Chapter 13 B

Agrometeorology and groundnut production

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I. Importance of the crop in various climates

I.1 General

Groundnut (*Arachis hypogaea* L.) is an annual legume which is also known as peanut, earthnut, monkeynut and goobers. It is the 13th most important food crop and 4th most important oilseed crop of the world. Groundnut seeds (kernels) contain 40-50% fat, 20-50 % protein and 10-20 % carbohydrate. Groundnut seeds are a nutritional source of vitamin E, niacin, falacin, calcium, phosphorus, magnesium, zinc, iron, riboflavin, thiamine and potassium. Groundnut kernels are consumed directly as raw, roasted or boiled kernels or oil extracted from the kernel is used as culinary oil). It is also used as animal feed (oil pressings, seeds, green material and straw) and industrial raw material (oil cakes and fertilizer). These multiple uses of groundnut plant makes it an excellent cash crop for domestic markets as well as for foreign trade in several developing and developed countries.

Cultivated groundnut originates from South America (Wiess 2000). It is one of the most popular and universal crops cultivated in more than 100 countries in six continents (Nwokoto 1996). It is grown in 25.2 million hectares with a total production of 35.9 million metric tons (FAO, 2006). Major groundnut growing countries are India (26%), China (19%) and Nigeria (11%). Its cultivation is mostly confined to the tropical countries ranging from 40° N to 40° S. Major groundnut producing countries are: China (40.1%), India (16.4%), Nigeria (8.2%), U.S.A (5.9%) and Indonesia (4.1%).

I.2 Production environments in major producing countries

I.2.1 China

Groundnut has a long history of cultivation in China and early accounts record its cultivation since the late 13th century (Shuren et al 1995). Groundnut is now one of the main cash and oil crops in China. Area under groundnut in China accounts for about 25 % of all oil seed crops. In high-income provinces, groundnut is grown for oil production and export. In other provinces it is grown primarily for food, especially as a snack (Yao 2004). Groundnut is becoming more attractive to the farmers due to higher net profit per unit area compared to other crops in several parts of China.

The main groundnut producing areas in China are Shandong, Henan, Guangdong, Hebei, and Guangxi, which account for more than 60% of cultivated area and total production. Shandong is the leading province (Shuren et al 1995). It accounts for 23% of the area and 33% of total production in the country (Shufen et al 1998). Groundnut is grown in rotation with various crops in diverse cropping systems in different regions. In Shandong province, groundnut is grown in summer season following winter wheat. It is also rotated with sweet potato, corn, tobacco, and vegetables in other regions.

As to production constraints, about 70 % of the total groundnut cultivation areas are hilly-mountainous, infertile, dryland, low lying area, which have low capacity to withstand drought or water logging. Poor farming practices such as lack of quality seeds, continuous mono-cropping are considered as constraints for groundnut production in China

I.2.2 India

Among oilseeds crops in India, groundnut accounts for about 50% of area and 45 % of oil production**.** In India, about 75% of the groundnut area lies in a low to moderate rainfall zone (parts of peninsular region and western and central regions) with a short period of distribution (90-120 days). Based on rainfall pattern, soil factors, diseases and pest situations, groundnut-growing area in India has been divided into five zones. In India, most of the groundnut production is concentrated in five states viz. Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, and Maharashtra. These five states account for about 86% of the total area under peanut cultivation. The remaining peanut producing area is scattered in the states of Madhya Pradesh, Uttar Pradesh, Rajasthan, Punjab, and Orissa. Although the crop can be grown in all the seasons, it is grown mainly in rainy season (*Kharif;* June-September). The *kharif* season accounts for about 80% of the total groundnut production. In the Southern and Southeastern regions, groundnut is grown in rice fallows during post-rainy season (*Rabi*; October to March). If irrigation facilities are available, groundnut can be grown during January to May as a spring or summer crop. Monsoon variations cause major fluctuations in groundnut production in India. Groundnut is grown in different cropping systems like sequential, multiple, and intercropping (Basu and Ghosh 1995).

As to production constraints, because groundnut is grown mainly as rainfed crop there is high a level of fluctuation in the production depending on the rainfall. The productivity is restrained by drought stress, the use of low levels of inputs by smallholders and marginal farmers in dryland areas, high incidence of foliar fungal diseases, and attack by insect pests.

I.2.3 United States of America

Most of the groundnut produced is consumed as food domestically. Although US represents about 10% of the world's groundnut production, it is a leading exporter and accounts for about 25% of the world's groundnut trade (Smith 2002). In the USA, groundnut is grown in three regions: the Southeast (comprising of Georgia, Alabama, and Florida), the Southwest (comprising of Texas, Oklahoma, and New

Mexico), and the Virginia-Carolina (comprising of Virginia, North Carolina, and South Carolina). Most of the groundnut producing areas are in humid zone (the Southeast), although some groundnut producing areas (mostly in the Southwest) have semi-arid condition (Hammons 1982; Isleib and Wybe, 1991).

As to production constraints, temperature is the major limiting factor for peanut yield in northern states since a minimum of 3,000 growing degree-days (with a base of 50°F) is required for proper growth and development (Robinson, 1984). A peanut crop will not reach optimum maturity for a marketable yield to justify commercial production in areas with fewer heat units during the growing season.

I.2.4 Nigeria

Groundnut is one of the most popular commercial crops in West African Nigeria north of latitude 10° N. Groundnut kernels, cake and oil, accounts for as much as 20% of total Nigerian export earnings, while satisfying the local requirements for edible nuts, while its husk (shell) is used as fuel, roughage, litter for livestock, mulch, manure, and as soil conditioner. Major areas of production have changed over the years.

Major groundnut-producing areas are located in the Sudan and Northern Guinea ecological zones where the soil and agro- climatological conditions are favorable (Misari et al 1980). Temperatures are moderately warm and relatively stable during the growing season at 20-25 ºC. Sudan Savannah zone receives adequate rainfall for groundnut production. The crop is grown usually as a component of a variety of crop mixtures including sorghum, millet, cowpea, and maize (Misari et al 1988). There are two main varieties grown in Nigeria, long season varieties maturing in 130 to 145 days; and short-season maturing in 90 to 100 days.

As to production constraints, the groundnut production in Nigeria faces problems that are many and complex. The drought coupled with rosette epidemic in 1975 resulted in decline in groundnut production. This has resulted in a southward shift of the suitable climatic zone for groundnut production. However, heavier soils of the south compared to the sandy soils of the Sudan Savannah, make harvesting difficult. Diseases such as the groundnut rosette, early leaf spot, late leaf spot, and rust have been on the increase. Leaf spot attack severely reduces the yield.

I.2.5 Indonesia

Groundnut is the second most important food legume crop after soybean in the Indonesia (Machmud and Rais 1994). Groundnut is grown mostly at low elevations up to 500 msl in nine provinces: West Java, Central Java, Yogyakarta, East Java, South Kalimantan, Lampung, Bali, West Nusa Tenggara, and South Sulawesi. The total rainfall in the leading production areas ranges from 2208 mm to 3442 mm. Most of the groundnut (66%) is produced under rainfed condition (Saleh and Adisarwanto 1995). On dryland and under rained condition, groundnut is generally grown in mixed cropping with maize or cassava, whereas on wetland, during the dry season it is generally grown as single crop. Farmers grow mostly small-seeded and early maturing varieties (85 to 90 days).

As to production constraints, major climatic and biotic constraints identified for the low production are: drought during the reproductive stage; diseases like leaf spot and rust; insects like aphids, jassids, and thrips. The major insect pest is A*proaerema modicella,* the most important diseases are bacterial wilt (*Pseudomonas solanacearum),* leaf spot (Cercospora *sp),* rust *(Puccinia arachidis)*, and groundnut mottle virus.

