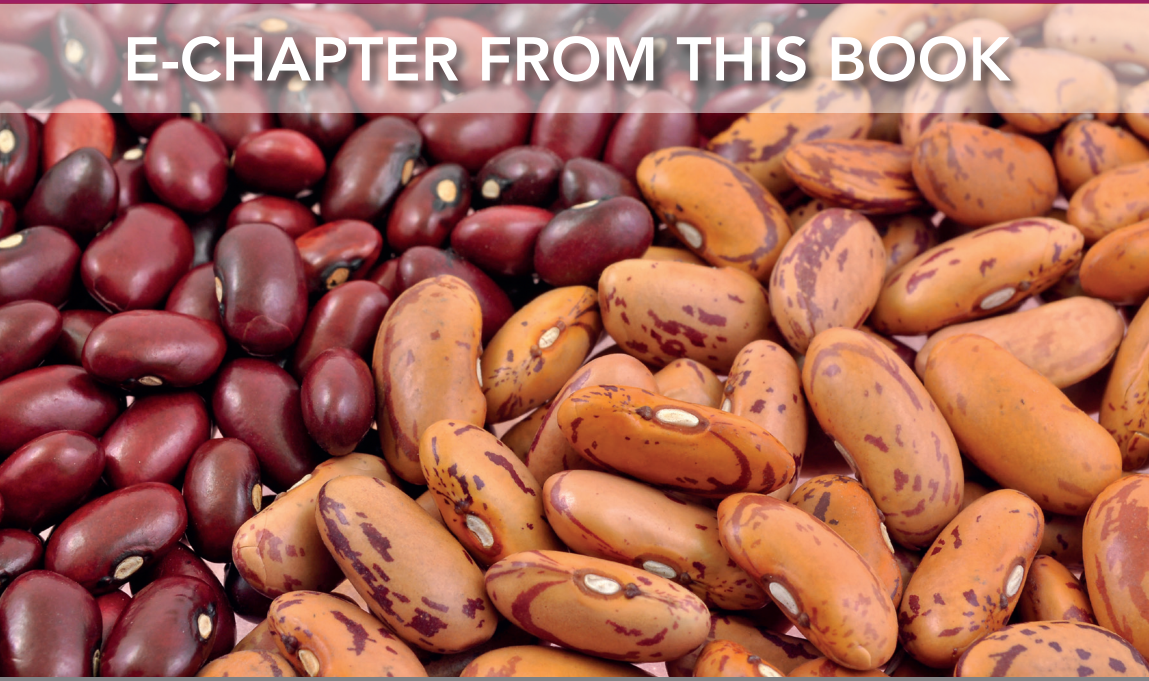
BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable cultivation of grain legumes

Volume 2: Improving cultivation of particular grain legumes

Edited by Dr Shoba Sivasankar, Dr David Bergvinson, Dr Pooran Gaur, Dr Shiv Kumar, Dr Steve Beebe and Dr Manuele Tamò

E-CHAPTER FROM THIS BOOK



burleigh dodds
SCIENCE PUBLISHING

Improving cultivation of groundnuts

S. N. Nigam, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India; D. L. Jordan, North Carolina State University, USA; and P. Janila, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India

1 Introduction

Groundnut (also known as peanut) (*Arachis hypogaea* L.), a native of South America, has often been referred to as an unpredictable legume in the past (Gregory and Gregory, 1979; Hammons, 1994). The genus *Arachis* contains 81 described species, categorized into nine taxonomic sections, and includes both diploids and tetraploids belonging to either annual or perennial type. The classification is based on morphology, geographical distribution and cross-compatibility among the species (Valls and Simpson, 2005). The only cultivated groundnut, *Arachis hypogaea* L., is further divided into two sub-species '*hypogaea*' and '*fastigata*' based on the branching pattern and the distribution of vegetative and reproductive axes. Although it has been known to humankind for many centuries, its commercial cultivation started only in early 1900, when it began receiving research attention.

Groundnut is cultivated on 26.5 million ha globally with a total production of 43.9 million tons and an average productivity of 1660 kg/ha (FAO, 2014). Its global area, production and productivity increased at an annual growth rate of 1.0%, 2.7% and 1.4%, respectively, in the last two decades, from 1995 to 2014. Least developing countries account for 41.24% of the global area and 22.47% of global production (FAO, 2014). Groundnut yield in these countries

http://dx.doi.org/10.19103/AS.2017.0023.27

Chapter taken from: Sivasankar, S. et al. (ed.), *Achieving sustainable cultivation of grain legumes Volume 2: Improving cultivation of particular grain legumes*, Burleigh Dodds Science Publishing, Cambridge, UK, 2018, (ISBN: 978 1 78676 140 8; www.bdspublishing.com)

varies from 330 kg/ha in Namibia to 3200 kg/ha in Egypt with an average of 900 kg/ha. Most countries in Africa and some in Asia and South America led by India, Nigeria, Sudan, Sierra Leone, Tanzania and Myanmar produce yields below the world average. The yields are low largely because the crop is grown under rainfed conditions in marginal and eroded soils with very little or no input. There is limited opportunity for increasing area under the crop in Asia. Any increase in groundnut production in Asia has to come through gains in productivity, whereas in Africa both area expansion and gains in yield are possible to have sustained and enhanced groundnut production in the continent. In Australia, Argentina, China and the United States, groundnut production during 2014 was 0.016, 1.16, 16.5 and 2.35 million tons, respectively (FAO, 2014). Greater yields in these industrialized nations are most likely the result of access to seeds of new cultivars, inputs, technologies and mechanization that increase overall production and efficiency (Diop, 2004).

1.1 Groundnut ecologies

The crop is grown as a sole crop, intercrop or mixed crop. In rainfed ecologies, all three cropping systems are prevalent and only a single crop in a year is taken. In bimodal rainfall regions like Haiti and Uganda, two crops per year can be taken. Under irrigated and residual soil moisture conditions, the crop is largely grown as a sole crop. Under residual soil moisture conditions, mostly in rice fallows, only a short-duration single groundnut crop is possible, and in the post-rainy season and sometimes where soil moisture recedes towards later stages of crop growth, supplementary irrigation is provided (Sarkar and Pal, 2004). Being a legume, including groundnut as rotation crop contributes to soil fertility through biological nitrogen (N) fixation.

1.2 Groundnut farming systems

At least, two distinct production scenarios of groundnut cultivation exist at the global level, one is mechanized cultivation on large farms under input intensive conditions, and the other is non-mechanized or partially mechanized cultivation on small farms under limited resources. Subsistence groundnut farming is predominant in Asia and Africa and is characterized by low inputs, rainfed cultivation, smallholdings, manual operations using conventional tools, sole crop, mixed or intercrop (Tadele, 2017) and low productivity (700–1000 kg/ha). It covers more than 76% of the global groundnut area under cultivation in subsistence farming, where groundnut haulms are valued as fodder for livestock and contribute to farmers' income. Resistance to foliar fungal diseases is a must-have trait for varieties in subsistence farming to ensure good quality and quantity of haulms besides pod yield. The commercial farming is practised largely in the United States, Australia, Argentina, Brazil, China and South Africa and in small pockets in other countries. It is characterized by high inputs, availability of irrigation in some areas, medium to large holdings, mechanized or semi-mechanized cultivation, sole crop or rotated with other crops and high productivity (3000–4000 kg/ha).

1.3 Yield gap

Groundnut is an efficient crop. A pod yield of 10 500 kg/ha over a small area under intensive cultivation in Shandong province in China (Yanhao, 1996), 9600 kg/ha in large plots in Zimbabwe (Hildebrand, 1996) and 9400 kg/ha in a 0.2 ha plot in summer season in

Maharashtra and 9500 kg/ha in a small area in Andhra Pradesh in India (Nigam, 2000) have been reported. However, these reflect the upper end of the yield spectrum. At the other end of the spectrum, the crop may face complete failure if drought is severe. Groundnut productivity largely varies not only among the countries but also among the regions within a country. There exists a large yield gap across all agroecologies. Simulated rainfed yields in India indicated a much higher potential for groundnut productivity than what is realized at present in the country (Bhatia, 2006).

Groundnut pod yield and quality have to be improved in the large majority of groundnut-growing areas. Under different farming systems the extent of improvement that can be achieved is variable. Genetic and management options are available to achieve and/or sustain the pod yield and quality; some of the options reduce the input cost and are key to improve the profitability of groundnut cultivation. In this chapter, the options available to improve and/or sustain groundnut pod yield and quality under different groundnut farming systems that include subsistence to precision cultivation are discussed.

2 Limitations of present agronomic recommendations

In developing countries, most of the farmers are resource-poor with little or very low risk-taking capacity. With the majority of the groundnut crop being grown under rainfed conditions, it remains vulnerable to vagaries of weather, which discourages farmers to adopt recommended crop management practices to keep the cost of cultivation low. Such farmers require low-cost technologies based on locally available resources. On the other hand, under irrigated conditions, farmers, being resourceful, are able to follow intensive agriculture following all the recommended practices to obtain higher yields where options to reduce inputs cost and precision cultivation can be useful.

In most developing countries, agronomic recommendations made are of a general nature and they fail to take into account local variations in agroclimatic conditions, soils, cropping systems and other factors across regions/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 of the crop adversely. Moreover, diverse growing conditions of the crop necessitate development of different crop management modules meeting the requirements of different agroecologies and strata of the farmers.

The recommendations often are not adopted by farmers, particularly in developing countries as access and usage of inputs and technologies are determined by the several policies of the governments such as input and credit policy and minimum support price for the produce. Besides, prevailing market prices of the commodity, cost of technologies and business opportunities determine the extent of inputs used by farmers in developing countries.

Peanut yield is the result of genotype, environment, management and their interactions as follows:

$$\text{Yield} = \text{Cultivar/Variety (V)} + \text{Management (M)} + \text{Environment (E)} + V \times M + V \times E + M \times E + V \times M \times E$$

For higher net profits and stable yields, all the components and interactions in the above equation need to be fully exploited.

