanthium is more rapid. The flower contains 10 anthers, five of which are small and globular and five are oblong. One of the anthers is usually sterile and difficult to observe. The anther attains a maximum length of 5-7 mm at the time of anthesis.

Flowers open early in the morning as soon as they receive light. The dehiscence of anther occurs just before or when the flower opens or sometimes much earlier. The stigma is receptive from 24 h before to 12 h after flower opening. Groundnuts are usually self-pollinated and pollination occurs just before the flowers open.

It has been observed that sporogenesis and gametogenesis occurs 3 to 6 days prior to anthesis when buds are about 5mm long. Pollination occurs just before anthesis. After pollination the pollen tube grows at a rate of 1 cm/h resulting in fertilization about 5-6 h after pollination. This may vary with cultivar and environment. After fertilization the flower withers and in doing so activates the growth and elongation of the intercalary meristem, which is located at the base of the ovary.

A stalk-like structure, called a peg (Figure 2b), becomes visible within 4-6 days after fertilization under optimum environmental conditions. Peg extension is slow at first and takes about 5-6 days to penetrate the bracts. Once pegs are 3-4 mm long they become positively geotropic and start to grow towards the soil (R2, pegging stage). The rate of elongation then increases rapidly between 5-10 days after fertilization and pegs can be as long as 15cm. The peg bears the ovary with the fertilized ovule at its tips. The peg typically reaches and penetrates the soil surface in about 8-14 days after fertilization (Figure 2c).

Once the peg enters the soil and penetrates to a depth of 4-5cm, the tip of the ovary begins to swell (R3, podding stage) and turns horizontally away from the base of the plant and develops into a pod (Figure 3). The time from R1 to R3 is usually 15 to 20 days, after which the pod begins to expand rapidly until it reaches dimensions characteristic of the cultivar. The R4 stage (first full pod stage) is defined as the time when 50% of the plants have achieved fully expanded pods.

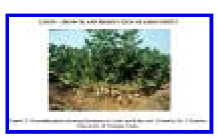

Figure 3. Groundnut plant showing formation of pods inside the soil.Courtesy Dr. J. Beasley, University of Georgia, USA).

The number of flowers produced per day increases gradually; maximum numbers typically appear at 14-28 days after flower initiation, and numbers then decline to zero during the pod filling stage. However, cultivars within and between botanical types may vary in their flowering behavior. Pods become countable and pod weights become measurable at about 60-70 days after planting. Pod number per plant rises rapidly to a maximum at 80-120 days depending upon cultivar and botanical type.

The fresh weight of the whole pod increases very rapidly during the first 14 days of subterranean growth and pods attain their maximum size after 21 days. During the seed growth phase (R5 growth stage), when seed cotyledon growth is visible in at least one pod on 50% of the plants, the endocarp recedes as the ovule grows and has disappeared completely by the time seeds are mature. During this period the inner phase of the shell is darkened by tannin deposition and turns dark brown on maturation. Pod growth rates differ among cultivars, and are affected by temperature of the fruiting zone. Pod growth rates slow down as pods mature.

6. Nodule Formation and Nitrogen Fixation

Nodule initiation and subsequent growth and function are an interactive process involving the eukaryotic host legume and the prokaryotic Rhizobium. The process is complex, resulting in biochemical and morphological changes in both symbionts and leading to the capacity of reducing atmospheric nitrogen. Nodule formation occurs generally in three sequential steps, i.e. root colonization and infection, multiplication of bacteria, and development of nodules.

6.1. Root Colonization and Infection

Groundnuts are nodulated by a wide range of species of rhizobia. Proliferation of compatible rhizobia in the rhizosphere of legumes is the first step towards nodule formation. There is no clear specificity in groundnut nodulation and root colonization. In most legumes rhizobia enter through root hairs via an "infection thread", but in groundnut roots the invasion process is rather different. Normal root hairs are absent; instead tufted rosettes of hairs are found in the junctions of root axils. It is at these junctions that nodulation occurs.

6.2. Nodule Development

Once the rhizobia have entered the root and occupied the space between the root hair wall and the adjoining epidermal and cortical cells, the cells adjacent to the point of *Rhizobium* penetration separate at their middle lamellas and the resultant spaces become filled with bacteria, forming intercellular zones of infection. The bacteria penetrate into progressively deeper cell layers and intracellular infection then occurs. Soon after intracellular infection, the bacteria multiply rapidly.

Further development of the nodule occurs by repeated division of the infected host cells, and the bacteria become transformed, into different morphological forms known as bacteroids. As the size of bacteroids is relatively large, the number of bacteroids per unit nodule weight in groundnut is small when compared to other tropical legumes such as cowpea. The initial spherical shape of legume nodules can develop into various morphological variants, but in groundnut they remain more or less spherical throughout.

6.3. Nodule Function

The bacteroids contain the nitrogenase enzyme which reduces gaseous nitrogen. The effectiveness of the nodule to fix nitrogen depends on the presence of leghemoglobin, which gives a pink coloration to the nodule tissue. Quantitative determination of leghemoglobin during certain stages of plant growth (e.g. flowering) could be used as an indicator of dinitrogen fixation in groundnuts. The host plant provides energy in the form of carbohydrates for dinitrogen fixation and the carbon skeleton for the assimilation of reduced nitrogen (NH_4). The fixed nitrogen is transferred to shoots mainly in the form of o-methylene glutamin. Not all the rhizobia that produce nodules fix nitrogen. It is important therefore to select good inoculant strains for survival in rhizosphere, competition with indigenous strains, infectivity and fixation potential.

7. Climatic Requirements

Groundnut has spread from its centre of origin in the Matto Grosso State of Brazil to most tropical, sub-tropical, and warm temperate regions between 40° North and 40° South latitudes. This dissemination indicates adaptability to a wide range of soil and climatic conditions, and to the value of the crop for food, oil, and feed.

Groundnut can be grown in a wide range of temperate and humid regions, but maximum production comes from the semiarid tropics. Optimum temperature ranges between 20 and 30º C; productivity is limited below 16º C and above 32º C. The thermal time requirement for groundnut depends upon cultivar and ranges from 1800 to 2400 degree-days (at a base temperature of 10ºC) or heat units. Growing degree days are the measure of heat accumulation during the growing season. Developmental events in plants are dependent upon accumulation of specific quantities of heat, thus the concept of growing degree days helps predict developmental events regardless of temperature variations from year to year. Growing degree days are calculated for each day as the average of maximum and minimum temperature, and subtracting the base threshold temperature (here being 10° C).