II. Agroclimatology of the crop

Groundnut is essentially a tropical plant and requires a long and warm growing season. The favorable climate for groundnut is a well-distributed rainfall of at least 500 mm during the crop-growing season, and with abundance of sunshine and relatively warm temperature. Temperature in the range of 25 to 30°C is optimum for plant development (Weiss 2000).

Once established, groundnut is drought tolerant, and to some extent it also tolerates flooding. A rainfall of 500 to 1000 mm will allow commercial production, although crop can be produced on as little as 300 to 400 mm of rainfall. Groundnut thrives best in well-drained sandy loam soils, as light soil helps in easy penetration of pegs and their development and their harvesting. The productivity of groundnut is higher in soils with pH between 6.0-6.5.

II.1 Rainfall or soil moisture

Rainfall is the most significant climatic factor affecting groundnut production, as 70% of the crop area is under semi-arid tropics characterized by low and erratic rainfall. Low rainfall and prolonged dry spells during the crop growth period were reported to be main reasons for low average yields in most of the regions of Asia and Africa, for example in India (Reddy et al., 2003), China (Zeyong (1992) and several parts of Africa (Camberlin and Diop, 1999). Zeyong (1992) reported that drought is the most important constraint to groundnut production in China, especially in parts of northern China where rainfall is less than 500 mm yr^{-1}. Naing (1980) reported that rainfall was the main factor determining yield in Myanmar.

Camberlin and Diop (1999) reported that after removing decadal trends, almost half of the variance in groundnut production in Senegal is explained by rainfall variability, especially during the early part of the rainy season (July – August). Persistent droughts and insufficient rainfall represent one of the greatest constraints on groundnut crop in Senegal. Groundnut requiring average rainfall of 600-1200 mm per year under Senegal's climatic conditions is receiving 500-700 mm of rainfall per year (Badione, 2001). Dulvenboooden et al. (2002) reported that groundnut production in Niger is significantly determined by rainfall during July to September.

In India groundnut yields were reported to be vulnerable from year to year because of large inter–annual variation in rainfall (Sindagi and Reddi 1972). Bhargava et al. (1974) reported that 89% of yield variation over four regions of India could be attributed to rainfall variability in the August to December growing period. Challinor et al. (2003) analyzing 25 years of historical groundnut yields of India in relation to seasonal rainfall concluded that rainfall accounts for over 50% of variance in yield. Gadgil (2000) observed that the variation in groundnut yield of Anantapur district arises to a large extent from the variation in the total rainfall during the growing season. It was observed that seasonal rainfall up to 50 cm is required to sustain a successful groundnut crop in this region.

Yield in this region can be indirectly related to El-nino events, as in 87% of El-nino years the Anantapur region received less than 50 cm of rainfall affecting the groundnut yield. At Anantapur centre of India, pod yield of groundnut showed highly significant curvilinear relationship with moisture use i.e., sum of rainfall and soil moisture (AICRPAM, 2003). Moisture use of 350-380 mm was found to be optimum for getting maximum yield and moisture use either less than or more than this amount reduced pod yield. However, Popov (1984) and Ong (1986) showed poor relationship between groundnut yield and seasonal rainfall, highlighting the higher importance of rainfall distribution to groundnut yield than the quantum of rainfall.

The importance of rainfall distribution to groundnut yield is well appreciated, but experimental evidence is poorly documented (Ong, 1986). Work in a controlled environment at Nottingham University, U.K, showed yield of a crop to be four times greater than the yield of crop which used the same amount of water, but was irrigated during vegetative phase only (ODA 1984). Results from a series of experiments at ICRISAT (1984) showed that early stress or lack of rainfall/soil moisture during 29-57 days after sowing (DAS) did not influence pod yield significantly, where as pod yields were increased by 150 kg/ha/cm of water applied during seed filling stage (93-113 DAS). Pod yield of groundnut and rainfall received during pod formation to maturity were positively correlated in a rainfed crop grown at semi-arid region of Andhra Pradesh in India (Subbaiah et al., 1974).

In subtropical environment in south- east Queensland, Australia, soil water deficits occurring during the flowering to the start of pod growth phase significantly reduced pod yields (range 17-25%) relative to the well watered control plots for two Spanish and two Virginia cultivars (Wright et al., 1999). The reduction in yield was greatest when severe stress occurred during the pod-filling phase. Several other reports also observed pod development stage to be most sensitive to moisture deficit (Rao et al., 1985; Stirling et al., 1989; Patel and Gangavani 1990; Meisner 1991 and Ramachandrappa et al., 1992). Analysis of the relationship between simulated groundnut yield and Climate in Ghana of western Africa showed that yield was predominantly influenced by rainfall from flowering to maturity (Christensen et al., 2004). Naveen et al. (1992) found that water stress imposed during the flowering and pegging stages of JL-24 produced greatest reductions in pod yield followed by water stress at early and late pod stages.

Prabawo et al., (1990) reported that irrigation applied before and /or after early pod filling stages increased pod yields of Spanish type groundnuts (100 day) to 2.4 t ha^{-1} compared with 0.53 t ha^{-1} in dryland groundnut crop. Nageswara Rao et al. (1985) confirmed that irrigations could be withheld during much of the vegetative period without any apparent effect on pod yield, implying that water stress during vegetative stage has no effect on yield. Nautiyal et al. (1999) proved that soil moisture deficit for 25 days during vegetative phase was beneficial for growth and pod yield of groundnut while Stirling et al. (1989) observed insensitivity of pod yield to early moisture deficit. Sivakumar and Sharma (1986) imposed drought stress or soil moisture deficit at all the growth phases of groundnut during three growing seasons observed that stress from emergence to pegging gave increased yields over control in all the three years while stress in other stages decreased the yield.

Not only yield but also other yield attributes, growth and development are affected by soil moisture deficit or water stress. The start of flowering as well as pod elongation was delayed by drought stress (Boote and Ketring 1990). The rate of flower production was reduced by drought stress during flowering but the total number of flowers per plant was not affected due to an increase in the duration of flowering (Gouda and Hegde 1986; Meisner and Karnok 1992). Boote and Hammond (1981) reported a delay of 11 days in flowering when drought was imposed between 40-80 DAS. Stansell and Pallas (1979) found that the percentage of mature kernels was reduced to 34% of the control when drought was imposed during 36-105 DAS.

Moisture stress also affects physiological characters like photosynthesis, stomatal conductance, leaf water potential, radiation and water use efficiencies, partitioning of dry matter (Boote and Williams, 1995). Bhagsari et al. (1976) observed large reductions in photosynthesis and stomatal conductance as the relative water content of groundnut leaves decreased from 80 to 75% (due to moisture stress). Subramanian and Maheswari (1990) reported that leaf water potential, transpiration rate and photosynthesis rate decreased progressively with increasing duration of water stress. Black et al. (1985) recorded lower water potential and stomatal conductance when moisture stress was imposed. Clavel et al. (2004) reported that water deficit decreased leaf area index, relative water content and transpiration at about 3 weeks after the occurrence of water deficit at the soil level.

Collino et al. (2001) observed that the fraction of photosynthetically active radiation intercepted and harvest index were reduced under water stress. In Argentina, under water stress condition, groundnut varieties (Florman INTA and Manfredi 393 INTA) produced significantly reduced water use efficiency compared to irrigated regime (Collino et al., 2000). Vorasoot et al. (2003) observed a drastic reduction in yield as well as yield attributing characters like total dry weight and shelling percentage when plants were grown at 25% of the field capacity of the soil.