Regardless of country, farmers also must consider the ramifications of government legislation (trade policies and financial support available to the agricultural sector), regulations (pesticide registrations and availability and food safety requirements) and other incentives that promote environmental stewardship such as conservation tillage practices and adoption of integrated pest management (IPM) when developing sustainable production systems. Government policies play a critical role in availability, cost and use of technologies such as new varieties, quality seed and other inputs. Market prices often determine the extent of cultivation of groundnut, a higher market price in the current year might result in larger areas being planted in the next season/year under groundnut that may bring down the market price. The input use in Asia and Africa is largely determined by inputs supplied by the government agencies, subsidies on the inputs and credit policies of the government as farmers often depend on credit for making inputs investments. In the absence of cultivar replacement policy and seed systems, an obsolete cultivar, TMV 2 continued to occupy over 50% area under groundnut cultivation in India (Deb, 2005). On the other hand, business opportunities contribute to fast variety turnover in the United States, Argentina and Australia. Therefore, the equation above can be further expanded to include government and business; however, in this chapter, we discuss the components of the above-mentioned equation.

3 Choice of variety/cultivar

Cultivar is a critical component of any crop production module to ensure consistent sustainable production of the crop. Genetic components of a cultivar/variety include agronomic traits that determine suitability of a cultivar to a farming system, host-resistance or -tolerance to various biotic and abiotic stress factors, and both physical and nutritional quality parameters such as high oleic acid profile, for enhanced shelf-life (Janila, 2016a). Resistance/tolerance to prevailing diseases and insect pests is important for cultivars; otherwise, chemical control measures will add to the cost of cultivation besides raising environmental concerns. Several disease-resistant varieties have been released for cultivation and are summarized by Janila (2016b). The cultivar choice thus has to meet the needs of the producer, processor and consumer.

The choice of cultivar at a location/in the region is guided by the following factors: i) length of soil moisture availability period, ii) type of product preferred by the processors and market, iii) prevailing diseases and insect pests' spectrum and iv) prevailing environmental conditions including rainfall pattern. Groundnut cultivars with crop duration varying from 90/100 to 160/180 days are available. There are three distinct plant types in groundnut – erect, semi-erect/semi-spreading and runner/spreading (Stalker, 1997). In North America, where only a single crop is possible due to temperature limitations and where the crop is grown with intensive inputs, the long duration cultivars with spreading growth habit adapted to local agroecologies are grown. On the other hand, in rainfed environment in India or West Africa, in multiple cropping situations (common in East and Southeast Asia) and in residual soil moisture situation (common in South Asia), the shorter duration (90/100 days) erect type cultivars are needed. Under rainfed conditions, soil moisture stress becomes an important issue in the choice of a cultivar. Depending upon the long-term pattern of rainfall, cultivars having tolerance to mid-season or end-of-season drought can be selected.

The end-use of the product will influence the choice of cultivar to be grown. Groundnut is grown for food uses (direct consumption after roasting and boiling, in confections and peanut butter, etc.) and for extraction of high-quality oil for edible and industrial use.

4 Field preparation and soil resources management

4.1 Selection of field

The ideal groundnut soil is well drained, light coloured, with either sand, loamy sand or sandy loam texture and pH ranging between 6.0 and 6.3 (Jordan, 2016). The right soil for groundnut should not ribbon out but fall apart easily when the moist soil is rubbed between index finger and thumb. The produce from such soils is clean and bright. Groundnut should regrow in the same field only after two seasons/years.

4.2 Land preparation and conservation tillage

In conventional tillage, the field is cleared off all stubbles and plant residues of the previous crop before ploughing to obtain a fine tilth to a depth of 15–20 cm. Very deep ploughing encourages pod formation in deeper layers of soil rendering harvest more difficult and is hence not desirable. Groundnut is sown on flat beds or ridges or on raised beds separated by furrows. Raised beds with a slope of 0.4–0.8% are beneficial as they allow easy drainage of excess water, avoid compaction of seedbeds and facilitate field operations as all traffic is restricted to furrows (Kuotsu, 2014).

Conservation agriculture (continuous no-till, maintaining soil cover with plant residues) is now widely recognized as a viable concept for practising sustainable agriculture with benefits in production, economic and environmental aspects of the farming. In groundnut, conservation tillage practices can impact pest complexes and yield compared with conventional tillage, and in some cases, efficiency of digging pods is an important factor in selecting the appropriate tillage system (Johnson, 2001; Jordan, 2017). Preliminary results at ICRISAT on Alfisols suggest that conservation tillage (no-tillage and minimum tillage) produced pod yield equal to the conventional tillage. In North Carolina, conservation tillage peanut increased from 10% in 1998 to 23% and 41% in 2004 and 2009, respectively, and later decreased to 20% in 2014 (Jordan, 2017). The no-tillage system resulted in higher population of various biological agents in soil than under reduced tillage condition, thus showing the lowest incidence of peanut blight (*Sclerotinia minor*) and root rot (strains of *Fusarium solani*) in peanut (Gil, 2008). Porter and Wright (1991) reported a greater incidence of early leaf spot and defoliation in conventionally tilled plots than in those that employed the conservational tillage system (band-tilled or in-row plots). Compared with conventional tillage, conservation tillage showed a reduced incidence of tomato spotted wilt disease of peanut in North Carolina (Hurt, 2006). The nodule size is larger in conservation tillage compared to conventional tillage (Rowland, 2015). In Georgia, the conservation production system increased water-holding capacity of the soil and enhanced soil water conservation (Hawkins, 2016).

4.3 Fertilizers and amendments

Groundnut responds better to residual soil fertility than to the direct application of fertilizers. Crop(s) preceding groundnut crop should be well fertilized to build up soil fertility, particularly for phosphorus (P) and potassium (K). Basics of the fertilization strategy include nutrient application based on soil test, building up soil P and K to a medium or a high level and providing calcium (Ca) to the pegging zone. Based on the soil test results and the expected pod yield from the crop, fertilizer doses for both macro- and

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

	Quantity (Kg/ha)[1]									
Pod yield (Kg/ha)	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B
1000	58	5	18	11	9	4	2	0.09	0.08	0.05
2000	117	10	36	23	18	9	4	0.19	0.16	0.11
3000	174	15	54	34	27	13	6	0.29	0.24	0.16
4000	232	20	73	45	36	18	8	0.38	0.32	0.22
5000	290	25	91	56	45	22	10	0.48	0.41	0.27
6000	348	30	109	68	54	26	12	0.58	0.49	0.33
7000	406	35	126	77	63	30	14	0.68	0.56	0.38
8000	464	40	144	88	72	34	16	0.78	0.64	0.44
9000	522	45	162	99	81	38	18	0.88	0.72	0.49
10 000	580	50	180	110	90	42	20	0.98	0.80	0.54

[1] Calculation based on Sahrawat, Srinivas Rao, and Nambiar. 1988. *Plant and Soil* 109:291–293.

micronutrients should be determined. Table 1 gives an idea of the requirements of the nutrients at different levels of targeted yields. Whatever is extracted from the soil, it has to be replenished from regeneration in the soil, external fertilizers and other sources to maintain soil fertility status.

4.4 Macronutrients

Under most conditions, enough N is fixed through symbiotic relations with the native *Bradyrhizobium* ssp. However, N deficiency can occur in poor and eroded soils; in new soils brought under cultivation and rice fallows; and in soils having inefficient *Bradyrhizobium*, drought and high temperatures, etc. In addition to seed inoculation with efficient *Bradyrhizobium* strain (there is specificity between a cultivar and *Bradyrhizobium* strain in groundnut), a basal dose will be useful before nodules appear and become effective (Elsheikh and Mohamedzein, 1998).

Phosphorus deficiency in groundnut is widespread (Kumar, 2015) and can be corrected by application of P fertilizers. 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.

Groundnut responds to application of K when available K in the soil is very low. There is an antagonistic effect on the uptake of K, Ca and Magnesium (Mg). The proportion of K:Ca:Mg is more important than the total amount of any one of them. A high level of K in the pod zone is harmful because it affects pod quality, especially at low levels of Ca. The suggested proportion in the literature is 4:4:2 (Nigam, 2006). The latter was reported from studies on sandy loam soil under rainfed and irrigated conditions in Andhra Pradesh, India. The P and K fertilizers should be turned in deep before sowing to keep them out of the pegging zone, where they can interfere with Ca uptake (Singh, 1999).

Ca is essential for pod and seed development. Adequate quantities of Ca should be present in the top 8–10 cm of soil to enable pods to directly absorb it (Arnold, 2017). If soil pH, based on soil test, is to be raised, lime may be used both to adjust pH and to provide Ca to the pegging zone. However, lime (calcium oxide) should 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. The rate of application of lime depends on the degree of pH to be raised, type of lime, soil type and depth of application. Instead of lime, calcium sulphate (gypsum or land plaster) can be applied when needed if soil pH is not an issue (Nigam, 2006). Regardless of the test Ca level, gypsum should be applied to all large-seeded groundnuts at the peak flowering stage and should be mixed thoroughly with the soil rather than leaving the added gypsum on top soil (Singh, 1999). Adequate Ca supply in the podding zone reduces infection from *Aspergillus flavus* and other pod-rot-causing fungi (Fernandez, 1997).

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. The deep root pattern of groundnut allows plant to forage deeply for Mg and other nutrients. Application of gypsum provides adequate sulphur (S) to the crop. S deficiency is most likely to occur in very sandy soils, which possess little anion exchange capacity (Singh, 1999).