The crop can also be grown in regions with a rainfall ranging from 200 to 1000 mm. The effects of temperature and drought are discussed in more detail in later sections.

Groundnut is affected by day length and light intensity. The crop prefers clear days with lots of sunlight for optimum production. It is a day-neutral plant with the flowering time controlled by temperature. However, photoperiod plays an important role in reproductive efficiency (flowers producing pegs and pods), and assimilate distribution during the post-flowering period. Long days promote vegetative growth at the expense of reproductive growth. During the post-flowering period, reproductive development is restricted when the photoperiod increases from 13 to 16 hours of day length. In addition, long days and high temperature further reduce reproductive efficiency. Certain cultivars are also sensitive to photoperiod as the time of flowering is influenced by photoperiod.

8. Soil Requirements

Soil selection for groundnut is very important because pods are produced under the surface. The best soil for groundnut production is well-drained, light colored sand, loamy sand, or sandy loam. Light textured soils ease penetration of pegs and development of pods. In addition, this also aids in easy harvesting and in minimizing pod losses during harvest.

The quality of the harvest from light textured soils is increased by the clean and shiny appearance of the pods, and their higher market value. Groundnut produces good yields in soils with pH of 6.0- 6.5. Although groundnut is considered to be tolerant to acid soils, some cultivars grow well in slightly alkaline soils with a pH up to 8.0 which helps in nitrogen fixation.

9. Land Husbandry and Crop Management

9.1. Cropping System

Groundnut is a versatile crop that can easily be incorporated in various cropping systems. Groundnut is commonly grown in rotation with wheat, barley, chickpea, and lentil in northern India, while in south India it thrives on residual soil moisture after rice harvest. About 90% of the total groundnut production is in the rainy season. In West Africa it is grown in the rainy season either as a sole crop or mixed with sorghum or millets (*see also: Growth and Production of Sorghum and Millets*).

It is generally recommended that groundnuts be rotated with cereals, whereby the latter crops (maize, sorghum, cotton, or millet) can take advantage of nitrogen fixation from groundnut and also benefit from the earlier fertilizer applications. Crop rotation also reduces the effects of pests and diseases from insects, nematodes and weeds. In addition, it provides better management and more profits by minimizing costs of weed control and pest management.

9.2. Cultivar Selection

As indicated earlier there are different types of groundnuts, mainly linked to the two botanical types *Hypogaea* and *Fastigiata*. *Hypogaea* holds two market types: Runner and Virginia; *Fastigiata* has also two market types: Spanish and Valencia. The selection of cultivars is location-specific and depends upon the growing season and market types. There are several choices of cultivar within each group. Cultivar selection should also be based on tolerances to both biotic and abiotic stresses.

9.3. Seedbed Preparation

Seedbed preparation is an essential part of crop management to improve soil properties, decrease weed pressure, conserve moisture, improve soil water holding capacity, and improve germination percentage. Seedbed preparation of groundnut depends upon rainfall and soil type. In regions where tillage is a common practice, soils are plowed and harrowed soon after harvest of the previous crop or done before the rains to facilitate water harvesting. In parts of the United States strip tillage is being adopted. In the strip tillage method land is not turned but is subsoiled and only a strip of soil is tilled (about 20 – 30 cm), while the soil between the rows remains undisturbed.

9.4. Planting Date

Planting date is highly locality- and region-specific. The best planting date depends largely upon soil temperature, available soil moisture and availability of land within the given growing season. In India, groundnuts can be grown in three seasons, i.e.: the rainy, post rainy or summer seasons. Most groundnuts in India are sown in the rainy season and are planted with the onset of rains in May to June; the crop is then rain fed.

In the post rainy season and where cool temperature does not limit production, the crop is sown in September-November. During this post-rainy season crop growth and development is dependent upon stored soil moisture. However, providing 2 to 3 irrigations during critical stages of crop development (flowering and early seed growth) might well increase productivity. In some regions where irrigation facilities are available groundnut can also be cultivated as a summer crop; it is then sown in January.

In most of Africa groundnut is a rainy season crop and is planted between May and July. In the southeastern United States the typical planting time ranges between March and early April.

9.5. Plant Population and Spacing

Groundnut is propagated through seeds directly sown in the soil. In developed countries (United States and Australia) a tractor operated seed drill is commonly used, while in developing countries sowing is done manually or with animal drawn seed drills. The crop is generally planted in rows either on flat beds or raised beds and furrows. Raised beds and furrows help conserve soil moisture, minimize soil erosion, and aid in easy cultural operations (*see also: Soil Engineering and Technology*).

Although recommended plant population in Asia and Africa is about 330,000 plants/ha for bunch types and 250,000 plants/ha for spreading types, the actual planting densities used by farmers are much lower. This is either due to the high cost of planting material or to poor seed quality and related poor germination. The distance between rows and plants varies with cultivars. In general, 30cm between the rows and 10cm between the plants within rows is recommended for bunch types; for spreading types, this is 40cm between rows and 10cm between plants within rows.

In the United States recommended plant population is 250,000 plants/ha for short season Spanish cultivars and 215,000 plants/ha for long season Virginia types. In the United States, most groundnuts are planted in single rows about 90-100 cm apart with about 20 seeds per meter in the row. The standard twin row system (two rows spaced 20 cm apart on 90 cm centers) is becoming common, as the twin row system often has less incidence of the tomato spotted wilt virus.

Optimum planting depth for groundnut is about 5 cm for heavy soils and 6 cm for light soils. Planting deeper than 7.5 cm decreases emergence percentage. If soil moisture is limited, irrigation before planting is recommended. In addition, in some places it is recommended to treat the seeds with *Rhizobia* to help nitrogen fixation. If groundnut are being sown either for the first time in a new field, or after a long period, it is recommended to treat the seed with a proper strain of *Rhizobia*.