II.2 Growth stages and water use

The growth stages of groundnut were described and defined by Boote (1982) This widely adopted system describes a series of vegetative (V) and reproductive(R) stages. The total water use by a groundnut crop is controlled by climatic conditions besides agronomic and varietal factors. A summary of the reported water use of groundnut (reproduced from Sivakumar and Sharma 1986) in Table 1 shows that water use varies from 250 mm in the rainfed conditions to 830 mm under irrigated conditions (with irrigation at weekly intervals). Naveen et al. (1992) reported that spraying of 3% Kaolinite during dry periods at 35 and 55 days after sowing showed significant yield increases over control.

From the lysimetric studies in groundnut (ICGS-76) at Rakh Dhiansar, Jammu region of India, water requirement of crop was estimated as 494 mm and 500 mm in two individual years and crop water use was observed to be maximum (crop coefficient 1.9) during pod formation stage (AICRPAM 1997 and AICRPAM 1998). Doorenbos and Kassam (1979) worked out stage wise water requirement as well as total water requirement of the crop. The water requirement of the crop ranged from 500 to 700 mm for the total growing period. The growing period of the crop is divided into five stages.

The stages, their duration and crop coefficients of individual stages are presented in Table 2. The data from Table show that mid season stage (pod formation and filling) requires higher water as indicated by the high crop coefficient value. In a field experiment conducted with JL-24, a bunch variety in two summer seasons in eastern India, water use recorded for three treatments with applied irrigation of 0.9, 0.7 and 0.5 of cumulative pan evaporation were 434, 391 and 356 mm, respectively (Bandopadhyay et al.2005). Maximum average K_c value of 1.19 occurred around 9 weeks after sowing in the same experiment.

II.3 Temperature

Temperature was identified as a dominant factor for controlling the rate of development of groundnut (Cox 1979). Every crop has its cardinal temperatures (i) base ($T_{b;}$), (ii) optimum (T_o) and (iii) maximum temperatures(T_m). These are defined respectively as: (i) temperatures above which growth and development begins, (ii) temperatures at which growth and development are maximum, and (iii) temperatures above which growth and development ceases. Mohamed (1984) reported cardinal temperatures for seed germination in 14 contrasting genotypes of groundnut, which are shown in Table 3. These values showed that T_b is not varying much across genotypes (ranges from 8-11.5ºC), whereas optimum temperatures (29-36.5ºC) and maximum temperatures (41-47ºC) are varying much. Base temperature was reported to be highest during reproductive phase (3-10^{o0} C higher) than during vegetative phase (Angus et al. 1981). In contrast, Leong and Ong (1983) showed T_b to be conservative for many processes and phases of groundnut cv robut 33-1. Optimum temperatures for different growth and developmental processes of the crop are presented in Table 4. Optimum temperatures for different processes ranged between 23 to 30 ^{0}C. Optimum temperature for germination and leaf appearance was observed to be higher than for other processes. Williams et al. (1975) reported that the optimum temperature for vegetative growth of groundnut plants were in the range of 25-30ºC while optimum temperature for reproductive growth lower (20-25º C).

Table 1 Summary of reported values of total water use (mm) of groundnut

Reference	Total water Use (mm)	Remarks
Ali et al. (1974)	530	Irrigated at 60% water depletion
Angus et al. (1983)	250	Rainfed
Charoy et al. (1974)	510	Rainfed
Cheema et al. (1974)	337	Rainfed
	597	Irrigated at 40% water depletion
Kadam et al. (1978)	342	Rainfed
Kassam et al. (1975)	438	Rainfed
Reddy et al. (1980)	560	Irrigated, winter months
Reddy et al. (1978)	417	Rainfed
Reddy and Reddy (1977)	505	Irrigated at 25% water depletion
Panabokke (1959)	404	October to January
Keese et al. (1975)	500-700	Irrigated at 50%water depletion
Samples (1981)	450-600	Irrigated at 50% water depletion
Nageswara Rao et al. (1985)	807-831	Irrigated at 7-10 day interval during winter months

(Source: Sivakumar and Sharma 1986)

Table 2: Stage wise crop coefficients (K_c) in groundnut

Crop Stage	Duration (days)	Crop coefficients
1.Initial stage	15-35	0.4-0.5
2.Development stage	30-45	0.7-0.8
3.Mid season stage	30-50	0.95-1.1
4.Late season stage	20-30	0.7-0.8
5.Harvest stage	-	0.55-0.6

Table 3. Base (T_b), optimum (T_O) and maximum(T_m) temperatures of 14 groundnut cultivars for seed germination

Cultivars	T_b	T_O	T_m
Valencia R2	8	35	43
Flammings	8	34.5	42
Makulu Red	8.5	29	42
ICG 30	8	36	44
EGRET	9	29	43
ICG 47	9	36.5	47
Robut 33-1	10	36.5	46
TMV 2	10	36	42
MK 374	10	36	44
Plover	10.5	34	42
ICG 21	11	35.5	45
M 13	11	34	45
Swallow	11	29	42
N.Common	11.5	29	41
Ranges	8-11.5	29-36.5	41-47

(Source: Mohamed 1984)

Table 4. Optimum temperature for vegetative and reproductive growth and development of groundnut.

Trait	Optimum Temp. (ºC)	Reference
Seed germination	28 - 30	Mohamed et al., 1988
Seedling growth	28	Leong and Ong, 1983
Leaf appearance and leaf area development	28 - 30	Fortanier, 1957; Cox, 1979
		Leong and Ong, 1983; Ketring 1984;
Branching and stem growth	28	Leong and Ong, 1983
Flower production	25 - 28	Fortanier, 1957; Wood, 1968; Cox, 1979
Pollen production	23	Prasad et al., 1999
Pollen viability	23	Prasad et al., 1999; 2000; Kakani et al., 2002
Peg formation	23	Prasad et al., 1999
Pod formation, pod growth and seed yield	23 - 26	Williams et al., 1975; Cox 1979; Dreyer et al., 1981
		Prasad et al., 1999; Prasad et al., 2003
Root growth	23 - 25	Ahring et al., 1987; Prasad et al., 2000
Harvest index	23 - 27	Prasad et al., 1999; Craufurd et al., 2002
		Prasad et al., 2003
Nitrogen fixation	25	Nambiar and Dart, 1983

The duration of the crop is very much influenced by temperature. Bell et al. (1992) reported an early bunch variety maturing in 120-130 DAS at mean temperature of 23^{o0} C while the same variety matures in 105 DAS when grown in coastal environment with slightly higher mean temperatures (25^{o0} C). Such strong effects of temperature on groundnut phenology have also been reported by others (Leong and Ong 1983; Bagnall and King 1991). Crop duration was shortest in humid tropical and sub-tropical environments, with both high and low temperatures apparently affecting crop maturity (Bell and Wright 1998). Williams et al. (1975) reported the total growing period of the crop to be shortened from 176 days at temperature 18ºC to 151 days at 23ºC. The duration of groundnut cv Robut 33-1 from sowing to the end of seed filling increased from 95 days at 31ºC to 222 days at 19ºC. Not only the duration of crop but also the growth and yield traits were influenced by temperature. Craufurd et al. (2000) exposed 8 genotypes to either high (day/night temperature, 40/28ºC) or optimum (30/24ºC) temperature from 32 DAS to maturity and reported that rates of appearance of leaves and flowers were faster at 40/28ºC when compared to 30/24ºC. As groundnut pods are developed under the soil it is important to understand the influence of soil temperature. Prasad et al. (2000) reported that exposure to high air and or high soil temperature (38/22ºC) significantly reduced total dry matter production, partitioning of dry matter to pods and pod yields in two cultivars. High air temperature had no significant effect on total flower production but significantly reduced the proportion of flowers setting pegs (fruit-set) and in contrast high soil temperature significantly reduced flower production, production of pegs forming pods and 100 seed weight. Furthermore, the effects of high air and soil temperatures were mostly additive. Higher temperature, promoted greater vegetative growth and higher photosynthesis in 3 genotypes of groundnut, but the reproductive growth was decreased, due to greater flower abortion and decreasing seed size (Talwar et al. 1999; Prasad et al., 2003).