4.5 Micronutrients

Most micronutrients are more likely to be deficient at high pH, particularly in calcareous soils. The deficiency symptoms of different micronutrients can be observed in any standard book on groundnut. Boron (B) deficiency can be corrected by application of borax to the soil at a rate of 3–4 kg/ha or by spraying 0.1% borax early in the season to assure uptake before flowering. Iron (Fe) deficiency can be a serious problem in calcareous soils and it can be alleviated by soil application of 10 kg/ha ferrous sulphate or spraying of 0.5% ferrous sulphate + 0.2% urea. Zinc (Zn) deficiency can be corrected by basal application of 10–20 kg/ha zinc sulphate once every three years to the soil where groundnut is continuously grown. Application of Zn and other micronutrients should be based on soil analysis report; otherwise, it may lead to toxicity. Manganese (Mn) deficiency occurs in soils which are inherently low in this nutrient, and foliar Mn application can correct Mn deficiency more rapidly than soil Mn application (Singh, 1999).

4.6 Organic and other amendments

Most soils in developing countries are low in soil carbon content. Application of organic matter to the soil improves its structure and reduces its compaction and crusting (Hawkins, 2016). Farmers in Asia commonly apply 8000–10 000 kg/ha of farmyard manure (FYM) and other organic manures (compost and cattle and sheep penning). It also improves nodulation and enhances the availability of P to the crop. However, with dwindling cattle populations, application of FYM to the soils has reduced drastically, leading to poor soil health and an increased incidence of soilborne diseases. Application of tank silt and green manuring crop in crop rotation are some of the options to improve soil organic matter content.

4.7 Biofertilizers

Biofertilizers help enhance the efficiency of externally applied nutrients and transform, mobilize and make available fixed or unavailable form of nutrients (Jeffries, 2003). They are low cost, reduce external application of N and P by 25% and may increase crop yield up to 15%. Some of the biofertilizers used in groundnut are *Bradyrhizobium*, plant-growth-promoting rhizobacteria (PGPR), phosphorus-solubilizing microorganisms (PSM) and arbuscular mycorrhizal (AM) fungi. In addition to fixing atmospheric N, *Bradyrhizobium* also secretes siderophores, which help in promoting Fe uptake in soils where lime-induced Fe chlorosis is observed. PGPR, a mixture of beneficial rhizosphere microbes, provides benefits to plants by mobilizing the majority of macro- and micro-nutrients besides producing hormones which lead to enhanced plant yield. It also suppresses soilborne pathogens such as *Aspergillus niger* and *Sclerotium rolfsii* (Dey, 2004). Phosphate-solubilizing bacteria and fungi play an important role in converting insoluble phosphatic compounds such as rock phosphate, bone meal and basic slag and the chemically fixed soil P into available forms. AM fungi possess special structures known as vesicles and arbuscules, with the latter helping in the transfer of nutrients from soil into the root system. Mycorrhizal plants increase the surface area of the root system for better absorption of nutrients from soil, especially when the soil is deficient in P and Zn (Bell, 1989).

Several types of formulations of biofertilizers in the form of dry products and suspensions are available in the market. They can be applied as seed treatment, as a mix with FYM and through irrigation water.

5 Seed preparation, planting and weed and water management

Groundnut differs from other legumes in that its pod develops under ground and therefore soil health and water management are very critical in groundnut cultivation. Groundnut pods directly absorb Ca from soil for their development and growth (Skelton and Sheer, 1971). The crop requires moisture both in the root zone and in the pegging zone to give sustainable high yields (Hawkins, 2016).

5.1 Sowing

Seeds should be tested for germination and postharvest seed dormancy before sowing. If required, seeds should be sprayed 2–3 times with etherel (5 mL in 1L of water) to break postharvest dormancy and air-dried (Nigam, 2006). In groundnut, seed cost is one of the major components of the cost of cultivation; in developing countries of Asia and Africa the seed cost constitutes one-third of the total cultivation cost. Every effort should be made to ensure germination and growth of each planted seed. Seed size, spacing and germination per cent of seed should determine seed rate to obtain optimal plant stand. Maintaining optimal plant stand is key to realising improved.

5.2 Seed treatment and seed priming

Plant losses of 50% or more are possible with untreated seeds (Ruark and Shew, 2010), which directly impact pod yield. Seed treatment ensures their safety, uniform and healthy seedling, fast emergence and optimum plant population to achieve high yields. Seed treatment varies from basic seed dressing to coating and pelleting. Seed treatment is resorted to in order to protect the seed from soilborne diseases and insect pests, as well as providing nutrients and growth stimulus to growing seedlings and plants. By using inert material, seed pelleting also allows modification of seed shape and size for precision planting.

5.2.1 Management of soilborne plant pathogens

In the United States, commercial seeds are almost always treated with fungicide, and insecticides are frequently applied in the seed furrow at planting to control thrips (*Frankliniella* spp.) (Jordan, 2017). In Asia and Africa, seed treatment using fungicides, pesticides or their combination is done by farmers before planting. The seed should be treated first with liquid chemicals followed by powder/dust. Recently, biocontrol agents have also found a place in seed treatment (Rojo et al., 2007; Ruark and Shew, 2010) as fungicides are not effective enough to control soilborne diseases. Now, *Trichoderma viride* and *T. harzianum* are widely used to manage soilborne diseases such as collar rot, stem rot, brown root rot, etc. Commercial preparation of *Trichoderma* spp. and *Bacillus* spp. is available in developed countries.

Evaluations conducted by Ruark and Shew (2010) in North Carolina showed that seed treatment with Kodiak, a commercial preparation of *Bacillus subtilis*, increased seedling emergence and survival over untreated seeds. The effect of seed treatment with *B. subtilis* was more pronounced when groundnuts were subjected to stresses such as limited water availability, poor rotational practices or cool soil caused by early plantings (Turner and Backman, 1991). It resulted in improved germination and emergence, increased nodulation by *Bradyrhizobium* spp., enhanced plant nutrition, reduced levels of root cankers caused by *Rhizoctonia solani* and increased root growth. Seed treatment with VOTiVOTM, a commercial product of *B. firmus* from Bayer Crop Science, is used to reduce the impact of nematodes.

Enhanced resistance to abiotic stresses: *Pseudomonas fluorescens* strain TDK 1 possessing ACC deaminase activity enhanced salinity resistance and improved yield parameters under salinity stress (Saravanakumar and Samiyappan, 2007). Pelleting groundnut seed with Ca enhanced plant growth and reduced seedling mortality in acid soils (Murata, 2008).

5.2.2 Nutrient supply

Seed treatment with *Bradyrhizobium* to makes N available to growing seedlings and plants. It is a common practice in legumes cultivation. Although commercial preparations of *Bradyrhizobium* are available, their quality and effectiveness remain doubtful particularly in developing countries. In groundnut, cultivar and *Bradyrhizobium* strain specificity is observed, and therefore, the strain of *Bradyrhizobium* that matches with cultivar should be used for better performance. If the strain of *Bradyrhizobium* is not compatible with other chemicals used in seed treatment (see manufacturer's instructions), the culture can be applied in sowing rows following the slurry method. The success and effectiveness of seed coating and pelleting with micronutrients depend on the nutrient used, coating material, soil type, soil moisture and fertility status and the nutrient:seed ratio (Halmer, 2008).

5.2.3 Seed priming

Seed priming techniques include hydro-priming (soaking the seed in water before sowing and may or may not be followed by air-drying of the seeds), halo-priming (soaking of seeds in solution of inorganic salts), osmo-priming (soaking of seeds for a certain period in solution of sugar, PEG, etc.) and hormonal-priming (seed treatment with different hormones) (Singh, 2015). Generally, in seed priming, seeds are partially hydrated to allow metabolic events to occur without actual germination, and are then re-dried (near to their original weight) to permit routine handling (Bradford, 1986). Limited studies were done on seed priming in groundnut. Seed priming of groundnut seeds with $CaCl_2$ 1% resulted in higher percentage of field emergence, plant height, number of pods per plant, seed yield per plant and seed yield per ha in addition to early flowering and early maturity than the control (Bhingarde, 2015). Seed treatment with hot water (50°C for 20 min) or seed priming with hot aqueous solutions of $Ca(OH)_2$ enhanced the rate of germination and increased final plant stand in groundnut. The rapid rate of emergence gave a chance to seedlings to escape diseases assisted by antifungal properties of $Ca(OH)_2$ (El-Rehim, 1981). Seed priming with $CaSO_4$ significantly reduced seedling mortality and resulted in the early emergence of groundnut in acid soils (Murata, 2008).

5.2.4 Addressing micronutrient deficiency

Although micronutrient deficiencies are traditionally addressed by soil or foliar application, micronutrient seed treatment is an alternative cost-effective method to supply micronutrients and in most cases, it improves stand establishment, advances phenological events and increases yield and micronutrient contents of the grains (Farooq, 2012). Seeds may be treated with micronutrients either by soaking in nutrient solution of a specific concentration for a specific duration (seed priming or nutripriming) or by coating with micronutrients. Oxygen supply, temperature of the priming media and solution concentration (water potential) are important factors affecting seed priming (Corbineau and Cõme, 2006). Seed priming has been used to address Zn, B, Mo, Mn, Cu and Co deficiencies (Farooq, 2012).

5.3 Sowing time

The temperature profile of a location and season of cultivation decide the optimum time of sowing of the crop at that location. The optimum air temperature for growth and development of groundnut is between 25°C and 30°C. Temperatures above 35°C are detrimental to groundnut production. Groundnut is more sensitive to heat stress in the reproductive phase than in the vegetative phase. Studies have shown that responses of groundnut genotypes to high temperatures are variable, and genotypes with superior performance under high temperature are identified (Akbar, 2017). Under lower temperatures, germination is delayed and crop duration is prolonged (Prasad, 2000). In places where the crop is sown after winter season, groundnut should not be sown until the average soil temperature at 10 cm depth is 18°C or greater for a minimum of three consecutive days and favourable air temperature are forecast. Sowing time can also impact pest damage and is a key component of production strategies where inputs are limited (Singh, 1986).