9.6. Nutrition and Fertilizer Use

Nutrient requirements for groundnuts are lower than for most other crops, like corn or soybean for example. In the United States groundnut is commercially grown and fertilized; in parts of Africa and Asia where most of the crop is used for local consumption, fertilizer application is not a common practice.

The crop responds rather well to fertilizers. In general, groundnut requires about 20kg N/ha, 50-80kg P/ha, and 30-40kg K/ha. For a yield of 3000kg pod and 5000 kg of vine (biomass) per hectare, nutrient removal is estimated at about 120kg N, 11kg P, and 18kg K per hectare for pods, and 72kg N, 11kg P, and 48kg K per hectare for vines. This makes a total of about 192kg N, 22kg P, and 66kg K/ha, respectively.

In addition, the crop also responds well to the application of organic matter or farm yard manure. Groundnut requires more Ca during flowering and pod formation, as the Ca taken from the roots cannot be used by pods, and has to be absorbed directly by the pegs and pods. The mineral nutrition aspects of groundnut are discussed in later sections.

9.7. Water Use and Irrigation

The amount of moisture needed to produce an acceptable yield of groundnut is approximately 500 to 600 mm. Groundnut can be grown in regions receiving more (800 mm) or less rainfall (about 350 mm), provided rainfall is well distributed. The amount of irrigation depends on the soil type. Light textured soils need about 600-700 mm of water (about 10 irrigations), and medium to heavy soils need about 500-600 mm (6-7 irrigations). If only limited irrigation facilities are available, then priority should be given to irrigate at critical stages of development, i.e. flowering and pod development. Irrigation in developing countries is currently by furrow irrigation, which is more efficient than flood irrigation.

9.8. Weed Management

As for other crops proper weed control is essential for improving crop productivity. Weeds do not only compete with crops for nutrients and water, but also reduce seed quality. Both annual grasses and broad-leaved weeds are common in groundnut cropping. The types of weeds are regional-specific and should be removed as necessary. In developing countries of Asia and Africa weed control is done manually by hand pulling or by using hoes and/or animal drawn small equipment. Some commercial producers and large farmers also apply herbicides for weed control.

Proper field preparations during planting and intercultural operations after planting help establish and obtain initial crop vigor. Early season weed control is very important as groundnut is highly sensitive to weeds during the first 25-30 days after planting. Early weed control is beneficial for yield. However, weeds can also emerge later in the season and be controlled at that moment. In developed countries (e.g. United States) the use of herbicides is common. Pre-emergence and post-emergence herbicide options are available for effective control. Either pre-plant incorporation or pre-emergence herbicides options are available for groundnut. Most of the times only pre-plant or pre-emergence application is not enough to control weeds, and one to two applications of post emergence herbicides are also recommended.

Environmental conditions, either extremely dry or wet will influence the efficacy of herbicide application. Proper scouting of weeds, their identification and prior knowledge of potential weeds is the key to design an effective weed control strategy. The selection of herbicides should depend on the mixture of weed population and weed intensity (*see also: Weed Science and Management*).

9.9. Harvesting, Drying and Storage

As groundnut pods are developed underground they have to be extracted for harvest. Moreover, under these conditions it is sometimes difficult to define maturity; as flowering occurs during long periods, care should be taken in selecting pods for testing maturity. In practice, plants are ready for harvest when leaves become yellow and begin to fall, the pods become reticulate, the internal hull color is dark, and the seeds are easy to separate.

Timing of harvest is very critical for groundnut, as an early harvest decreases yield and crop quality, while a delayed harvest causes pods to remain in the soil and/or to become prone to diseases and post harvest losses. In developing countries harvesting is generally done by pulling the plant or digging the plant using animal-drawn equipment (Figure 4a) or small machines. Uprooted plants are generally dried in the field or on leveled platforms. Plants should be placed roots up, so that pods dry faster and uniformly. They should be left in the field for 2-3 days (depending upon the weather conditions). After drying, pods are separated from the plants either by hand or by using threshers.

After threshing, seeds are separated using mechanical shellers, and stored in a dry and aerated place. Improper handling while harvesting or storage leads to infections with *Aspergillus* and aflatoxin contamination. In developed countries harvesting is done by machines (Figure 4b) which dig the plants, and picks pods by striping. After drying, pods are shelled with machines and stored in bins.

Figure 4. Harvesting of groundnut with animal drawn equipment in India (Courtesy Dr. P.Q. Crauford, University of Reading, UK) and mechanical harvesting of groundnut in with tractor in United States (Courtesy Dr. J. Beasley, University of Georgia, USA).

10. Abiotic Stresses

Approximately 70% of the world's groundnut production comes from semiarid regions, and developing countries contribute about 90%. The semiarid tropics (SAT) in India, Senegal, Nigeria, Sudan, Zaire, Brazil, Burma, Argentina, Thailand and Zimbabwe are characterized by extremes of moisture availability and temperature during the peak period of crop cultivation. The productivity of groundnuts in SAT regions of Asia and Africa is very low (< 900 kg/ha) when compared to world's average of about 1500 kg/ha. This is due to various abiotic and biotic constraints.

Abiotic factors of prime importance include temperature extremes, drought stress, soil factors such as alkalinity, poor soil fertility and nutrient deficiencies. However, the major yield limiting factors in the SAT are drought and heat stress. Groundnuts grown in this region are often exposed to damaging hot soil and air temperatures of 40° C or more during parts of the growing season. Water deficits at critical stages can reduce pod yields by more than 70%.

The influence of abiotic stress is complex, given that it is often confounded and associated with hot temperatures, water deficits and high light intensities. Heat and drought stress significantly affect physiological processes, e.g. inhibition of photosynthesis, disruption of respiration, changes in membrane permeability, and interfere with nutrient mobility.

Edaphic factors such as alkalinity and salt stress are also known to reduce pod yields. In many groundnut growing regions evaporation often exceeds precipitation, and both irrigation water and soil are moderately saline, resulting in the accumulation of salt in the pod zone of the soil profile. This can decrease nitrogen fixation, reduce vegetative growth, increase the percentage of immature pods, and lead to smaller yields.

Groundnuts, when effectively nodulated, seldom respond to applications of nitrogen. Symptoms of P and K deficiency can occur and are important. However, the crop has a large demand for Ca, and any deficiency can reduce productivity by as much as 30%. Alkaline and lime-rich soil causes iron chlorosis, which leads to yield losses of the order of 30-40%.