The groundnut variety ICGV 86015 exposed to short episodes (1 to 6 days) of heat stress showed strong negative linear relation between day temperature over the range of 28 to 48ºC and characters like number of flowers , proportion of flowers setting pegs, number of pegs and pods per plant, pollen production per flower and pollen viability (Prasad et al.1999; 2001). The periods of microsporogenesis (3 d before anthesis) and flowering were identified as most sensitive stages of high temperature stress in groundnut (Prasad et al., 2001). Karunakar et al. (2002) reported that yield attributes like number of effective pegs, developed pod numbers and pod dry weight per plant of groundnut grown under semi-arid tropical conditions of India were positively influenced by minimum temperature and relative humidity during the crop growing period. Among the four groundnut cultivars of Spanish or Virginia types viz.'Chico, Manipintar, early bunch and McCubbin tested in a subtropical environment of Queensland, Australia. all varieties except Manipintar showed lower Radiation Use Efficiency (RUE) with decrease in minimum temperatures (Bell et al., 1993). The responses of pollen germination and pollen tube growth to temperature were quantified by Kakani et al. (2002) for identifying heat tolerant groundnut genotypes.

A modified bi-linear model most accurately described the response of percentage pollen germination and maximum pollen tube length to temperature. Based on temperature response, genotypes 55-43, ICG 1236, TMV-2 and ICGS 11 were grouped as tolerant to high temperature and genotypes Kadiri-3, ICGV 92116 and ICGV 92118 were grouped as susceptible genotypes. Ntare et al. (2001) observed that pod yield of most of the 16 genotypes of groundnut tested under actual field conditions of Sahelian region of Africa, declined by more than 50% when maximum temperatures averaged around 40ºC occurred during flowering and pod formation. Craufurd et al. (2002) observed that high temperature (38/22ºC) from 21 to 90 days after planting reduced total dry weight by 20 to 35%, seed harvest index by 0 to 65% and seed dry weight by 23 to 78%. Genotypic differences in response to temperature were noticed and reductions in total dry matter, pod and seed dry weight and harvest index at high temperatures were noticed only in susceptible genotypes.

The interactive effects of temperature and other environmental factors are less understood and need further attention. Prasad et al. (2003) studied the effects of temperature in combination with elevated CO_2 on various physiological and yield processes of groundnut. At ambient CO_2 (350 ppm CO_2), seed yield decreased progressively by 14%, 59% and 90% as temperature increased from 32/22 (daytime maximum/ nighttime minimum) to 36/26, 40/30 and 44/34ºC, respectively. Similar percentage decrease in seed yield occurred at temperatures above 32/22ºC at elevated CO_2 despite greater photosynthesis and vegetative growth at elevated CO_2. Seed harvest index decreased from 0.41 to 0.05 as temperature increased from 32/22^{o0}C to 44/34ºC under both ambient and elevated CO_2. A 30%decrease in pod yield was observed due to lower thermal and photoperiodic conditions during the reproductive phase of groundnut (AICRPAM 1998).

Similarly, temperature (expressed as degree day) and rainfall during the reproductive period positively influenced the pod yield and together they explained 86% of yield variation (AICRPAM 1997). Temperature and light intensity affected flower numbers of groundnut varieties and these changes were also well correlated with growth related changes in leaf number and pod dry weight (Bagnall and King 1991). In crop models, the optimum temperature for canopy photosynthesis was between 24-34ºC (daytime mean temperature) with linear reductions below 24ºCdown to 5º ^{0}C and with linear reductions above 34ºC up to 45ºC (Boote et al.1986). Vijaya Kumar et al. (1997), while analyzing the variability of groundnut yield at 3 locations across varied soil and climatic conditions in relation to temperature and rainfall observed that Bangalore region despite experiencing higher rainfall than Anantapur and Anand regions, had lower average pod yield due to comparatively lower than optimum mean temperatures .

II.4 Thermal time or accumulated heat units requirement of the crop

Phenological development of groundnut responds primarily to heat unit accumulation. Leong and Ong (1983) calculated heat units requirements for different phenological stages (Table 5). Two papers reporting on heat units to flowering for groundnut have suggested a base temperature of 13-14º C, below which reproductive development stops (Emery et al.1969, Mills 1964). In sixteen sowings ranging from the wet tropics in Indonesia to the elevated subtropics in

Australia, harvest date corresponded to the accumulation of about 1800 (base temperature of 9^0C) degree days (Cd) after sowing (Bell and Wright 1998).

Thermal units required for groundnut cultivars to reach maturity were 2247º Cd in Sudan (Ishaq 2000). Ong (1986) reported a maturity index or thermal units of 2000º Cd for the cultivars in warm regions of India - at a base temperature of 10º C. The varieties TMV-2 and Robut 33-1 grown in semi-arid Anantapur region of India required 1732º Cd and 1839º Cd of growing degree days, respectively (AICRPAM, 1998). In the same year, Robut 33-1 grown in Bangalore, a semi-arid region of India took 1491º Cd. The thermal time requirement for maturity of the same variety seems to be different for different sowing dates and locations.

Table 5. Thermal time requirement in º Cd of several developmental processes of groundnut cv Robut 33-1.

Developmental Process	Thermal time (º Cd)
Leaf production	56 per leaf
Branching	103 per branch
Time to first flowering	538
Time to first pegging	670
Time to first podding	720

Source: Leong and Ong 1983

II.5 Photoperiod or day length

Early studies in controlled environments showed that phenology of groundnut is not affected by day length (Fortainer 1975). However, later studies showed that pod yield is significantly influenced by day length (Ketring 1979; Witzenberger et al., 1988). It is now well established that long days promote vegetative growth at the expense of reproductive growth and increased crop growth rate, decreased partitioning of photosynthesis to pods and decreased duration of effective pod filling phase (Ketring 1979, Witzenberger et al.1988; Nigam et al 1994 and 1998). Some contradictory results on the influence of day length on the duration of reproductive growth were reported. While Sengupta et al. (1977) found that a day length shorter or longer than 10 h delayed flowering , Ketring (1979) did not observe any effect of day length (8,12,16 h) on flower initiation. The contrasting results might have been obtained due to cultivars differences, which are known to vary in response to photoperiod.

In a study of Bagnall and King (1991), flower, peg and pod numbers were consistently enhanced by short day treatments for a range of groundnut varieties. Flower and peg number at 60-70 days from emergence were approximately doubled by 12–h days exposure compared with plants in 16-h days. Pod number and therefore yield was more influenced by photoperiod than was flower or peg formation. Bell et al. (1991) while studying the effects of photoperiod on reproductive development of groundnut in a cool subtropical environment observed that number of pegs, pods and total pod weight per plant were reduced in long (16 or 17 h) photoperiods, but no effect of photoperiod was evident on time to first flower. It was further observed that the photoperiod responses were more significant in the environments where daily accumulations greater than 34-35° C were observed. Nigam et al. (1994) studied the effect of temperature and photoperiod and their interaction on plant growth as well as partitioning of dry matter to pods in three selected groundnut genotypes grown in growth chambers. It was observed that photoperiod did not significantly affect partitioning of dry matter to pods under low temperature regime (18/22ºC) but at higher temperatures (26/30ºC) partitioning to pods was significantly greater under short days (9 h) and this study provided evidence of genotypic variability for photoperiod temperature interactions. In a field study on the effect of photoperiod on seed quality (Dwivedi et al., 2000), shelling percentage and palmitic acid increased under short day (8 h) treatment compared to normal day (12 h) treatment while oil content, oleic and linolenic fatty acids and their ratio were unaffected.