5.4 Planting density, sowing depth and sowing methods

Plant density in groundnut varies from region to region in a country and also from country to country. The growth habit of the cultivar, the sowing method and the type of farming have a bearing on the plant density to be adopted in a region. The plant spacing adopted should ensure groundnut cover as quickly as possible. A wider row spacing leaves ground uncovered, which attracts thrips and aphids, the vectors of viruses. Row spacing varies from as low as 20 cm to as high as 100 cm and within row spacing from 7.5 to 15 cm in different countries (Lanier, 2004). A closer spacing for Spanish/Valencia cultivars and a wider spacing for Virginia/Runner cultivars are recommended. In some places farmers use criss-cross sowing and paired row sowing, particularly in rice fallows. The optimum sowing depth is 5 cm. Deeper sowing delays germination and results in poor root and shoot development and poor nodulation, thereby adversely affecting the yield. The seed rate would be dependent on the row-to-row and plant-to-plant spacing, seed weight and adjustment to be made for germination percentage.

The sowing methods include manual (dibbling and behind the plough), animal-drawn seed drill, tractor-drawn seed drills and vacuum planters. For sowing, the use of seed drill is recommended as it results in faster sowing, quick emergence and uniform plant stand.

5.5 Intercropping/crop rotation

Intercropping/mixed cropping is often practised in rainfed semi-commercial and subsistence agriculture as an assurance against crop failures and to meet diverse food needs of the family. Groundnut is generally intercropped with cereals such as maize, sorghum and pearl millet. In some provinces in India, groundnut and pigeonpea (both legumes) intercropping is also popular (Ong, 1986; Sarkar and Pal, 2004). Recently, intercropping of two legumes is referred to as double-up legumes technology, which results in doubling grain yield and soil fertility. Pigeonpea and groundnut intercropping is gaining popularity as double-up technology in Malawi. Good crop rotation of the crops helps to maintain soil fertility, improves organic matter and physical structure of the soil and reduces diseases inoculum and insect pest population in the soil (Bationo and Ntare, 2000). 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 and groundnut–maize rotations are common.

Groundnut should be rotated with a well-fertilized cereal crop (Bationo and Ntare, 2000) as it can make effective use of residual fertilizers from the previous crop(s). A proper crop rotation can result in higher yields and in substantial saving in disease control and fertilizer requirements. The crop planted prior to groundnut can impact yield of groundnut and cost of production required to maintain yield. For example, in the United States, maize (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.) are more effective rotation crops than soybean (*Glycine max* (L.) Merr.) because these crops more effectively break cycles associated with soilborne pathogens and plant parasitic nematodes (Jordan, 2008).

5.6 Weed management

It is essential to keep groundnut fields weed-free up to 45 days after crop emergence. In mechanized farming, weeds interfere with digging and inverting of pods. Weeds can harbour insect pests which may be the vector of viruses. Recommendation on chemical control of weeds is available in each country, and should be followed accordingly. Lastly, hand-weeding or intercultural operation can be done along with gypsum application so as to incorporate it into the soil. Once pegs have entered the soil, the plant should not be disturbed. Interculture in a rainfed crop helps to reduce weeds and also encourages infiltration of rainwater. Many farmers in South Asia practise earthing up (mounting soil around the plant) to allow pegs from higher nodes to enter soil. This practice may promote growth of stem-rot-causing fungus (*Sclerotium rolfsii*) and may also deteriorate the quality of the earlier set of mature pods while waiting for the later set of pods to mature.

5.7 Water management

Groundnut is very sensitive to moisture stress at flowering, pegging and pod and seed development stages. Similarly, it cannot tolerate water stagnation in its field. Thus, water management becomes very important in groundnut. In an irrigated crop in the post-rainy season, it is easy to regulate water supply to ensure optimal crop growth. Depending upon the soil type and climatic conditions at a given location, the water requirement of groundnut varies from 420 to 820 mm in India (Ong, 1986; Deb, 2005). Groundnut can withstand 2- to 3-week moisture stress at seedling stage. After providing full irrigation for the seeds to germinate, water supply can be withheld for the next 2–3 weeks. This forces the roots to go deeper in search of water, and when the moisture stress is released after 2–3 weeks, a sudden burst of profuse flowering would occur, resulting in uniform maturity and high yield. At pegging and pod and seed development stages, the crop requires frequent but light irrigation. The preferred method of irrigation is sprinkler method or any other system of overhead irrigation. Flood or furrow irrigation results in water wastage and does not distribute water uniformly (Naveen, 1992).

In rainfed agriculture, it is essential that the duration of the selected cultivar matches 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 entry into the soil and during the pod and seed development (Reddy, 2003; Hawkins, 2016). 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 (Nigam, 2009). Groundnut fields should be well drained. Standing water even for 4–6 h in the field can damage the crop. Planting on raised beds or ridges facilitates drainage. Quality of irrigation water can affect groundnut productivity. The limits of saline water for groundnut are EC (electrical conductivity) <4.0 mmhos/cm and RSC (residual sodium carbonate) <2 meq/L.

5.8 Groundnut cultivation under polythene mulch

Groundnut cultivation under polythene mulch is very popular in China and Vietnam. It is described in detail in a publication by Wenguang (1996). Mulching can be done either before or after sowing. In sowing before mulching, normal sowing with two seeds per hill on bed surface is followed by mulching. As 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. In sowing after mulching, after spreading the polythene mulch over beds, holes, 3–4 cm deep, are made at the desired spacing with a hole-maker. Two seeds are placed in each hole and covered with soil. If soil moisture is low, some water can be poured into the hole and the seeds can be covered with moist soil. Some additional soil is placed over the hole to cover the edges of polythene film. Cultivation under polythene mulch can increase groundnut yield by 20–50% (Nigam, 2006; Jain, 2017). The advantages of this practice include an increase in pod yield, proportion of well-filled pods and oil and protein contents in seeds. It results in early emergence and early maturity of the crop (heat entrapment due to sunlight transmittance raises soil temperature), giving opportunities to increase cropping intensity; requires fewer irrigations; suffers less insect pest damage as compared to non-mulched crop; and provides better weed control with pre-emergence herbicide application. The crop can be sown under lower temperatures and thus helps in extending the cultivation of the crop in non-traditional areas. Polymers are also used for conserving water and enhancing crop productivity and thereby increasing water-use efficiency of crops. Use of mulching with polymer and integrated nutrient management enhanced pod, haulm, kernel, and oil yields and net economic returns (Jain, 2017).

5.9 Use of growth regulators

The use of chemical growth regulators on groundnut to suppress vegetative growth, achieve higher yield and improve pod quality has met with varying degrees of success. But their use in groundnut is very common in China and Vietnam. Some of the growth regulators are Dinocap (DPC), Fosamine, 2,3,6-trichlorobenzoic acid (TCBA) and Paclobutrazol (P 333). DPC 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 ppm DPC as foliar spray. Foliar application of P 333 at 60 ppm around 25–30 days after the first flowering arrests excessive growth of the plant by reducing stem growth and increasing pod number per plant, pod and seed mass and pod yield. Fosamine inhibits the growth of aerial parts and flowering of groundnut. Foliar application of 500 ppm is recommended at the late pod-forming stage to reduce late-forming flowers. However, the seeds from fosamine-treated groundnut have poor germination and produce abnormal seedlings (Chengrong, 1996). Therefore, they should not be used as seeds to grow the next crop. TCBA inhibits growth of the aerial parts and late ineffective flowers. It should be sprayed (250 ppm) at the peak or the late peak flowering stage. Once the effect of the chemical has waned, the plant may grow more rapidly. Response to TCBA application (increase in yield) varies with the genotypes. It gives good results with large-seeded cultivars of medium- and long-duration. Its effect on Spanish cultivars is very little. The plant growth regulator prohexadione calcium, which is used in some parts of the United States, prevents internode elongation and increases pod retention (Beam, 2002; Jordan, 2009).

6 Plant protection practices

Groundnut yield and quality is constrained by insect pests and diseases caused by wind and soilborne pathogens and viruses; insects that consume foliage and pods; soil-parasitic nematodes; interference by weeds; and storage pests (Janila, 2013). Some of these are widespread and others are localized. Since pods develop and grow underground they are also exposed to different kinds of soilborne fungal pathogens and insect pests.

Genetic and preventive and management options and their combinations are desirable to reduce the losses to diseases and insect pests. Resistance or tolerance to diseases and insect pests, if available, is the best-bet option. Other options include cultural, chemical and biological/botanical control measures. No single option alone can give effective control of biotic constraints. An integrated insect pest and disease management (IPM and IDM) approach is both effective and safe to contain the damage caused by insect pests and diseases. Chemical sprays should be need-based, and appropriate safety measures should be taken while applying them.

6.1 Foliar fungal diseases

Cultivars resistant/tolerant to rust and late and early leaf spots are available. They should be the first choice for growing. If needed, these varieties should be supported by 1–2 chemical sprays at the critical stages to obtain the maximum quality yield from the crop. Carbendazim 50WP 500 g/ha or Mancozeb 50WP 1 kg/ha for both leaf spots, Calixin 250 mL/ha for rust alone and Chlorothalonil 75WP 1 kg/ha for both rust and leaf spots can be effectively used. Cultural management practices such as removal of debris from fields and volunteer plants in the vicinity, intercropping with cereals, deep ploughing and crop rotation can reduce inoculum load, particularly of leaf spots (Nigam, 2006).

6.2 Soilborne fungal diseases

There are several soilborne diseases which can infect groundnut seed and seedlings. Some of these are collar rot, white mould/stem rot, *Aspergillus flavus*, rhizoctonia damping-off, etc. Soilborne diseases, once appeared, are difficult to control. Therefore, it is essential to maintain good soil health following good agricultural practices. Available genetic resistance against soilborne diseases is weak and cannot offer protection against them in disease-endemic areas. These diseases are best managed by appropriate chemical seed treatment (see Section 5.2), following crop rotation and other field sanitation practices including summer ploughing. Soilborne pathogens such as stem rot are controlled using 2–5 sprays applied bi-weekly when pathogens are active (Jordan, 2017).