10.1. High Temperature Stress

In groundnut as in other annuals, temperature moderation of growth and development can be expressed in terms of thermal time above an appropriate base value or days after sowing or absolute temperature. Groundnut is relatively more tolerant to high temperature when compared to cereal crops. In terms of high temperature tolerance, its performance would be better than soybean and be on par with that of cowpea.

Effect on seed germination and seedling emergence - The time from sowing to seedling emergence (in days) as well as the proportion (in percentage) of seedlings that emerge is influenced by temperature. The optimum temperature for maximum germination ranges from 28 to 36° C. The base temperature ranges from 8 to 11.5° C, while maximum temperature ranges from 41 to 47° C. Temperatures warmer than 36° C are supra-optimal and lead to poor rates of germination. The optimum temperature for seedling development is close to 30°C. Seedlings emerge between 4 to 6 days after sowing at 23° C, while at 27° C it is about one day earlier. In terms of thermal time depending on cultivar, they emerge between 74 and 101° Cd (degree-days) above the base temperature of 10° C.

Effect on vegetative growth - Number of leaves, plant height and mainstem node number in groundnut are all responsive to temperature. An increase in leaf numbers occurs (17 to 86 per plant) with an increase in day temperature from 15 to 35° C. The rate of node number is accelerated as temperature increases: the optimum temperature for a node to appear is 27° C, and increases up to an optimum value of 35° C. Similarly, internode length and branch number increase with higher temperature.

Temperature significantly influences the vegetative growth of groundnuts. The optimum temperature range for leaf and stem growth is 28 to 30° C. Temperature influences carbon assimilation by the crop canopy by affecting the initiation, expansion, senescence, longevity and death of leaves and, therefore, canopy leaf area at any time. Crop growth rate, leaf area and total dry matter production are maximal at a site with mean daily maximum and minimum temperature of 30 and 17° C, respectively. Long-time exposure to hot temperatures (up to 35° C) reduces the number of leaves, leaf growth rate, specific leaf area and total leaf area per plant when compared to values obtained at 30 or 32° C. Day temperature of 35° C is supra-optimal for growth and development even under well watered conditions. The rate of crop photosynthesis is remarkably conservative over a range of mean air temperature from 19 to 30° C. Groundnuts attain their maximum leaf apparent photosynthesis at 30° C but show a reduction by 25% at 40° C.

Groundnuts accumulate less total biomass whenever night temperatures are consistently at or below 16° C. Dry matter accumulation of groundnuts ceases at temperatures cooler than 14° C. Night temperature is negatively correlated with rates of growth during germination and the vegetative growth stage. As the day/night temperature decrease from 32/26° C to 17/11° C the duration of the germination period and the vegetative stage increases from 31 to 75 days.

Effect on root growth - Root growth compensates for the effects of above-ground stress events, like high temperature and low humidity, by supplying water and nutrients to the shoot under stress. Any injury to the roots due to the high air temperature may aggravate the stress effects. High day temperature reduces root growth, while high night temperature does not result in similar response. During the early stages of growth, the optimum shoot growth occurs at soil temperatures between 31 and 37° C, whereas optimum root growth occurs between 25 and 31° C. Root dry matter increases with increasing soil temperatures from 20 to 30° C. The effect of soil temperature on root growth is less understood.

Effect on the time to first flower, peg and pod formation **-** Initiation of flowers and subsequent flower production (i.e. flower number per plant) play a vital role in the reproductive cycle as they determine the potential sink size and the duration of seed filling. However, actual sink size is often limited by environmental stresses. Variations in the duration from sowing to flower opening in groundnut are correlated to mean temperature and thermal time.

Similar to germination and leaf production, genotypes also differ in their time to flowering in response to temperature. Warmer day and night temperatures hasten flower initiation. Once fertilization is complete, the fertilized ovary (gynophore) begins to elongate geotropically towards the soil within 5-7 days after flowers are fertilized. An intercalary meristem, which is most active just below the base of the ovarian cavity, is responsible for the rapid growth of the peg during the aerial and early subterranean phases of fruit development.

Peg initiation rate increases as temperature increases. In terms of thermal time, peg initiation occurs when the plants have accumulated 660° Cd (cumulative degree-days) above a base temperature of 10° C. The optimum air temperature for pod development is about 25-28° C and varies with the cultivar. High temperature delays time from flowering to peg formation and pod initiation.

Effect on flower, peg and pod numbers **-** Flower production in groundnut is affected by temperature. Continuous high temperature during later stages of vegetative development can decrease flower production due to its effect on branching and growth. Reduction in flower number can also occur if flowers drop due to abscission when plants are exposed to severe or stressful environments. Exposure to short periods of heat stress can decrease flower production during the period, but plants generally recover and produce more flowers later. There is an increase in the rate of flower production following the episode of heat stress, and the cumulative number of flowers produced at high temperature (>35° C) is greater than produced at the optimum temperature of 28° C.

Peg numbers are affected by both high day and night temperatures. There is a decrease in the formation of pegs and pods at temperatures above 33/23°C. An increase in day temperature reduces peg number at the rate of 0.9 plant per degree Celsius above an optimum temperature of 28° C. An increase in night temperature from 22° C to 28° C reduces peg number from 7.7 to 5 per plant. In contrast, soil temperature does not affect peg numbers, but influences the conversion of pegs to developing pods and pod numbers.

Decreases in flower and peg numbers reduce the number of pods formed. Air temperature above the optimum of 28° C reduces pod numbers. The decrease in peg and pod numbers above the optimum temperature is generally related to a decrease in fertility of flowers. This is due mainly to the negative effects of high temperature on viability of pollen grains and lower pollen production. Groundnut flowers are most sensitive to high temperature stress 9 days prior to flowering and at the time of flowering. Stress prior to flowering decreases the viability of pollen grains, while stress at flowering decreases the ability of pollen grains to germinate and complete fertilization. Once the flower is fertilized its sensitivity to temperature is relatively lower.