II.6 Saturation deficit

Saturation deficit (SD) is an important agroclimatic factor for any crop including groundnut, because it is a major determinant of potential evapotranspiration. Stomatal response to SD to limit actual rate of transpiration was studied (Black and Squire 1979). Large SD accelerated the depletion of soil moisture reserves in the non-irrigated stands and greatly reduced leaf area index of groundnut, particularly in the driest treatment (Ong et al., 1985). Leaf number per plant and leaf size both decreased as SD increased, but the effect of SD was more on leaf size than on number. Turgor potential and leaf extension rate were also reduced at high SD. In another study on responses to SD conducted in glass houses, developmental processes such as timing of flowering, pegging and pod formation were found to be unaffected by SD, but the number of branches, flowers and pegs were reduced in the drier treatments (Ong et al., 1987). In the same study, in un-irrigated stands, drymatter production in shoots was reduced by 40% as the maximum SD increased from 1.0 to 3.0 kPa. Productivity per unit of water transpired decreased with increasing SD. Simmonds and Ong (1986) reported a strong dependence of transpiration on SD in groundnut and when SD exceeded 2 kPa, canopy expansion was restricted.

III. Other background information on the crop

III.1 Relationship between diseases and weather

Several diseases and insect pests causing large losses in both yield and quality of seeds affect the groundnut crop. Weather indirectly influences the yield and quality by occurrences and development of diseases and pests. Kolte (1985) reviewed diseases of groundnut in relation to weather conditions. The important plant diseases and meteorological conditions affecting them are described in this section.

III.1.1 Early and late leaf spots

Early and late leaf spots (*Cercospora arachidicola* and *Puccina personate*) are considered the most important diseases of groundnut. They have been reported throughout the groundnut growing areas of the world. Leaf spots cause huge yield loss in groundnut due to severe defoliation. Weather conditions congenial for occurrence of early and late leaf spots, as reported by different researchers are summarized in Table 6, which basically tell the same story that rainfall, leaf wetness and temperature are most important factors for occurrence and epidemiology of leaf spots.

Table 6.Summary of the relationships between leaf spots and weather conditions

Country	Disease	Weather conditions	Reference
India	Early and late leaf spots	High Relative Humidity and dew	Wangikar and Shukla (1977)
U.S.A	Early and late leaf spots	Rainfall and leaf wetness	Jensen and Boyle (1965)
Nigeria	Early leaf spots	Rainfall, relative humidity and low temperature	Garba et al. (2005)
India	Early and late leaf spots	Max.Temp: 31-35º C, Min.Temp: 18-23ºC mean monthly and rainfall of at least 60 mm	Venkataraman and Kazi (1979)
USA	Early and late leaf spots	Rainfall	Davis et al. (1993)
USA	Early and late leaf spots	Rainy days during June -September	Johnson et al. (1986)
USA	Early leaf spot	shortly after the onset of rainfall	Smith and Crossby (1973)
India	Late leaf spot	Leaf wetness index of 2.3 or more	Butler et al., (1994)
Central India	Leaf spots	200-500 mm Rainfall, 25-30°C Temperature and 74 to 87% RH during crop season	Lokhande and Newaskar (2000),. Mayee (1985)
USA	Leaf spots	No. of hours with RH > or = 95% and Minimum Temperature	Jensen and Boyle (1966)
USA	Leaf spots	Temperature>16 °C and Leaf wetness	Alderman and Beute (1986), Shew et al., (1988)
India	Leaf spots	Decrease in Maximum temperature and Increase in relative humidity	Adiver et al., 1998
India	Late leaf spot	Temperature (-ve relation)	Mayee 1989
USA	Leaf spots	Rainfall, RH 80% and mean temp. of 23.2°C	Frag et al.1992
USA	Early leaf spots	Temperature and duration of wetness	Wu et al.1999
USA	Early leaf spots	Nearly 100% humidity and 16-25°C Temperature	Alderman and Beute 1987
India	Leaf spots	Max.Temp<34 °C, Min.Temp<22 °C, morning RH>82% and afternoon RH>78%	Samui et al. (2005

III. 1.2 Rust

Rust (*Puccinia arachidis*) has now become a disease of major economic importance in almost all the groundnut-growing areas of the world. It becomes devastating under conditions of high rainfall and humidity. In the 'postrera'-planting season in Honduras and Nicargua of central America (Arneson 1970) and in Venezula, this disease becomes severe when the rainy season is almost over or when dew is abundant (Hammons 1977). In India, a continuous dry period characterized by high temperature (>26º C) and low relative humidity (<70 %) is reported to delay rust occurrence and severity, whereas intermittent rain, high relative humidity and 20 to 26º C temperature favor disease development (Siddaramaiah et al., 1980). Mayee (1987) observed that average temperature of 20-22º C, relative humidity above 85% and 3 rainy days in a week, if prevailed for 2 weeks, an out break of rust is likely in Parbhani region of Maharashtra, India. In the same region, from the long-term observations of rust and weather conditions, guide-lines similar to the above study for outbreak of rust were outlined (Sandhikar et al., 1989). If these conditions prevail for a week, rust outbreak is likely to occur in next 15 days.

Mayee and Kokate (1987) observed that incubation period of *Puccinia arachidis* causing groundnut rust was prolonged as the mean or maximum temperature increased while it is negatively correlated with relative humidity. Multiple regression analysis of different environmental factors combinations including rainfall, evaporation rates explained more than 96% of the observed variation in incubation period. Mayee (1986) reported that the leaf rust epidemic commonly occurs during prolonged dry spell after heavy showers. In their study on the influence of rainfall, temperature and relative humidity on groundnut leaf rust epidemiology, Lokhande et al. (1998) observed that rainfall of about 200 mm, temperature between 23.5 to 29.4 º C and relative humidity in the range 67 to 84% are congenial weather conditions for initiation and development of this disease.

II.1.3 Sclerotinia blight

Sclerotinia blight (*Sclerotina minor*) occurs through out groundnut growing areas of the world in the tropics and in warmer parts of the temperate zone. Moisture, temperature and innoculum in the soil exert considerable influence on the disease (Onkarayya and Appa Rao, 1970). Moisture, soil temperature, vine growth and foliar canopy have been identified as congenial factors for the onset and progress of this disease (Dow et al., 1988;Lee et al., 1990; Phipps 1995 and Bailey and Brune, 1997). A study by Phipps (1995) showed that rainfall usually preceded disease onset by 6 to 15 days in non-irrigated fields. Maximum and minimum air temperatures over the 15 days period to disease onset fluctuated between 32 and 20^0 C, while maximum and minimum soil temperatures were between 30 and 25^0 C, respectively. Optimum sclerotial germination and infection of groundnut by S.minor have been reported to be between temperature of 20 and 25^0 C (Dow et al., 1988). In Texas, S.minor was reported to be inactive in groundnut fields when soil temperature exceeded 28^0 C at the 5-cm depth (Lee et al., 1990). Although both moisture and temperature are commonly mentioned as significant factors affecting development of sclerotinia blight, evidence in the Virginia groundnut production area suggests that plant growth and rainfall are the primary forces at work in triggering outbreak of this disease (Phipps 1995).

III.1.4 Collar rot

High soil and air temperatures predispose the groundnut plants to collar rot infection (*Aspergillus.niger*) (Kolte 1985). Development of different symptoms is dependent on temperature. Maximum seed rot occurs from 15ºC to 40ºC, whereas the collar rot infection appears severest at 31 to 35º C (Chohan 1969).