6.3 Aflatoxin contamination

Aflatoxins, which are carcinogenic, are secondary metabolites produced in groundnut seeds by *A. flavus* and *A. parasiticus*. These fungi (soilborne and airborne) infect groundnut 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 the pods. Moisture stress at the pod and seed development stage predisposes them to *A. flavus*/*A. parasiticus* infection in the field (Navya, 2015). The rainfed crop is more vulnerable to fungal infection in the field. Postharvest infection is serious under wet and humid conditions. In addition to the seed treatment, the following steps minimize the extent of aflatoxin contamination.

1. Grow tolerant cultivars, if available.
2. Apply farm yard manure/compost @5–10 t/ha to the soil.
3. Apply gypsum @400–500 kg/ha at peak flowering.
4. Provide light but frequent irrigation, if available, during pod and seed development stages.
5. Avoid mechanical damage to pods during weeding, harvesting, curing, threshing and storage.
6. Harvest the crop as soon as it matures (in case of severe drought, the crop should be harvested early).
7. Dry pods to lower moisture content below 8%.
8. Do not mix gleanings (pods left into soil at the time of harvesting) with main produce.
9. Remove damaged and underdeveloped pods from the produce.

10 Store groundnut in-shell and at low temperature, low humidity and in moisture-free conditions.
11 Protect the stored produce from damage of storage insect pests.
12 Remove immature pods from haulm before feeding it to the animals.

6.4 Virus diseases

Important virus diseases include peanut bud necrosis disease (PBND) in South Asia and Southeast Asia, tomato spotted wilt virus (TSWV) in the United States, peanut stem necrosis diseases (PSND) in some parts of India, peanut stripe disease (PStV) in East and Southeast Asia and groundnut rosette disease (GRD) in Africa (Janila et al., 2013). Except for PStV disease, other virus diseases are not seedborne. Cultivars resistant/tolerant to viruses causing these diseases and to their vectors are available, and they should be grown in virus endemic areas (Nigam, 2012). Cultural practices such as timely sowing, optimum plant population, effective control of vectors and intercropping and border cropping with tall growing cereals, removal of alternate weed hosts of the virus and the vector during off-season should be adopted to manage virus diseases. Chemical seed treatment helps in reducing virus diseases through the control of their vectors. In the United States, risk indices have been developed to suppress TSWV and include cultivar selection, plant population and pattern, insecticides to control thrips (the vector of TSWV), the sowing date, and the tillage system (http://tomatospottedwiltinfo.caes.uga.edu/peanut/risk.html).

Efficacy to manage virus diseases through chemical control of vector is also dependent on the nature of the virus (persistent or nonpersistent), its acquisition period, its transmission period, virus retention in the insect and insect knock-down time, etc. It is easy to manage GRD by chemical control as the acquisition period of the virus complex by aphid vector is long thereby giving enough opportunity to chemicals to kill the vector. On the other hand, management of PBNV through chemical control of thrips vector is not effective as the virus is nonpersistent and its transmission period is very short before chemicals could kill the vector. In such situations, it is likely that agitated vectors could spread virus inoculum further before they die.

6.5 Field insect pests

Major insect pests include thrips, jassids and aphids as sucking pests; leaf miner, tobacco caterpillar, gram pod borer and hairy caterpillar as defoliators; and white grubs, termites, earwig and jewel beetle as soil-inhabiting insect pests. Readers may note that the chapter presents some broad recommendations for control of insect pests, which may differ from specific recommendations in the growing ecology, and the availability of the chemicals, their formulations and regulations of their use may vary in different countries.

IPM is desirable for effective control of insect pests in an eco-friendly manner. For sucking insect pests, grow resistant cultivars, treat seeds with insecticide to protect the crop in the early seedling stage, and spray systemic insecticides at economic threshold levels. For leaf miner, chemical control should be adopted when the larval population reaches 61–70 per 100 leaflets. Other options include installing of pheromone traps and light traps for destroying the moths.

For tobacco and hairy caterpillars and gram pod borer, provide perches, grow sunflower and castor bean trap crops on borders and inside the groundnut field (1 plant per 20 m^2), and destroy egg masses on trap crops and groundnut plants manually. Biological control measures like nuclear polyhedrosis virus (NPV) and neem seed kernel extract can also be used. Insecticide spray is recommended at economic threshold levels (Ghorpade and Thakur, 1989). For red hairy caterpillars, digging 15–20 cm deep trench all around the field or short barricade of polythene fence (10 cm high) across the migrating route can prevent their entry in the field and they can be collected manually and destroyed.

6.6 Control of soil insect pests

As a prophylactic measure, soil application of granular insecticides is recommended, and seed treatment with insecticides offers protection against white grubs in the initial stages. Feeding trees of adult white grubs can be sprayed with insecticides as a community approach. Destroying the termite mounds in the vicinity of fields, removal of plant residues and debris from fields and timely harvesting can help to minimize the termite damage.

6.7 Major storage insect pests

Groundnut bruchids damage both pods and kernels. Eggs are laid on the pods and kernels and young larvae cut through the shell and burrow into the kernel and feed. Cocoons are papery white and tough, and pupation takes place on the pods or kernels. Red flour beetle and rice moth are considered secondary pests as they are not able to infest intact pods. However, with mechanical damage caused to pods due to poor intercultivation and harvesting and curing practices, their damage in storage is quite common. Signs of damage include webbing in the case of rice moth and powdery remnants without webbing in the case of red flour beetle. Red flour beetles are oblong in shape and brown in colour and rice moth has greyish brown forewings. Development of storage insect pests can be arrested if seed moisture content is kept low (not more than 5%). Storage sanitary measures are recommended.

7 Harvesting, drying, curing and storage

Because of indeterminate growth habit, the pod maturity in groundnut is not uniform. It is important to harvest the crop at optimum maturity for maximum economic returns. Several biochemical (optical density of oil, arginine maturity index, methanol extract and maturity protein marker) and physical (kernel density, internal pericarp colour, seed hull maturity index and hull scrape) methods to estimate maturity in groundnut are available. The hull scrape method is commonly used in large farms, while the easiest method of assessing optimum time of harvesting on small farms in Asia and Africa is by evaluating internal pericarp colour of the pods collected from a few representative plants in the field. If more than 75–80% pods in case of Spanish/Valencia cultivars and 70–75% pods in case of Virginia cultivars show internal pericarp darkening, the crop is ready for harvest. If sprouting of seeds is observed in Spanish/Valencia cultivars (due to rains at harvest time in cultivars lacking fresh seed dormancy), the crop should be harvested as soon as the conditions permit without waiting for 75–80% pods to mature. In the case of end-of-season drought or under severe disease pressure, sometimes, forced premature harvesting may be required to salvage the crop. However, premature/forced harvesting may result in low shelling turnout. Over maturity or delay in harvesting can result in greater pod loss in the soil and deterioration in pod quality. In the absence of dormancy, *in-situ* germination of kernels in overmature pods can be a serious quality concern.

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

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 flavour and texture development in bringing the produce into storable condition) of the harvested produce ensure good quality of the produce. Harvested plants are kept inverted with pods facing upwards in windrows for about 2–3 days in the field for initial curing of plants and pods under ambient temperatures. If day temperatures are high, the plants should be dried in circular heaps avoiding direct exposure of pods to the sun. Exposure to high temperatures adversely affects the seed quality and germination. Groundnut pods at harvest contain moisture ranging between 35% and 60%. Plants should be dried till the moisture content in pods is brought down to 18–20% for mechanical threshing and 15% for hand threshing. Pods should be further dried, preferably under shade, to <10%.

7.1 Storage

Groundnut stores better in pods than in seeds. It is important to remove all damaged, discoloured, rotted, immature and sprouted seeds/pods, other plant materials and soil from the produce before storage. Well-dried pods with about 5% moisture content should be stored to avoid fungal and insect pests attack in storage. Pods should be stored in polythene-lined gunny bags or in some other safe storage structure in a well-ventilated and rodent free room which is not in general use and out of bound for children. The use of triple-layer 'Purdue Improved Crop Storage (PICS)' bags, was found to be safe for short-term groundnut pod storage. These hermetic triple-layer bags consist of three bags, one inside the other, made up of an outer woven polypropylene layer for strength, and two inner bags composed of 80-micron thick high-density polyethylene. They have been used with success for storing several crops including cowpea, maize and groundnut. PICS bags support retention of seed weight, germinability and oil content significantly better than cloth bags along with safeguarding the groundnuts from bruchids and retarding aflatoxin accumulation (Sudini, 2015). Bags should be placed on wooden planks (not more than five in a stack) and away from walls to avoid damage from dampness and should be protected from damage by storage pests by dusting the bags with insecticides. In case of pest outbreak during storage, the seed bags, after covering with polythene sheet, should be fumigated with insecticide. Storage temperature should be low; temperatures below 13°C inactivate most insects, arresting insect growth and the influence of other quality-deteriorating factors. Seed quality can be maintained for at least a year at temperatures ranging from 1°C to 5°C and moisture content of 7% or lower. Relative humidity in storage should be between 65% and 70%. Under unfavourable conditions, groundnut seeds lose viability quickly. High kernel moisture causes more deterioration than any other single factor.

8 Precision cultivation

In Argentina, Australia, and the United States farmers have greater access to synthetic fertilizers and crop protection materials including fungicides, herbicides, and insecticides than farmers in many other countries in the world. These farmers also have greater access to mechanization and technology that enables greater efficiency and flexibility in production systems and often results in higher yields and market grades than realized in resource-poor countries. Drying and storing facilities also contribute to minimize postharvest loss and improve and sustain quality over a longer period of time than in some regions of the world. Regulations through State and Federal inspection agencies contribute to greater food safety and quality for the consumer. An established and maintained seed system in both private and public sectors that insures known origin, quality, purity, and germination of varieties is a major contributor to consistency of production. While these resources, technologies and regulations add cost to farmers and the supporting industry, they are often cost-effective to the farmer and increase the likelihood of meeting consumer demands in both domestic and international markets.