Effect on dry matter accumulation, pod growth and yield - The amount of dry matter accumulated in groundnut per unit input (light, water and nutrients) determines the efficiency of the production system. Crop growth rate, which indicates the rate of conversion of inputs into dry matter, is influenced by temperature. Temperatures above or below an optimum value reduce dry weight or biomass accumulation. An optimum temperature of 28° C has been identified for dry matter accumulation. Temperatures 4° C above or below this optimum reduce dry weight.

Soil temperature is also important in determining groundnut yield as the pod growth occurs in the ground. Plant dry weight decreases with an increase in air and/or soil temperature. Pod yield is usually correlated positively with total dry matter accumulation and, therefore, any effect of temperature on total dry matter accumulation will affect pod yield. Once the peg penetrates the soil, the growth of the peg and that of the pod is influenced more by soil temperature than by air temperature. Maximum yield and quality will be produced when the geocarposphere temperature is between 21 and 29° C during pod addition and pod maturation periods. A 6 to 9° C increase in canopy temperature above 28° C and a 3 to 4° C increase in podding zone temperature above 23° C during the reproductive period results in adverse effects on pegging and pod formation.

Pod production may also be reduced in circumstances where vigorous vegetative growth competes with reproductive organs for assimilates. Increased vegetative growth also involves greater stem elongation, which prevents the pegs from reaching the soil surface. Yield per unit area is reduced due to a decrease in the duration of the pod filling period under high soil temperature conditions. Combinations of high air and soil temperatures are especially detrimental to pod yields. Both high day and night temperatures result in reduced partitioning of biomass to yield in groundnut.

Hot soil temperatures above 33° C significantly reduce pod dry weight and yield. Pod development is most seriously affected by the soil environment in the podding zone. When, in an experiment, the podding zone was submitted to hot soil temperatures of 37° to 39° C at successive 10 day intervals after peg penetration, it was shown that pod development was suppressed by the treatments given during the first 30 days, with greatest reductions occurring between 20 and 30 days after peg penetration. The optimum soil temperature for pod yields was in the range of 30° to 33° C. Soil temperature has a marked effect on reproductive growth and development of groundnuts, and day/night soil temperatures of 38/32° C compared with 26/20° C or 32/26° C, significantly reduce pod yields. This reduction was primarily due to soil temperature effects on the processes of pod initiation rate, pod growth rate, and 100% mature seed weight.

In addition to seed yield, elevated temperatures during seed production can as well decrease the seed composition, decrease the subsequent percent emergence, and seedling vigor of the seeds and seedling dry matter production.

Effect on nodulation and nitrogen fixation **-** Groundnut production in most agricultural systems is heavily dependent on symbiotic nitrogen fixation. Heat and moisture stress interfere with any or all of the processes of root infection, nodule development or nitrogen fixation *per se*. High soil temperature adversely affects the growth and survival of rhizobia in soils and their symbiotic association with legumes, and prevents nodulation. Soil and root temperatures in tropical and subtropical regions are often in the range of 35° to 40° C and are detrimental to nodule formation and nitrogen fixation. At these hot temperatures, the groundnut root biomass is reduced and the roots are thin, unbranched and with very few root hairs and so produce fewer nodules.

Groundnut-*Bradyrhizobium* symbiosis is completely inhibited by a soil temperature of 40° C. The effects are due not only to the failure of nodulation but also to the inability of nodules to function even if they were formed. Hot temperatures adversely affect the process of infection more than the process of nodule growth. Continuous exposures to a root temperature of 37° C reduce total nitrogen content by 49% due to impaired nodule function, but it does not reduce nodulation. In the SAT, surface soil temperatures can occasionally reach 50° C or more at 5cm depth, which is sufficient to inhibit germination of seeds and to kill many bacteria.

Most of the heterotrophic free living nitrogen fixing bacteria and rhizobia are not resistant to desiccation, and excessive soil temperatures can therefore kill most of the bacteria in the surface layers of dry soils. Many aspects of the Rhizobium-legume symbiosis are affected by hot root temperatures, including: growth and survival of rhizobia formation of root hairs; binding of rhizobial cells to the surface of root hairs; formation of infection threads; structure and development of root nodules; leghemoglobin content of nodules; activity of the nitrogenase enzyme; and the nitrogen concentration and dry matter production of nodulated plants. Temperatures of 30° and 35° C significantly reduce the nitrogenase activity of groundnut root nodules as compared to those at a temperature of 25° C. The optimum temperature for the symbiotic system in groundnut is comparable with other tropical and subtropical grain legumes.

The inhibition of nitrogen fixation due to heat stress varies between crops; for soybean it is 30° C, for pea (*Pisum sativum* L.) and lupin (*Lupinus polyphyllus*) it is 25° C, and for alfalfa (*Medicago sativa*) and faba bean (*Vicia faba*) it is 20° C.

10.2. Drought Stress

The effect of drought on groundnut growth and development depends on the stage of crop growth, the duration of drought stress, and the intensity of the stress. About 500-700 mm of moisture is required for optimum yield depending on the climatic conditions. Ninety percent of the variation in yield in semiarid topics is due to the availability of water. Groundnut developmental stages close to flowering and the post-flowering stages are especially sensitive to drought stress.

Effect on vegetative growth **-** Drought stress inhibits leaf expansion and stem elongation through a reduction of relative turgidity thus altering both leaf and stem morphology. Reductions in leaf number and individual leaf size contribute to decreases in leaf area. The extent of the reduction is determined by the intensity and duration of drought stress and stage of crop at which the stress is imposed. A 30 days drought stress would reduce the leaf area by 23%. Leaf longevity and leaf area duration are reduced by decreasing soil water potential. Main axis and cotyledonary branches are shorter and generally decrease more drastic in internode length than the node numbers. Exposure to drought stress decreases the overall vegetative growth of the plant.

The first 50 days after emergence are important for root growth, and a decrease in water availability during this period severely reduces root growth. Root growth in groundnut is influenced by drought. Moderate drought stress stimulates root growth into deeper soils; under drought roots in the lower depths continue to grow deeper even though vegetative growth appears to stop. Groundnut roots can effectively extract soil water from depths of 180cm in fine sandy soils.

Cultivars with drought tolerance usually explore a larger root volume and have a higher root density at deeper depths when grown under stress conditions. However, under severe drought conditions root growth is decreased. Root parameters such as root volume, root dry weight, root length and number respond to water availability and can be used to screen for improved water use efficiency.