III.1.5 Molds causing aflatoxin contamination

Aflatoxin contamination of groundnut is a major problem in most of the groundnut production regions across the world. It is mostly influenced by the occurrence of drought during the late seed filling duration. It is caused by the growth of the moulds *Aspergillus flavus* and/or *Aspergillus parasiticus*. Toxicity of groundnut from aflatoxin endangers the health of humans and animals and lowers market value (e.g. Abdalla et al., 2005). Hence, it is a problem to groundnut producers as well as consumers. The moulds are common saprophytic fungi found in soils throughout the major groundnut producing areas of the world (Pettit and Taber 1973; Griffin and Garren 1974). Pettit (1986) reviewed the influence of changing environmental conditions on the activity of the moulds on groundnuts. Aflatoxin is more serious during and following alternating dry and wet periods i.e. droughts following showers.

Pettit et al. (1971) observed that peanuts grown under dryland conditions and subjected to drought stress accumulated much more aflatoxin before digging than peanuts grown under irrigation. Wilson and Stansell (1983) reported that water stress during the last 40-75 days of the crop contributed to higher aflatoxin levels in mature kernels. Sanders et al. (1993) reported aflatoxin contamination in groundnut when pods were exposed to drought stress although roots of the crop were well supplied with moisture. In a field study in Niger, Craufurd et al. (2006) confirmed that infection and aflatoxin concentration in peanut can be related to the occurrence of soil moisture stress during pod filling when soil temperatures are near optimal for *Aspergillus flavus*.

Cole and his co-workers (Cole et al., 1985; 1989; Dorner et al., 1989) have shown that preharvest contamination of aflatoxin requires drought period of 30-50 days and a mean soil temperature of 29-31^{o} C in the podding zone. In Sudan, the irrigated region (Central Sudan) used to be free from aflatoxins while the rainfed region (Western Sudan) showed high levels of aflatoxin contamination (Hag Elamin et al., 1988). In the same study, temperature of 30^{o} C and relative humidity of 86% were identified as optimum conditions for aflatoxin production. Rachaputi et al. (2002) observed Aflatoxin contamination to be widespread in the Queensland region of Australia during the 1997-98 seasons with severe and prolonged end of season drought and associated elevated soil temperature and lower aflatoxin risk during 1999-2000 seasons with well-distributed rainfall and lower soil temperatures.

III.2 Insect pests

Major insect pests in groundnut are: termites (*Odontotermes*), whitegrubs (*Lachnosterna consanguiea*), thrips, jassids (*Empoasca kerri*), aphids (*Aphis craccivora)*, leaf miners (*Aproaerema modicella*), tobacco caterpillars and red hairy caterpillars (*Amsacta albistriga*). Environmental conditions are important factors in survival, rate of development and fecundity of various crop pests.

III.2.1 Leaf miner

In the Anantapur region of south India, leaf miners emerge during drought periods with no rainy days for more than 21 days during 35-110 days of the cropping period (Gadgil et al. 1999; Narahari Rao et al., 2000). Ranga Rao et al. (1997) also observed it to be severe during moisture stress conditions. The conditions favorable for the leaf miner growth are long dry spells resulting in high temperature and low humidity (Amin and Reddy 1983). At Anantapur under late sown conditions, the groundnut leaf miner incidence was significantly and negatively correlated with rainfall and minimum temperature and positively with sunshine hours (AICRPAM 2001).

III.2.2 Heliothis armigera

Heliothis armigera (Hubner) has become a serious pest on groundnut in recent years. The study on the relationship between seasonal incidence of heliothis and weather parameters (Upadhyay et al.1989) showed that heliothis population was positively associated with maximum and minimum temperatures.

III.2.3 Aphids

Aphids distribution across a drought stress gradient created by a long line source over-head irrigation system (ICRISAT 1989) showed that aphid density was much higher where most of the irrigation water had been applied and lowest at a point farthest from the water source, where plants were experiencing drought stress. Interestingly, rain falling on plants infected with aphids physically suppresses the aphids' population and a single heavy rainfall event decreased their density by 90%.

III.2.4 Red hairy caterpillars (*Amsacta albistriga*)

In the Anantapur region of India, a major groundnut growing region, emergence of red hairy caterpillar (RHC) was found to be closely related to heavy rainfall events (AICRPAM 1997). The numbers of RHC reached a peak 3 to 4 days after a rain event and the outbreak of RHC could be predicted 8 to 9 days in advance. Red hairy and Bihar caterpillars appear after the onset of pre-monsoon showers during May/June (Padmavathamma et al. 2000).

III.2.5 *Spodoptera litura*

Under both laboratory and field studies at ICRISAT, Hyderabad, India, lower and upper threshold temperatures for development of *Spodoptera* in groundnut worked out to be 10.5ºC and 30ºC, respectively (Ranga Rao et al., 1989). The study also approximated the degree-day accumulation requirements for each stage of development of spodoptera like pre-oviposition females (30), eggs (55), larvae (315), pupae (155) and adult stages (generation time, 550).

IV Management aspects of the crop in various environments

IV.1 Protection measures

A history of leaf spot monitoring, forecasting and their increasing use in its control can be followed through the literature (Jensen and Boyle 1966, Smith et al. 1974, Parvin et al. 1974, Phipps and Powell 1984, Johnson et al., 1985, Smith 1986). In 1989, a new advisory program (89-ADV) was released in Virginia that improved leaf spot control through better timing of fungicide sprays (Cu and Phipps 1993). This advisory program was evaluated over the years (1990-1995). These evaluations showed that the program saves on average 3 fungicide sprays per season, and decreased input cost by 43% and increases net returns by 26% (about $9000 per year) compared with the earliest 14-day program.

Another approach to provide advice for control of late leaf spots uses the number of days when rainfall exceeds a threshold (Davis et al., 1993). This was the basis for the AU-Pnut advisory developed to schedule initial and subsequent fungicide applications for control of early and late leaf spots. The AU-Pnut advisory uses number of days with precipitation greater than 2.5 mm and the National Weather Service precipitation probabilities to predict periods favorable for development of early and late leaf spots (Jacobi et al., 1995). The AU-Pnut advisory can be used to reduce the number of leaf spot fungicide applications and achieve disease control and yield similar to that with 14-day spray schedule. AU-Pnut advisory II, a modified version of this advisory for partially resistant groundnut cultivars, saved 0.5 and 2.5 sprays per season compared with 21-day and 14-day schedules (Jacobi and Backman 1995). At ICRISAT, India, Buttler et al. (2000) using information from controlled environment experiments on the response of leaf spots to temperature and leaf wetness periods formulated a weather based advisory scheme (WBAS) for control of leaf spots in groundnut. Bailey (1999) developed weather–based advisories using temperature and relative humidity for determining conditions favorable for early leaf spot development in North Carolina, U.S.A. Johnson et al. (1999) used leaf wetness counting for predicting occurrence of late leaf spot in groundnut in Anantapurr region of India. In this study application of fungicidal spray according to a leaf wetness index resulted in highest net returns and cost benefit ratio.

Ghewande and Nandagopal (1997), based on a research review on Integrated Pest Management of groundnut in India, reported that intercrops of groundnut with pearl millet and soybean suppress the population of thrips, jassids and leaf miner; while with castor they suppress jassids and *spodoptera*; and with pigeon pea early leaf spot, late leaf spot and rust. Wider row spacing of 50x30 cm and late maturing and spreading type varieties were found to be effective in reducing Cercospora leaf spot compared to narrow spacing (50x20) and early maturing and erect varieties under Nigerian conditions (Garba et al., 2005). Intercropping of groundnut with sorghum and pearl millet could reduce the incidence of *P. arachidis* (Reddy et al.1991). Padmavathamma et al. (2000) suggested the following management for controlling hairy caterpillars in groundnut: i) Pre monsoon deep ploughing to expose hibernating pupae to sunlight and predators ii) Growing trap crops like cowpea, castor and Jatropha on field bunds to trap and kill caterpillars iii) Form a deep furrow trench around the fields and dust with 2% methyl paratian to prevent mass migration of caterpillars etc.