Land preparation and precision planting are important steps in establishing adequate and uniform plant populations that optimize yield potential. Implements associated with both conventional and conservation tillage allows seed placement that results in rapid and uniform emergence across the field. Fertilizers and lime are often applied using equipment that utilizes global positioning systems (GPS) which enable variable application to increase uniformity of soil resources and in some instances to decrease produciton costs. Air and vacuum planters with plates that match seed size (runner market types versus Virginia market types, for example) allow precision seed placement. Modern twin-row planters also allow staggered seed placement which optimizes plant arrangement and minimizes competition between groundnut plants. Modern planters are also equipped to deliver insecticides, fungicides and *Bradyrhizobium* inoculant in the furrow, along with seed drop. These materials are applied either in water as a carrier or as granular formulations and in some instances as seed treatments. In Argentina, where the length of season and rainfall is limited, the seed is treated with a propriety polymer that allows successful stand establishment in conservation tillage systems when groundnut is planted in soil with sub-optimum temperatures.

During the growing season fungicides, herbicides, insecticides, micronutrients and plant growth regulators are applied to water solutions using ground equipment. Sprayers are calibrated frequently to ensure proper rates are applied to obtain adequate pest control, fertilizer delivery, and decrease the likelihood of crop injury and negative environmental impact. When equipped with GPS, sprayers have capacity to deliver pesticides and fertilizers in a manner that prevents overlap and subsequent decreases in efficiency (Battea and Eshanib, 2006; Luck, 2010). In current production systems pesticides are applied frequently (Jordan, 2016) and savings can result in a positive economic impact. Although not widely used, some modern sprayers have capacity to apply variable rates depending upon pest incidence, severity and soil characteristics. Research efforts are currently underway to determine if multi-spectral and hyperspectral imaging can be used to define incidence and severity of disease and other biotic stresses as well as abiotic stresses. Weather-based models have currently been used by some farmers to initiate fungicide sprays to protect groundnut from leaf spot disease (caused by *Cercospora arachidicola* or *Cercosporidium personatum*) and *Sclerotinia minor* (Jordan, 2016). These respective models use algorithms that use a combination of air temperature and soil temperature in concert with air humidity to define when the pathogen is active and the likelihood of epidemics developing. Predictive models are being developed to determine the likelihood of aflatoxin contamination in peanut based on temperature and rainfall (Chauhan, 2010). Understanding temperature and moisture thresholds for aflatoxin contamination will help to improve crop management to minimize levels of contamination at harvest (Bowen and Hagan, 2015).

Irrigation is an important component of efficient peanut production where water is available for this purpose. Several methods are used to initiate and schedule overhead or sprinkler irrigation and many of these systems are becoming sophisticated and automated. Although limited, surface and sub-surface drip irrigation has proven successful in some fields (Jordan, 2014; Sorensen, 2005).

Timely, efficient and precise digging of pods and inversion of vines is important to optimize pod yield and market-grade characteristics and to ensure desirable fatty acid composition and economic return. Heat unit accumulation using growing degree day calculations with minimum and maximum temperatures of 56°F (13.3°C) and 95°F (35°C) are used to approximate digging. Using thermal data to target the digging date assumes limited or no biotic stress, especially from inadequate soil moisture, minimal damage from insects and abiotic stress from pesticide damage. Farmers often use thermal data as the estimate for the first possible digging date and then sample fields several times to fine-tune the actual digging date. Commercial pressure washers with rotating nozzles are used to remove the exocarp, which reveals the mesocarp. Darker mesocarp colour is correlated with greater pod and kernel maturation. This approach enables farmers to determine when to initiate digging and vine inversion and establish a timeline for each field. Some attempts have been made to use multi-spectral imaging of the peanut canopy to determine when to initiate digging but this approach has had limited success (Colvin, 2014; Rowland, 2006; Rowland et al., 2008).

Many farmers use GPS to dig pods and invert groundnut in a precise manner regardless of morphological characteristics of groundnut, planting pattern, and row configuration. Roberson and Jordan (2014) reported that yield was higher when peanut was dug using GPS than when done manually. The increase in yield was greater with GPS than when the plant growth regulator prohexadione calcium was applied to minimize excessive vine growth later in the season. Pod loss in the digging process can occur when changes in soil texture and other characteristics occur in the same field and the digger is set at the same setting on the tool bar across the entire field. Prototype diggers have been developed and are currently being evaluated that allow digger blades to be maintained at the same depth across the entire field regardless of the changes in soil conditions (Warner, 2014). Yield monitors for peanut have the potential to enable farmers to define areas in fields that are less productive and can be managed more specifically based on biotic and/or abiotic stresses in those areas (Vellidis et al., 2001). Commercial availability and cost of drones and other platforms have the capacity to generate multi-spectral and hyperspectral images to assist growers in managing groundnut. Efforts are currently underway to correlate imaging with biotic and abiotic stresses so that the information derived from field scouting using drones could be used to increase efficiency of management.

Success of production systems is enabled by the availability of accurate and timely information that can be used by farmers. In addition to traditional methods of outreach and delivery of information, risk management through development of indices for specific pests and composite risk of multiple pests can help farmers more effectively implement practices with less risk (Lassiter, 2016; Lassiter et al., 2017). In future developing applications that can use complicated information to present effective options for pests in real time will be valuable in managing groundnut in a sustainable manner.

9 Seed systems

In developed countries, an established and well maintained seed system in both private and public sectors ensures production and supply of quality seed of improved varieties. On the contrary, the adoption rate of improved groundnut cultivars in most developing countries remains low primarily because of non-availability of their seeds in required quantities and at affordable price. Old cultivars, which have outlived their utility, continue to dominate groundnut cultivation affecting productivity in many countries. In Asia and Africa, ICRISAT together with national partners promotes formal and informal seed systems to improve the availability of quality seed of new cultivars where groundnut seed production has failed to attract participation of private seed sector due to absence of hybrids, low seed multiplication ratio (1: 8–10), large seed mass/volume resulting in high storage and transportation costs, and quick loss of seed viability. Most of the formal seed production remains under the domain of public sector seed-producing agencies, which often fail to meet their expected obligations. A majority of the groundnut seed production in developing countries occurs in the informal seed sector by well-off farmers often passing off the commercial produce after grading it as seed. Local traders also indulge in groundnut seed trade by procuring local commercial produce and selling it as seed in local markets after cleaning and grading the produce. Consequently, the seed sold in the local markets is often a mixture of several cultivars. A majority of the farmers either use saved seed or buy it from local traders. In the United States, the farmers source seed from a seed dealer or can save their own seed; sometimes, a farmer may bring saved seed into the co-op to be shelled, cleaned, treated, and bagged and can take back the seed for planting next season crop (Jordan, 2017). In China, some seed companies have emerged in partnership with public research institutes that produce and sell the seeds of improved varieties. In the absence of formal seed systems, informal and semi-formal seed systems have been contributing to seed supply to some extent in several countries of Africa and Asia.

A seed production crop requires more care and attention than commercial crop to meet the standards of genetic purity and physical quality. The field selected for seed production crop should not have had groundnut crop in the past two seasons to avoid contamination from volunteer groundnut plants. An isolation distance of 3 m is required between cultivars in all classes of seeds in the field. In addition to cultural practices described above, the following additional measures should be taken for the seed crop. Only one seed per hill should be sown to facilitate roguing. Diseased plants in the field, if any, should be removed and destroyed. Seed crop should be weed-free till harvest as weeds interfere with inspection and monitoring of the field and with harvest. A minimum two (preferably three) times of roguing should be carried out before harvest to remove off-type groundnut plants in the seed production field.

10 Conclusion

Reducing the input cost is critical to increasing the profitability of groundnut cultivation across different farming systems, from subsistence to precision farming. Host resistance to biotic and abiotic factors improves the pod yields and reduces the input cost, thus making cultivars/varieties critical component of improved groundnut cultivation. Achieving optimal plant population is central to optimize pod yields; thus, seed treatment and priming are cost-effective methods to achieve a good crop establishment. Groundnut farming in Asia and Africa is highly labour intensive and urgently requires mechanization that is suitable to operate on small farms. Awareness among producers, traders and consumers in Asia and Africa on food safety concerns is needed along with low-cost drying and storage techniques to reduce aflatoxin contamination in the absence of reliable host-resistance. Environmentally sustainable management of weeds may be a viable option to reduce the losses caused by weeds in Asia and Africa where herbicides are not readily available or affordable. Understanding the nutrient-use efficiency under water-limiting conditions may be useful to better manage soil and water resources. For precision farming, yield monitors, drones and applications will be valuable in managing groundnut farming. Studies on conservation tillage practices may provide options for sustainable management of groundnut on small farms in Asia and Africa.

11 Where to look for further information

A great deal of information exists on groundnut production and pest management in many parts of the world. Universities that support agriculture are also critical resources and may have solutions that address farmers' questions. However, depending on the country or regions of the world, universities and extension services may lack the infrastructure and resources to conduct research and deliver these findings to farmers. In these cases nongovernmental organizations can play a major role in developing and promoting production practices. These organizations often partner with local groups not only to foster improved production through education and technology (improved varieties, for example) but also to work toward developing markets and supply chains for groundnut. ICRISAT together with national agriculture research and extension partners provides information on production packages and supports technology delivery. Private industry also plays a major role in developing new technology and delivery systems.

ICRISAT's collaborative work with partners in Asia and Africa provides good information, and institutes like Oil Crops Research Institute in Wuhan, China, and Directorate of Groundnut Research in India, and Universities in the United States (e.g. North Carolina State University, University of Georgia and New Mexico State University) are sources of additional information.

12 References

Akbar, A., Manohar, S. S., Variath, M. T., Kurapati, K. and Janila, P. (2017), 'Efficient partitioning of assimilates in stress-tolerant groundnut genotypes under high-temperature stress', *Agron.*, 7, 30.