Furthermore, the plant's ability to maintain a viable root system during drought stress contributes to drought tolerance. Greater carbon partitioning to the root system before pod set and a root system that maintains itself for a long period for water extraction may have advantage over plants whose roots continue dying and re-growing during reproductive development. Such a habit will help decrease the effects of drought stress during critical stages of reproductive development.

Drought stress can also influence biological nitrogen fixation of the crop. This is particularly critical as most groundnut crops in the semiarid tropics are dependent upon biological nitrogen, while application of inorganic fertilizers is limited. Lower nitrogen fixation generally affects not only the leghemoglobin in the nodules, but decreases also the number of nodules, nodule weight and nodule activity. Drought stress delays the nodule formation, thus depriving crop mineral nutrition during critical pre-flowering stages of crop development.

Nitrogen assimilation is also decreased under drought stress due to reduction in the activity of nitrate reductase enzyme. Water is also essential for uptake of nutrients, the fertilizer use efficiency is lower under stress conditions and the response to fertilizer is limited. This is particularly true to Ca which is very critical for pod developing and has to be taken up by developing pegs and pod directly. Water is required for continuous supply of water soluble Ca.

Effect on reproductive growth and yield **-** Time to flowering is not modified by drought stress. Only severe water deficits of 35% of field capacity would delay flowering by about 1-2 days. However, the total flower number decreases when drought stress is experienced during the pre- or post-flowering stage. Reproductive development from meiosis to seed set is highly vulnerable to drought stress, which can cause pollen sterility, spikelet death or embryo abortion of newly formed seeds in groundnut. Drought stress either reduces or stops peg and pod development based on the degree of stress. The time of peg initiation, rate of peg elongation and pod initiation is delayed or inhibited by drought stress.

Pod development is sensitive to drought stress, where it decreases the pod and seed growth. Adequate pod zone moisture is critical for developing pegs to pods; adequate water in the root zone cannot compensate for the lack of pod zone water for the 30 days of peg developing. However, after 30 days adequate pod zone moisture, the pods can continue normal growth even if the pod zone is dry as long as roots can access adequate moisture.

A decrease in dry matter, flower, peg and pod number, and a delay in peg and pod initiation and pod growth under drought stress conditions individually and in combination contribute to reductions in pod and seed yields. Reductions in pod yield are more pronounced when stress is imposed at the pod development and flowering phases than during the vegetative phase. Pod yield decreases in a linear fashion as the intensity of drought increases.

The partitioning coefficient decreases from 0.52 (100% irrigation) to 0.24 (33% irrigation) as environments become less favorable. Under drought, already established pods have priority for partitioning of assimilates. Partitioning differences between genotypes are also attributed to ability of genotypes to initiate pods under drought conditions. The ability to produce pods under drought and the ability to recover from drought with greater pod growth are two different mechanisms for higher yields under drought conditions. Studies have also indicated that pods that are initiated and developed under drought stress conditions have lower seed quality in terms of reduced germination and seedling vigor.

10.3. Nutrient Stress

Nitrogen (N) - Groundnut being a legume, meets its nitrogen (N) requirements through a symbiotic relation with bacteria (*Bradyrhizobium* spp.). Generally, most soils will have nitrogen fixing bacteria in them; however, it may be beneficial to inoculate seeds with rhizobia to ensure nitrogen fixing.

Inorganic N fertilization is not typically recommended in United States, except in regions where nitrogen fixation is low. In India and Africa, a starter dose of 10-15 N/ha kg is recommended until the symbiotic nitrogen fixation is fully functional. Studies have also shown that higher doses of nitrogen application inhibit biological fixation. If nitrogen deficiency symptoms (yellowing of older leaves) are observed, a top dressing with nitrogen can be recommended.

Phosphorus (P) is an important nutrient for groundnut. Most of the groundnut production regions in Africa and Asia are deficient in P. On a global scale P is probably the most deficient nutrient element for groundnut production. Its deficiency usually occurs in soils with low organic matter, or in soils which are brought into cultivation recently and never have been fertilized with P before. In addition, soils with a long cropping history without any application of P fertilizer also show this deficiency.

Soils which are rich in Fe also induce P deficiency due to fixation of P by the iron compounds. This deficiency can easily be corrected by applying P fertilizer at the time of planting. Common sources of P fertilizer include rock phosphate, single super phosphate, triple super phosphate and diammonium phosphate. Foliar application of P is also used in areas where P fixation is problem.

Potassium (K) deficiency is not common in groundnut, due to its low requirement compared to soybean and other legumes. However, in soils with low organic matter content groundnut can respond to K application. In semiarid regions of Asia and Africa the crop can respond to application of K. In India, K supply at the time of planting is often recommended in order to improve oil and protein concentration in the kernels.

Calcium (Ca) is by far the most important nutrient for pod development. The crop has a very high Ca requirement; about 90% Ca is absorbed during flowering and pod formation and development. The required Ca for pod and seed development must be absorbed by the gynophore (peg) and developing pods via passive uptake through diffusion. Calcium absorbed from roots and stored in leaves cannot be moved into pods. Therefore, large quantities of Ca are required in the pod zone for direct absorption by pegs and pods. This requires continuous replenishment of Ca in the pod zone.

Lack of Ca leads to unfilled pods (also termed as pops), small pods, and high incidence of pod rot. In addition, plants deficient in Ca will also have poor growth and development. Deficiency of Ca is commonly observed in non-calcareous soils. It is recommended that Ca be supplied to groundnut cultures during flowering as top dressing with gypsum (calcium sulfate). Gypsum is a byproduct of the fertilizer industries and is the cheapest and most readily available form of Ca.

Gypsum is easily soluble in water and should be applied at the time of flowering and incorporated into the soil in the pod zone. Application of gypsum at flowering supplies Ca over a 60 days period. Depending on soil tests about 250-500 kg/ha of gypsum is recommended for groundnut production.

Other sources of Ca include ground limestone, which is common in southeastern United States and parts of Australia. Calcium chloride is not recommended due to high cost and high leaching losses.