In Virginia, U.S.A, an algorithm was developed to produce daily advisories for warning groundnut growers of the risk for *Sclerotinia* blight disease onset and need for fungicide application (Phipps 1995).This algorithm uses environmental factors like RH and soil temperature and condition of the host plant like vine growth and density of foliar canopy. Based on the success of this advisory program in providing early warning conditions for disease onset at many locations, this program was released to growers in 1996. In Georgia, USA also an algorithm was developed for predicting outbreaks of *Sclerotinia* Blight and improving the timing of fungicides to control it (Langston et al.2002). In this algorithm also disease risk was calculated by multiplying indices of moisture, soil temperature, vine growth and canopy density each day. These algorithm based sprayings proved efficient than the calendar based sprays, usually practiced.

The above are just examples of what is possible. Where these advisories were successfully used by farmers they are already examples of agrometeorological services. In Nigerian conditions, the significant relationship established between aflatoxin concentration and plant extractable soil water (using CROPGROW model) formed the basis for developing a decision support system to predict aflatoxin concentration in groundnut (Craufurd et al. 2006). Nageswara Rio et al. (2004) have used a similar approach to model the risk of contamination of aflatoxin in Queensland, Australia, using the crop simulation model APSIM and have shown how farmers in Queensland can manage aflatoxin given a Decision Support System (DSS). In Queensland, Rachaputi et al. (2002) identified early harvest and threshing as best management practices for minimizing aflatoxin contamination under high aflatoxin risk conditions. In general, early sowing or early harvest and even supplementary irrigation (if available) are possible ameliorating practices for reducing aflatoxin risk.

IV.2 Improvement measures

Below only some examples are given of management improvement issues but they are not in the form of any farmer oriented advices or decision support systems.

IV.2.1 Sowing time

In Nigeria, when sown with early rains the crop invariably takes advantage of higher solar radiation and warmer temperatures to become well established. According to Kowal and Knabe (1972), the optimum time to begin cropping with little or no drought risk in Nigerian conditions may be defined in terms of latitude (X) and expressed by the equation, $Y=1.43X-1.31$,where Y represents days in decades. In India, sowing of rainfed and irrigated crop early in the season provided favorable weather conditions for proper growth and yield of groundnut. Delay in sowing by one week from 17th July to 24th August resulted in linear decrease in pod yield of groundnut (Murthy and Rao 1986). In normal-sown crop (first week of July), the pattern of flowering is regular with two distinct peaks of flowering, whereas in late sown crop (end of July) erratic pattern of flowering occurs. In southern parts of India, November is the best period for sowing rabi crop raised on residual soil moisture and December to end of January is the period for obtaining higher yields in irrigated summer crop.

IV.2.2 Varietal selection

The choice of a groundnut variety for any particular area depends on matching the variety with the length of the growing season. Groundnut varieties whose growth cycle is longer than the duration of growing season at a particular location either fail to mature or mature at a time soil is too hard to dig the pods. In a majority of the groundnut growing regions, drought stress affects groundnut production. In Indian conditions ICGV 86699, K-134 and TMV-2 were considered as drought tolerant (Reddy and Setty 1995). Ali and Malik (1992) reported that ICGS (E) 52 and ICGS (E) 56 were promising short duration varieties that could escape end of season drought in rainfed areas of Pakistan. Schilling and Misari (1992) reported that short duration and erect varieties like 55-437 released in Niger, Nigeria, Chad, Gambia and Cameroon; and varieties 73-30 and 73-73 released in West Africa and ICGS (E) 30 and ICGS (E) 60 released in Botswana are drought tolerant.

IV.2.3 Plant population

The optimum population of groundnut differs with genotype. The short duration Spanish cultivar, Mc Cullin, showed yield response up to 40,000 plants ha^{-1}. The optimum population for Spanish bunch varieties under rainfed conditions in India is 33,000 plants ha^{-1} (NARP 1992). Crops grown on residual soil moisture should be planted at lower populations than grown during rainy seasons. An analysis of data from across the main groundnut growing areas of Nigeria indicates substantial increases of plant population from the currently advised population of 47.000 plants ha^{-1} for yield benefits (Yayock and Owonubi 1983).

IV.2.4 Scheduling and methods of irrigation

Maintenance of optimum soil moisture at critical growth stages is the key factor for achieving higher yields. Peak flowering and pod formation stages are more critical stages. Imposing drought of 20 days after 15-20 days of sowing (with pre-sowing irrigation) followed by releasing water stress (providing 2 irrigations at five days interval) helps in the development of deeper root system, synchronized flowering, higher biomass production and higher pod yield (Ghosh et al. 2005). Ratio of irrigation water and cumulative pan evaporation (IW/CPE) for groundnut ranges from 0.6 to 1.0. Ramachandrappa et al. (1993) reported that irrigation should be scheduled at 0.5 IW/CPE during 10-40 DAS and later on at 0.75 IW/CPE to realize higher pod yields. In sandy loams to sandy clay loam soils of eastern India, 4 cm of water at 0.9 IW/CPE or 4 cm of water at 7 days interval are suitable levels of irrigation for growing groundnut (Das 2004).

The furrow method of irrigation is the most effective with maximum water use efficiency of 3.71 kg ha^{-1}mm^{-1} and it also saves 2-3 irrigations compared to border strip and check basin methods (Kathmale and Chavan 1996). Use of sprinkler and drip irrigation methods are becoming popular since water requirement in these methods is about half and water use efficiency is high. A yield advantage of 32% over the check basin method was realized with sprinkler irrigation system (Devi-Dayal et al., 1989). Besides saving of 24.7% irrigated water, yield of groundnut under sprinkler irrigation was 18.8% higher than yield (1.67 tonnes ha^{-1}) obtained under surface irrigation (CPRWM 1984). At Konkan region of Maharashtra, India, sprinkler irrigation increased the pod yields by 20.8% and saved 33% irrigation water compared to the check basin method (Kakde et al., 1989). In America, groundnut yields with surface drip irrigation were 1.43 times the non-irrigated yield. The yield gain from surface drip irrigation was 10 kgha^{-1}mm^{-1} (Zhu et al., 2003). At Ludhiana, India, among the different irrigation systems, with 2.82 t/ha a trickle irrigation system exhibited yield increase of 21 and 11 % over conventional and micro-sprinkler irrigation systems, respectively in summer planted bunch groundnut cv SG-84 (Narda et al.2003). Sorren et al. (2004) show results of subsurface drip irrigation in the USA.

IV.2.5 Mulching

In dryland conditions, traditional practices like contour cultivation in a sloping field, soil mulching, inter cultivation and weed control help in soil moisture conservation in groundnuts (Stigter, 1988). In Rajasthan, Uttar Pradesh, Orissa and West Bengal, low soil temperature during Rabi season delays germination and high temperature at pod filling stage interferes with pod development.

Research conducted at National Research Centre for Groundnut, Junagadh, showed that application of chopped wheat straw at 5 tha^{-1} on the soil surface immediately after sowing of groundnut raised soil temperature by 2-3ºC at seedling emergence and lowered soil temperature by 3-5ºC during the pod development phase. Groundnut crop under wheat straw mulch thus maintained good vigor and growth and produced 20-24% higher yield than the control (Ghosh et al., 1997). De et al. (2005) found water hyacinth mulch to be conserving more soil moisture, maintaining low soil temperatures at soil depth and manifesting higher kernel yield in summer groundnut sown under rainfed conditions of West Bengal, India.