Arnold, J. A., Beasley Jr., J. P., Harris, G., Timothy, L. G. and Cabrera, M. (2017), 'Effect of gypsum application rate, soil type, and soil calcium on yield, grade and seed quality of runner peanut cultivars', *Peanut Sci.*, 44(1), 13–18.

Bationo, A. and Ntare, B. (2000), 'Rotation and nitrogen fertilizer effects on pearl millet, cowpea and groundnut yield and soil chemical properties in a sandy soil in the semi-arid tropics, West Africa', *J. Agric. Sci.*, 134, 277–84.

Battea, M. T. and Ehsanib, M. R. (2006), 'The economics of precision guidance with auto-boom control for farmer-owned agricultural sprayers', *Comput. Electron. Agric.*, 53, 28–44.

Beam, J. B., Jordan, D. L., York, A. C., Isleib, T. G., Bailey, J. E., McKemie, T. E., Spears, J. F. and Johnson, P. D. (2002), 'Influence of prohexadione calcium on pod yield and pod loss of peanut', *Agron. J.*, 94(2), 331–6.

Bell, M. J., Middleton, K. J. and Thompson, J. P. (1989), 'Effects of vesicular-arbuscular mycorrhizae on growth and phosphorus and zinc nutrition of peanut (*Arachis hypogaea* L.) in an oxisol from subtropical Australia', *Plant Soil.*, 117, 49–57.

Bhatia, V. S., Singh, P., Wani, S. P., Kesava Rao, A. V. R. and Srinivas, K. (2006), Yield gap analysis of soybean, groundnut, pigeonpea and chickpea in India using simulation modelling. Global Theme on Agroecosystems Report no. 31. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 156p.

Bhingarde, M. T., Kadam, R. S. and Tagad, L. N. (2015), 'Effect of seed priming on seed yield and seed quality of groundnut (*Arachis hypogaea* L.)'. *Life Sci. Int. Res. J.*, 2(2), 25–9.

Bowen, K. L. and Hagan, A. K. (2015), 'Temperature and moisture conditions that affect aflatoxin contamination of peanuts', *Peanut Sci.*, 42, 121–7.

Bradford, K. J. (1986), 'Manipulation of seed water relations via osmotic priming to improve germination under stress conditions'. *Hort. Sci.*, 21, 1105–12.

Chauhan, Y. S., Graeme, W., Rachaputi, R. C. N., Holzworth, D., Broom, A., Krosch, A. and Robertson, M. S. (2010), 'Application of a model to assess aflatoxin risk in peanuts'. *J. Agric. Sci.*, 148(03), 341–51.

Chengrong, N. (1996), 'Effect of fosamine and nitrogen manure on nitrogen metabolism and productivity of peanut', *China Oil*, 18(2), 31–3.

Colvin, B. C., Rowland, D. L., Ferrell, J. A. and Faircloth, W. H. (2014), 'Development of a digital analysis system to evaluate peanut maturity', *Peanut Sci.*, 41, 8–16.

Corbineau, F. and Cõme, D. (2006), 'Priming: A technique for improving seed quality', *Seed Test Int.*, 132, 38–40.

Deb, U. K., Bantilan, M. C. S. and Nigam, S. N. (2005), *Impact of Agricultural Research: Post-Green Revolution Evidence from India*. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Hyderabad, India.

Dey, R., Pal, K. K., Bhatt, D. M. and Chauhan, S. M. (2004), 'Growth promotion and yield enhancement of peanut (*Arachis hypogaea* L.) by application of plant growth-promoting rhizobacteria', *Microbiol. Res.*, 159, 371–94.

Diop, N., Beghin, J. and Sewadeh, M. (2004), Groundnut policies, global trade dynamics, and the impact of trade liberalization, World Bank Policy Research Working Paper No. 3226. SSRN, Washington DC, USA, pp. 1–36. https://ssrn.com/abstract=610267.

El-Rehim, M. A. Abd Backman, P. A., Rodriguez-Kabana, R. and Crawford, M. A. (1981), 'Peanut seed treatment with hot calcium hydroxide solutions', *Peanut Sci.*, 8, 36–9.

Elsheikh, E. A. E. and Mohamedzein, E. M. M. (1998), 'Effect of Bradyrhizobium, VA mycorrhiza and fertilisers on seed composition of groundnut', *Ann. Appl. Biol.*, 132, 325–30.

FAO. (2014), Food and Agriculture Organization. Faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor.

Farooq, M., Wahid, A. and Siddique Kadambot, H. M. (2012), 'Micronutrient application through seed treatments – Review', *J. Plant Sci. Plant Nutr.*, 12(1), 125–42.

Fernandez, E. M., Rosolem, C. A., Maringoni, A. C. and Oliveira, D. M. T. (1997), 'Fungus incidence on peanut grains as affected by drying method and Ca nutrition', *Field Crop Res.*, 52, 9–15.

Ghorpade, S. A. and Thakur, S. G. (1989), 'Assessment of need based monocrotophos application for the control of major pest of groundnut', *Pesticides*, 23(11), 19–20.

Gil, S. V., Meriles, J. M., Haro, R., Casini, C. and March, G. J. (2008), 'Crop rotation and tillage systems as a proactive strategy in the control of peanut fungal soilborne diseases', *BioControl*, 53(3), 685–98.

Gregory, M. P. and Gregory, W. C. (1979), 'Exotic germplasm of Arachis L. interspecific hybrids', *J. Hered.*, 70, 185–93.

Halmer, P. (2008), 'Seed technology and seed enhancement'. *Acta Hort.*, 771, 17–26. http://www.actahort.org/books/771/771_1.htm.

Hammons, H. O. (1994), *The Origin and History of the Groundnut*. Springer, Dordrecht, pp. 24–42. ISBN: 978-94-011-0733-4.

Hawkins, G. L., Kelton, J., Smith, N. and Balkcom, K. (2016), 'A note on comparing rate of soil moisture loss for conventional and conservation tillage production methods for peanut (*Arachis hypogaea*)', *Peanut Sci.*, 43(2), 168–72.

Hildebrand, G. L. (1996), 'The status of technologies used to achieve high groundnut yields in Zimbabwe', In: *Achieving High Groundnut Yields: Proceedings of an International Workshop* (Renard, C., Gowda, C. L. L., Nigam, S. N. and Johansen, C. (Eds)), 25–29 August 1995, Laixi City, Shandong, China, pp. 101–14.

Hurt, C. A., Brandenburg, R. L., Jordan, D. L., Royals, B. M. and Johnson, P. D. (2006), 'Interactions of tillage with management practices designed to minimize tomato spotted wilt of peanut (*Arachis hypogaea* L.)', *Peanut Sci.*, 33(2), 83–9.

Jain, N. K., Meena, H. N. and Bhaduri, D. (2017), 'Improvement in productivity, water use efficiency and soil nutrient dynamics of summer peanut (*Arachis hypogaea* L.) through use of polythene mulch, hydrogel and nutrient management', *Comm. Soil Sci. Plant Anal.*, 48(5), 549–64.

Janila, P. and Nigam, S. N. (2013), *Phenotyping for Plant Breeding.* Springer, Heidelberg, Germany, pp. 129–67.

Janila, P., Nigam, S. N., Pandey, M. K., Nagesh, P. and Varshney, R. K. (2013), 'Groundnut improvement: Use of genetic and genomic tools', *Front. Plant Sci.*, 4, 23.

Janila, P., Pandey, M. K., Shasidhar, Y., Variath, M. T., Sriswathi, M., Khera, P., Manohar, S. S., Nagesh, P., Vishwakarma, M. K., Mishra, G. P., Radhakrishnan, T., Manivannan, N., Dobariya, K. L., Vasanthi, R. P. and Varshney, R. K. (2016a), 'Molecular breeding for introgression of fatty acid desaturase mutant alleles (ahFAD2A and ahFAD2B) enhances oil quality in high and low oil containing peanut genotypes', *Plant Sci.*, 242, 203–13.

Janila, P., Murali, T. V., Pandey, Desmae, H., Motagi, B. N., Okori, P., Manohar, S. S., Rathnakumar, A. L., Radhakrishnan, T., Liao, B. and Varshney, R. K. (2016b), 'Genomic tools in groundnut breeding program: Status and perspectives', *Front. Plant Sci.*, 7, 289.

Jeffries, P., Gianinazzi, S., Perotto, S., Turnau, K. and Barea, J. M. (2003), 'The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility', *Biol. Fertil. Soils*, 37, 10–16.

Johnson, W. C., Brenneman, T. B., Baker, S. H., Johnson, A. W., Sumner, D. R. and Mullinix Jr., B. G. (2001), 'Tillage and pest management considerations in a peanut–cotton rotation in the southeastern Coastal Plain', *Agron. J.*, 93, 570–6.

Jordan, D. (2017), 'Peanut production practices', pp. 21–46. In: *Peanut Information 2017* (Jordan, D. L. (Coord.)). North Carolina Cooperative Extension Serv. AG-331. Raleigh, NC, USA, 172p.

Jordan, D. L., Barnes, J. S., Corbett, T., Bogle, C. R., Johnson, P. D., Shew, B. B., Koenning, S. R., Ye, W. and Brandenburg, R. L. (2008), 'Crop response to rotation and tillage in peanut based cropping systems'. *Agron. J.*, 100, 1580–6.

Jordan, D. L., Johnson, P. D., Grabow, G. L. and Corbett, T. (2014), 'Corn, cotton, and peanut response to tillage and sub-surface drip irrigation in North Carolina', *Agron. J.*, 106, 962–7.

Jordan, L. D., Brandenburg, R. L., Brown, A. B., Bullen, S. G., Roberson, G. T. and Shew, B. (2016), *Peanut Information*. North Carolina Cooperative Extension, Raleigh, NC, USA. https://content.ces.ncsu.edu/peanut-information/peanut-seed.

Jordan, L. D., Nuti, R. C., Beam, J. B., Lancaster, S. H., Lanier, J. E. and Dewayne Johnson, P. (2009), 'Influence of application variables on peanut (*Arachis hypogaea* L.) response to prohexadione calcium', *Peanut Sci.*, 36, 96–103.