Iron (Fe) **-** Groundnut is very susceptible to Fe deficiency when grown in calcareous and alkaline soils. It is often called as lime-induced Fe chlorosis. Deficiency symptoms are characterized by inter-venial chlorosis of young and newly emerging leaves. Under severe deficiency the complete leaves turn yellow or white and die. Fe-deficiency can significantly decrease growth and yield of crops. In groundnuts grown in calcareous soils, Fe-deficiency decreases leaf area and dry matter production of leaves, stems and root, leading ultimately to yield losses of 20%.

Severe Fe-deficiency decreases root growth and elongation. In most legumes including groundnut, early nodule development after nodule initiation is most sensitive to Fe-deficiency. In groundnut, Fe-deficiency decreases the number of excisable nodules, nodule mass, number of bacteroids and concentrations of leghemoglobin, nitrogenase activity and nitrogen fixing ability. Fe-deficiency does not limit the growth of rhizosphere populations of peanut *Bradyrhizobium*, and there is no effect on root infection processes or nodule initiation. This suggests that nodule development processes are more sensitive to Fe-deficiency than nodule initiation processes.

Soil application of iron is not often recommended as soils are generally rich in Fe, especially in the tropics and subtropics, and applied Fe is generally fixed and is not available to plants. As soil application of most Fe sources is generally less effective, foliar application is widely used for correction of Fe-chlorosis.

Both inorganic and organic Fe sources are effective as foliar sprays. Spraying of $FeSO_4$ solution with some surfactant is very effective in correcting Fe-chlorosis in many crops. However, because of the poor translocation of applied Fe within the plant, the applied Fe does not readily move from sprayed parts to other parts of the plants. The rate of translocation varies according to the type of crop, but is always less than 50% of applied Fe to a given leaf or leaflet. Therefore, under field conditions, growers need to apply foliar sprays of Fe more than once to provide adequate Fe to the developing canopy.

Boron (B) deficiency is a common problem for groundnut production, especially on highly weathered sandy soils. When grown in such soils it is highly advisable to apply B. Higher rates of B_2 can however, also be toxic to plants. Boron deficiency in groundnuts is often associated with fruit damage and has been termed as 'hallow heart'. It reduces the quality of the pod and the value of the crop. Severe B deficiency can result in split stems and roots, shortened internodes, terminal death, and extensive secondary branching. Leaves may be dark green and mottled with few or no well developed pods.

Boron deficiency can be corrected by either soil or foliar applications. These can be mixed with herbicides or fungicides.

11. Biotic Stresses

Biotic constraints to yield include insect pests, diseases and weeds. The impact of pests and diseases in the SAT reflects the use of locally grown cultivars which, apart from having a poor yield potential, also lack resistance to diseases and insects. The most serious pests in India include *Spodoptera litura*, *Aproaerema modicella*, and *Helicoverpa armigera.* In certain areas the two-spotted spider mite (*Tetranychus* sp.) is widespread and can cause severe yield losses, particularly when groundnuts are grown in light, sandy soils that become drought stressed. The populations of spider mite can build up rapidly, particularly if insecticide sprays kill natural predators.

Intercellular feeders such as aphids (*Aphis craccivora*), thrips (*Frankliniella* sp.) and leafhoppers (*Empoasca* sp.), and soil pests like termites (*Microtermes* sp. and *Odontotermes* sp.) and white grubs (*Eulepida marshona* and *Lachnosterna* sp.) are also important pests in some of the semi-arid regions.

Groundnuts are often attacked by fungi, bacteria and viruses. The most common fungal pathogens known to drastically reduce yield and/or quality of the crop include leaf spots (*Cercospora* sp.), rusts (*Puccinia arachidis*) and toxin producing *Aspergillus flavus*. Aflatoxin contamination is a major health risk in many groundnut producing countries. The soil-borne diseases like stem rot (*Sclerotium rolfsii*) and pod rot (*Phythium* sp.) also pose serious problems in some areas.

Root-knot nematodes (*Meloidogyne* sp.) are also an important yield limiting factor. Bacterial disease caused by *Pseudomonas solanacearum* is economically important and widespread in China and Indonesia. The important viral disease is a seed-borne groundnut mottle virus, which is found in most production areas.

Finally, weeds are important biotic factors causing significant yield losses; they compete with the crop for space, nutrients, light and water, and act as alternative hosts for various other pests and diseases. Nutsedge (*Cyperus* sp.), morning glory (*Ipomea* sp.), pigweed (*Amaranthus* sp.) and crabgrass (*Digitaria* sp.) all cause significant yield losses in groundnuts. Among the various production constraints cited above environmental constraints like drought stress and hot air and soil temperatures are the major targets of research in the SAT. These environmental constraints are of more concern because of the likely effects of global warming and climate change on agriculture.

12. Aflatoxins in Groundnut

Aflatoxin incidence in groundnut poses a continuing potential threat to peanut producers and consumers across the globe. Because of aflatoxin health risk, food inspection and regulatory agencies are continually decreasing the tolerance limits of aflatoxin in peanut products.

Aflatoxins are produced by the fungi *Aspergillus flavus* Link ex. Fries and *Aspergillus parasiticus* Speare. Aflatoxins (mainly AFB1) have been classified by the International Agency for Research on Cancer as a Group 1 Carcinogen, i.e. substances that can cause cancer in humans and animals. Chronic exposure to dietary aflatoxins is evident from the presence in human breast milk, blood and serum samples in Ghana, Nigeria, Benin, Gambia, Sierra Leone, Sudan, and Thailand. It is also found in milk products of cows fed with aflatoxin contaminated feed in India. Because of the potential health hazard of aflatoxin, stringent laws with very low threshold levels in food products are set by regulatory agencies in the United States and Europe.

Aflatoxin contamination is a major agricultural problem with health concern in the United States. Studies in the US, based on FDA sample data from farms and computer simulations, estimate that crop losses from mycotoxin contamination of peanut, corn and wheat average about $900 million annually.

Aflatoxin production in groundnut is two-folds (a) it can occur during pod development before harvest (pre-harvest contamination) and (b) it can also occur at post-harvest stages when harvested pods are not dried properly, or if storage facilities are not well maintained. Pre-harvest infection by *Aspergillus* and consequent aflatoxin incidence is strongly associated with the occurrence of drought stress during the last 3-6 weeks of the growing season. The duration requirement for pre-harvest contamination of aflatoxin is the accumulation of 20 to 30 days of drought stress before harvest with soil temperatures between 28° and 30.5° C. Occurrence of insect pests facilitates the infection of *Aspergillus*. Post-harvest contamination of groundnut is caused due to improper drying; slow drying, or storage of unclean pods with high moisture and/or contaminated with soil.