IV.2.6 Sowing methods

In high rainfall areas having deep vertisols, broad bed and furrow methods of sowing was found to be more effective than other methods. On average 15% higher yield of groundnut has been recorded when planted in broad bed and furrow when compared to the flat bed method (ICRISAT 1993). Similarly, in summer sown groundnut under rainfed conditions of West Bengal, India, the ridge planting method not only maintained slightly higher soil moisture (8.4%) compared to the flat planting method (7.3%) but also produced higher kernel yield of groundnut (0.57 t ha^{-1}) than flat planting (0.42 t ha^{-1}) (De et al., 2005).

IV.2.7 Shelterbelts

In drylands of northern China, 40 years data on agri-silvicultural practices with trees, shrubs and woody plants (as wind breaks) inter-planted with groundnut crop showed that yield of groundnut was increased by 5.8 to 12.8 % due to the wind breaks or shelter belts (Qi and Tishoon 2004). In Australia, a similar study suggested that incorporation of wind breaks in groundnut farming systems in Atherton table lands of Australia increased groundnut yield by an average of about 12% compared to the control (www.rirdc.gov.au/pub/short paper/sr 67).

V. User requirements for agrometeorological information on the crop

Up-to-date services of accurate weather data can be an important decision-making aid for all segments of groundnut industry.. In groundnut growing areas of America, before planting crops in the spring, growers routinely check soil temperature and weather forecasts to determine when conditions are favorable for seed germination and emergence of the crop. Groundnut seed should be planted in soils that reach 18ºC or warmer at 5 to 10 cm depth each day and when forecasts indicate that these conditions are likely to continue over the next 3 to 5 days.

Growers are also interested in reports of accumulated heat units and rainfall. These data are widely used to gauge the progress of crop development and forecast the maturity date and yield potential of groundnut. In Anantapur region of southern India, it was observed from long-term research on groundnut that rainfall of 500 mm is required to sustain a successful groundnut crop. Hence a prediction of seasonal rainfall of 500 mm is useful for groundnut growers in this region. As seasonal rainfall less than 500 mm are related with El Nino years, a prediction for El Nino has potential for application for farm level decisions in this region (Subbiah and Kishore 2005).

Growers want accurate long range weather forecasts with finer spatial and temporal scales for agricultural management applications like selection of varieties, choice of intercropping, increasing or decreasing the area to be planted, soil and water conservation techniques etc. During the course of crop growing season, certain midterm corrections will be required to minimize yield losses. Hence, medium range forecasts before 5 to 7 days will provide critical information for undertaking corrective measures. Accurate short range forecast for weather aberrations like frost, hailstorms etc should be made available to the users. In Virginia a groundnut frost advisory program uses separate algorithms to adopt the 7-day low temperature forecast to each regional site in the groundnut production areas (Phipps et al., 1997). Such types of advisories have to be made available in other regions having frost risk.

In Gambia, farmers store groundnuts in heaps in open air for 3 months till the government agent turns up. All this time groundnut harvest is vulnerable to rain. Short-range rainfall forecasts would facilitate the protection of stored groundnuts by warning the farmers against impending rain (Kuisma 1995). The value of one single good forecast for impending rain (even if only 10% of the harvest is saved) would be $600.000. The weather-based advisories for making disease management decisions and weather monitoring networks available in USA have to be extended to other groundnut growing areas of the world.

In the semiarid areas, soil water balance affects almost all stages of groundnut crop production. Decision support systems based on real-time weather conditions, identifying moisture stress due to early or midseason dry spells and adaptation options suited to the circumstances need to be developed in semi-arid and arid regions. Developments in information technology have to be used in groundnut growing areas for quick and cost effective dissemination of weather based agro advisories to the growers. Chapter 1 and Stigter (2006) deal with the initial and boundary conditions for such developments. Chapter 17 deals with details of communication of agroclimatological information.

Fraisse et al. (2004) explored the use of crop growth simulation models in combination with climate forecasts to decide insurance coverage levels for groundnut producers in 3 southeastern US counties viz., Henry in Alabama, Jackson in Florida and Mitchell in Georgia states. The World Bank drought index insurance seems to have been accepted by groundnut farmers, lenders and the insurers as the best way for management of drought risk in Malawi www.microinsurancecentre.org) In Andhra Pradesh, India rainfall insurance for payment of insurance money to groundnut (rainfed) farmers was implemented by ICICI (Lombard) Bank. This is implemented through rainfall index. Based on the commencement of rainy season and period of sowing, weights were used for constructing groundnut index. Farmers receive payment if the level of index falls below predetermined threshold.. Despite some problems, groundnut farmers are opting for the rainfall based insurance scheme.

VI. Agrometeorological services related to this crop.

Operational decision support systems increase profit for groundnut growers. Groundnut yield, quality, and net farm income depend on optimum and timely management. United States Department of Agriculture – Agricultural Research Service scientists at the National Peanut Research Laboratory (NPRL) in Dawson, Georgia, developed and released, through a Cooperative Research and

Development Agreement with the Peanut Foundation, an integrated decision support system (Farm Suite Version 2.0). This includes computer software for managing irrigated groundnut production (Irrigator Pro), harvesting (Harv Pro), capital investment service (CIS), sprinkler operation and ownership costs, and curing (PECMAN). Over 100 copies of the software have been distributed as shareware to growers, extension agents, and crop consultants throughout the groundnut growing regions of the United States. Producers from New Mexico to Virginia using Farm Suite have optimized irrigation, pesticide applications, and other production factors. Use of this decision aid tool not only increased groundnut yields by about 300 lb/acre but also improved grade, decreased aflatoxin contamination, and increased profits ($300 per ac) when compared to the average groundnut grower.

The website of the southeast climate consortium (www.agclimate.org) provides decision support tools like groundnut outlook, yield risk analysis, management options and crop insurance for groundnut growing states of southeast USA. The mesoscale atmospheric simulation system (MASS) was used to predict hourly weather information 48 hours in advance for one square kilometer pixels at the geographic center of two counties, Bertie and Gates of North Carolina (http//cipm.ncsu.edu/cipm projects).

Water balance/stress index models are applied rather routinely in west African countries for agrometeorological and food security assignment and groundnut is also one of the target crops. The creation of a regional Agrhymet center on agrometeorological services in the Sahelian countries gave solutions to some problems. This includes continuing earlier pilot projects for assistance to rural population in Mali where farmers receive and apply advice coming from a multidisciplinary group (GTPA) along the rainy season (e.g. Stigter, 2006).

In Sudan, Ibrahim et al. (2002) did on-farm quantitative work on water waste in the Gezira irrigation scheme as an agrometeorological service to tenants and administrators to assist in the development of better local water use efficiency policies. They compared less labor intensive groundnut irrigation methods, adopted because of the necessity to work with sharecroppers that also had off farm employments, to traditional modes of more labor intensive irrigation that were abandoned in the course of time. They found that there was water waste in both methods of irrigation but much more in the unattended fields and in the drier year of the two investigated growing seasons. In that year the water waste was 50% of the minimum water requirements determined. This did not yet include the readily available water still retained in the soil profile at the end of each growing season. Contrary to sorghum, the groundnuts also suffered from excess water.

For China, Stigter et al. (2006) report that traditional farmers have recently used contour native grass belts for erosion reduction, in rotation with tilling the land for growing groundnuts for income and sweet potatoes for animals. Farmers appear to have obtained the innovative knowledge from a disaster in which erosion caused by very heavy rain seriously damaged corn-based cropping systems on hilly sandy soil, while narrow plots of groundnut between native grasses escaped the disaster. Such contour belts of 2m wide are here short distance (1 – 1.5m) and the grasses are cut to feed working cattle. Local applied research would be able to improve these farmer developed systems, leading to agrometeorological services through design rules.

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