Kumar, A., Pandey, A. and Gowda, M. V. C. (2015), 'Evaluation of groundnut genotypes for tolerance to phosphorus deficiency', *J. Plant Nutr.*, 38(5), 687–99.

Kuotsu, K., Das Lal, A. R., Munda, G., Ghosh, P. and Ngachan, S. (2014), 'Land forming and tillage effects on soil properties and productivity of rainfed groundnut (*Arachis hypogaea* L.)–rapeseed (*Brassica campestris* L.) cropping system in northeastern India', *Soil Till. Res.*, 142, 15–24.

Lanier, J. E., Jordan, D. L., Spears, J. F., Wells, R., Johnson, P. D., Barnes, J. S., Hurt, C. A., Brandenburg, R. L. and Bailey, J. E. (2004), 'Peanut response to planting pattern, row spacing, and irrigation', *Agron. J.*, 96, 1066–72.

Lassiter, B. R., Wilkerson, G. G., Buol, G. S., Jordan, D. L., Shew, B., Brandenburg, R., Herbert Jr. A., Phipps, P. and Chapin, J. (2016), 'Peanut production in Virginia and the Carolinas: Development of a website and program', *J. Crop Forage Turfgrass Manag.*, 2.

Lassiter, B. R., Wilkerson, G. G., Buol G. S., Jordan, D. L., Shew, B., Brandenburg, R., Herbert Jr., A., Phipps, P. and Chapin, J. (2017), 'Development and deployment of a composite pest risk assessment decision support system for peanut (*Arachis hypogaea* L.) in the Virginia-Carolinas Region', *J. Crop Forage Turfgrass Manag*, 3 (accepted).

Luck, J. D., Pitla, S. K., Shearer, S. A., Mueller, T. G., Dillon, C. R., Fulton, J. P. and Higgins, S. F. (2010), 'Potential for pesticide and nutrient savings via map-based automatic boom section control of spray nozzles', *Comput. Electron. Agric.*, 70, 19–26,

Murata, M. R., Zharare, G. E. and Hammes, P. S. (2008), 'Pelleting or priming seed with calcium improves groundnut seedling survival in acid soils', *J. Plant Nutr.*, 31(10), 1736–45.

Naveen, P., Daniel, K. V., Subramanian, P. and Kumar, P. S. (1992), 'Response of irrigated groundnut (*Arachis hypogaea* L.) to moisture stress and its management', *Ind. J. Agron.*, 37, 82–5.

Navya, H. M., Naveen, J., Hariprasad, P. and Niranjana, S. R. (2015), 'Beneficial rhizospheric microorganisms mediated plant growth promotion and suppression of aflatoxigenic fungal and aflatoxin contamination in groundnut seeds', *Ann. Appl. Biol.*, 167, 225–35.

Nigam, S. N. (2000), 'Some strategic issues in breeding for high and stable yield in groundnut in India', *J. Oilseeds Res.*, 17, 1–10.

Nigam, S. N., Aruna, R., Giri, D. Y., Ranga Rao, G. V. and Reddy, A. G. S. (2006), *Obtaining Sustainable Higher Groundnut Yields: Principles and Practices of Cultivation*. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, 48p. ISBN: 92-9066-484-3. http://oar.icrisat.org/id/eprint/3217.

Nigam, S. N., Waliyar, F., Aruna, R., Reddy, S. V., Lava Kumar, P. L., Craufurd, P. Q., Diallo, A. T., Ntare, B. R. and Upadhyaya, H. D. (2009), 'Breeding peanut for resistance to aflatoxin contamination at ICRISAT', *Peanut Sci.*, 36 (1), 42–9.

Nigam, S. N., Prasada Rao, R. D. V. J., Bhatnagar-Mathur, P. and Sharma, K. K. (2012), 'Genetic management of virus diseases in peanut'. *Plant Breeding Reviews*, 36, 293–356.

Ong, C. K. (1986), 'Agroclimatological factors affecting phenology of groundnut' In: *International Symposium: Agrometeorology of Groundnut*, 21–26 August 1985, Niamey, Niger, pp. 115–24.

Porter, D. M. and Wright, F. S. (1991), 'Early leafspot of peanuts: Effect of conservational tillage practices on disease development', *Peanut Sci.*, 18(2), 76–9.

Prasad, P. V. V., Craufurd, P. Q., Summerfield, R. J. and Wheeler, T. R. (2000), 'Effects of short episodes of heat stress on flower production and fruit-set of groundnut *Arachis hypogaea* L', *J. Exp. Bot.*, 51(345), 777–84.

Reddy, T. Y., Reddy, V. R. and Anbumozhi, V. (2003), 'Physiological responses of groundnut (Arachis hypogea L.) to drought stress and its amelioration: a critical review', *Plant Growth Regul.*, 41, 75–88.

Roberson, G. T. and Jordan, D. L. (2014), 'RTK GPS and automatic steering for peanut digging', *Am. Soc. Agric. Biol. Eng.*, 30(3), 405–9.

Rojo, F. G., Reynoso, M. M., Ferez, M., Chulze, S. N. and Torres, A. M. (2007), 'Biological control by Trichoderma species of Fusarium solani causing peanut brown root rot under field conditions', *Crop Prot.*, 26(4), 549–55.

Rowland, D. L., Sorensen, R. B., Butts, C. L. and Faircloth, W. H. (2006), 'Determination of maturity and degree day indices and their success in predicting peanut maturity', *Peanut Sci.*, 33, 125–36.

Rowland, D. L., Sorensen, R. B., Butts, C. L., Faircloth, W. H. and Sullivan, D. G. (2008), 'Canopy characteristics and their ability to predict peanut maturity', *Peanut Sci.*, 35, 43–54.

Rowland, D. L., Smith, C., Cook, A., Mason, A., Schreffler, A. and Bennett, J. (2015), 'Visualization of peanut nodules and seasonal nodulation pattern in different tillage systems using a minirhizotron system', *Peanut Sci.*, 42(1), 1–10.

Ruark, S. J. and Shew, B. B. (2010), 'Evaluation of microbial, botanical and organic treatments for control of peanut seedling diseases', *Plant Dis.* 94, 445–54.

Saravanakumar, D. and Samiyappan, R. (2007), 'ACC deaminase from Pseudomonas fluorescens mediated saline resistance in groundnut (*Arachis hypogaea*) plants', *J. Appl. Microbiol.*, 102(5), 1283–92.

Sarkar, R. K. and Pal, P. K. (2004), 'Effect of intercropping rice (*Oryza sativa*) with groundnut (*Arachis hypogaea*) and pigeonpea (*Cajanus cajan*) under different row orientations on rainfed uplands', *Ind. J. Agron.*, 49(3), 147–50.

Singh, A. L. (1999), 'Mineral nutrition of groundnut', *Adv. Plant Physiol.*, 2, 161–200.

Singh, B., Sandhu, B. S., Khera, K. L. and Aujla, T. S., (1986), 'Groundnut response to irrigation and sowing time on a deep loamy sand in a subtropical monsoon region', *Field Crops Res.*, 13, 355–66.

Singh, H., Jassal, R. Kaur, Kang, J. S., Sandhu, S. S., Kang, H. and Grewal, K. (2015), 'Seed priming techniques in field crops - A review'. *Agri. Rev.*, 36(4), 251–64.

Skelton, B. J. and Shear, G. M. (1971), 'Calcium translocation in the peanut (*Arachis hypogaea* L.)', *Agron. J.*, 63(3), 409–12.

Sorensen, R. B., Butts, C. L. and D. L. Rowland. (2005), 'Five years of subsurface drip irrigation on peanut: What have we learned?', *Peanut Sci.*, 32, 14–19.

Stalker, H. T. (1997), 'Peanut (*Arachis hypogaea* L.)', *Field Crops Res.*, 53, 205–17.

Sudini, H., Ranga Rao, G. V., Gowda, C. L. L., Chandrika, R., Margam, V., Rathore, A. and Murdock, L. L. (2015), 'Purdue Improved Crop Storage (PICS) bags for safe storage of groundnuts', *J. Stored Prod. Res.*, 64, 133–8.

Tadele, Z. (2017), 'Raising crop productivity in Africa through intensification', *Agron.*, 7(1), 22.

Turner, J. T. and Backman, P. A. (1991), 'Factors relating to peanut yield increases after seed treatment with Bacillus subtilis', *Plant Dis.*, 75, 347–53.

Valls, J. F. M. and Simpson, C. E. (2005), 'New species of *Arachis* (Leguminosae) from Brazil, Paraguay and Bolivia', *Bonplandia*, 14, 35–63. http://www.jstor.org/stable/41941266

Vellidis, G., Perry, C. D., Durrence, J. S., Thomas, D. L., Hill, L. W., Kvien, C. K., Hamrita, T. K., and Rains, G. (2001), 'The peanut yield monitoring system', *Trans. ASAE*, 44, 775–85.

Warner, A. C., Kirk, K. R., Thomas, J. S., Monfort, W. S., White, J. W., Brantley, S. A., Peele, J. S., Han, J. and Massey, H. F. (2014), Variable depth Peanut digger: Part II – digging loss analysis. Paper Number 141914272, American Society of Agricultural and Biological Engineers, Saint Joseph, MI, USA.

Wenguang, H., Shufen, D. and Qingwei, S. (1996), 'High yield technology for groundnut', *Int. Arachis News.*, 15, 22.

Yanhao, S., Shouxiang, T. and Caibin, W. (1996), 'Theoretical foundations for high yield of groundnut in China', In: *Achieving High Groundnut Yields: Proceedings of an International Workshop* (Renard, C., Gowda, C. L. L., Nigam, S. N. and Johansen, C. (Eds)), 25–29 August 1995, Laixi City, Shandong, China. ICRISAT, Patancheru 502 324, Andhra Pradesh, India, pp. 129–39.