To minimize *Aspergillus* infection groundnut kernels should be dried to a moisture content below 10%. Similarly, high humidity in the storage also increases chances of occurring of *Aspergillus* infection and aflatoxin production.

As pre-harvest infection with *Aspergillus* and aflatoxin production requires a critical combination of soil temperature, soil water shortage and kernel moisture content during the pod growth period, it can be managed by irrigation. The potential risk of aflatoxin production can be decreased through integrated crop management practices and post-harvest storage treatments. The possible methods of minimizing the risk of aflatoxin under rainfed conditions include:

- Agronomic practices to improve soil moisture retention (mulches, crop residues) and to decrease effects of drought stress and high soil temperature during pod growth;
- Adjusting planting dates based on phenology of the cultivar and drought pattern to escape high temperature and drought stress conditions at the end of season;
- Cultivar selection;
- Judicious use of available irrigation water to minimize end-of-season drought;
- Harvesting at appropriate physiological maturity;
- Rapid drying of pods, sorting (remove insect-damaged pods);
- Using clean aerated storage structure;

- Avoiding contact of clean pods with soil; and
- Use of biological agents and integrated insect and disease management practices to decrease potential infection sites.

13. Genetic Resources

Groundnut genetic resources are conserved at many centers around the world. One of the major organizations which maintains groundnut germplasm and that has a global mandate for groundnut improvement is the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) located in Patancheru, Andhra Pradesh, India. It also has several centers in Africa (Niger, Mali, Nigeria, Kenya, Mali, Malawi, Mozambique and Zimbabwe).

At global level ICRISAT has the largest single collection of domesticated groundnut with more than 14,300 accessions from 92 countries and 413 accessions of *Arachis* species. The wild *Arachis* species could serve as reservoirs of high levels of resistance to biotic and abiotic stresses. Other institutions which have large collections include the United States Department of Agriculture (USDA), Texas A & M University, North Carolina State University, and the National Center for Genetic Resources in Brazil.

The United States Department of Agriculture also has 8000 accessions of cultivated groundnut and about 800 accessions of *Arachis* species. Germplasm exchange commonly occurs between various institutions, but it has become difficult in recent years due to imposition of strict quarantine polices to avoid introduction of diseases and weeds.

14. Conclusions

Groundnut is one of the important cash crops in Asia, Africa, South America and United States of America. It is produced in both subsistence and commercial systems. It is mainly used as a source of food (edible oil, vegetable protein, boiled or roasted directly or mixed in confectionary products). Groundnut haulms are in high demand for fodder, and the groundnut cake after the extraction of the oil is also mixed in animal feeds or organic fertilizers. More recently due to promotion of bioenergy production, use of groundnut oil in biodiesel production is also being evaluated.

The main production constraints for groundnut include abiotic stresses (drought, high temperatures, poor fertility, low pH, Ca deficiency, and chlorosis) and biotic stresses (diseases – rust, leaf spot, and aflatoxin contamination; and insect pests – pod borers, aphids, thrips and mites). Improved understanding of abiotic stress tolerance, aflatoxin management, and integrated pest management along with crop improvement for higher yield, diseases resistance, development new crop management practices and improved cropping systems for efficient use of resources is essential for increasing profitability and sustainability of groundnut production.

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Glossary

Anthesis	**:** Opening of flower.
Autotrophic	**:** Organisms that produce food from using energy from light of inorganic chemical reaction.
Bacteroid	**:** Symbiotic form of nitrogen-fixing bacteria, mostly genus of gram-negative, rod shaped bacteria.
Base Temperature	**:** Temperature below which plant growth or development does not occur.
Cd (Cumulative degree-days)	**:** Summation of growing degrees days accumulated over a critical base temperature (depending on the crop) and in a defined period of time. å [(maximum + minimum temperature)/2) – Base Temperature].
Chlorosis	**:** Yellowing of leaves.
Cotyledon	**:** Part of the embryo within the seed that becomes the embryonic leaves of seedling.
Epicotyl	**:** Embryonic shoot above the cotyledons that become the shoot / stem.
Epigeal	**:** Type of germination where cotyledons of the germinating seeds come out of the soil
Eukaryotic	**:** Organisms (all plants and animals) whose cells contain structures enclosed within membranes.
Gametogenesis	**:** Process by which diploid or haploid cells undergo cell division and differentiation to form haploid gametes. In flowering plants gametes are pollen grain (male) and ovule (female).
Ghee	**:** Class of clarified butter that originated in Indian subcontinent.
Gynophore	**:** Stalk supporting the gynoecium.
Hypocotyl	**:** The primary organ of extension of germinating seedling that develops into stem.
Inflorescence	**:** Arrangement and mode of development of flowers on the floral axis.
Leghemoglobin	**:** Oxygen carrying hemoprotein found in nitrogen-fixing root nodules of leguminous plants.
Meiosis	**:** Process in which the number of chromosomes in a cell are halved resulting in haploid cells.
Necrosis	**:** Localized death of the tissue on the leaves or stems.
Nitrogenase	**:** The enzyme (EC 1.18.1) used by some organisms to fix atmospheric nitrogen.
Nodules	**:** Structure formed after infection with nitrogen fixation bacteria with roots of host plant.
Peg	**:** Structure which is formed after fertilization and this grows towards soil to form pod.
Pericarp	**:** The tissue that develops from ovary wall and surrounds the seeds (not edible part in legumes)
Pod	**:** Structure which holds the seeds or kernels of groundnut.

Pollination	**:** The transfer of pollen grains from anthers to the receptive stigma.
Prokaryotic	**:** The cells which lack nucleus or any other membrane bound organelles.
SAT	**:** Semiarid Tropics.
Sink size	**:** The size of sink (organelle which receives photosynthates) e.g. kernel or seeds in legumes.
Sporogenesis	**:** The process of production of spores. In eukaryotic cells these refer to pollen grains and ovules.

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