Agroclimatological Factors Affecting Phenology of Groundnut

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Abstract

The quantitative response of groundnut to a wide range of temperature, humidity, and soil-water deficits is discussed in relation to the climate of the semi-arid tropics (SAT). Information obtained from controlled-environment facilities is used to provide a model applicable to the SAT. The consequence of irrigation and rainfall distribution on crop phenology and the general relation between phenology and yield are also discussed.

The limited information on daylength responses suggests that genotypic variation is an important factor and this is an urgent area for research. Humidity or saturation deficit does not have a direct effect on crop phenology and would probably influence phenology via the water-depletion rate in the soil. Delays in the start of the rainy season reduce the length of the growing period which may result in lower yields. Agroclimatological factors which affect crop phenology may also have a major influence on growth processes, e.g., in partitioning of dry matter to pods by temperature. Therefore, studies of phenology and growth processes should be integrated in crop-weather investigations.

Résumé

Facteurs agrométéorologiques affectant la phénologie de l'arachide : *La réponse de l'arachide à de grandes plages de température, d'humidité et de déficit en eau des sols est discutée en liaison avec le climat des régions tropicales semi-arides. Des informations obtenues dans des installations à environnement contrôlé sont utilisées pour réaliser un modèle applicable à ces régions. Les conséquences de l'irrigation et de la distribution des pluies sur la phénologie et la relation générale entre la phénologie et le rendement sont aussi discutées.*

Le peu d'information disponible sur la réponse à la longueur du jour indique que les variations génotypiques sont un facteur important qui devrait faire l'objet de recherches plus poussées. Le déficit hydrique n'a pas d'effet direct sur la phénologie de la culture et n'aurait probablement d'effet sur la phénologie que par le taux de diminution de l'eau dans le sol. Un retard de la saison des pluies réduit la période de croissance et risque de causer une perte de rendement. Les facteurs agroclimatiques qui affectent la phénologie de la culture peuvent avoir une grande influence sur le processus de croissance, soit la répartition de la matière sèche aux gousses par la température. Aussi, les études sur la phénologie et les processus de croissance devraient être intégrées aux recherches sur les relations culture-temps.

Introduction

Phenology is defined by the Chambers Dictionary (1981) as the study of organisms as affected by climate. Lieth (1974) restricted his definition of phenology to the study of developmental timing in relation to the calendar, while Huxley (1983) relegated it to a descriptive study of organisms in relation to

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their environment. The first definition is obviously too general, while the second definition is the one generally accepted by crop scientists, and I assume it to be the one meant by the organizers.

Knowledge of crop phenology is important for at least three reasons:

- First, for optimal crop yield in an environment it is necessary to match the life cycle of the crop to the length of the growing season. Such information is needed to develop better cropping systems so that high and/or stable productivity can be achieved.
- Second, the introduction of improved genotypes or new crops into new regions is largely determined by temperature and phenology (Aitken 1974).
- Finally, phenology is an essential component of whole-crop simulation models, which can be used to specify the most appropriate rate and time of specific developmental processes to maximize yield.

The first part of this review describes the responses of groundnut to temperature, daylength, humidity, and rainfall, and defines, where possible, relevant concepts and principles and their applications. Later sections will deal with the integration of phenological and physiological information, and finally highlight areas where information is needed.

Generalization

Both annual and perennial species of *Arachis* occur, but the perennial or indeterminate growth habit is most common in groundnut (*Arachis hypogaea* L.). Harvesting groundnut crops is rarely determined by physiological maturity. The standard harvesting procedure is dependent on the degree of defoliation of the crop or on the shelling percentage, i.e., the percentage of pods that have mature kernels. Drought affects the shelling percentage (Williams et al., this symposium) and weather conditions may indirectly affect the degree of defoliation through foliar disease (Smith, this symposium). In the absence of drought or disease problems the heat unit or accumulated temperature index is the most useful for predicting optimum harvest time (Mills 1964), as well as for analyzing other developmental processes such as the start of flowering and podding (Leong and Ong 1983). Various methods for determining the harvesting of groundnut crops have been reviewed by Sanders et al. (1982).

Phenological studies have been more concerned with the timing of developmental processes, i.e., the start, the duration, and the end rather than with the rate of development. The rate of developmental processes such as leaf production is usually expressed as numbers per day, whereas events which occur once in a life cycle, e.g., seedling emergence, are generally expressed as the duration (D), for example, for 50% of the population to reach that stage. The reciprocal of D is effectively a rate and this is a useful way to describe plant responses to temperature, for example, as a function of rate because the threshold or base (Tb), optimum (To), and maximum (Tm) temperature can be determined (Fig. 1).

Temperature

Temperature is the dominant factor controlling the rate at which groundnut develops (Fortanier 1957, De Beer 1963, Cox 1979). In terms of plant growth and development, the diurnal temperature cycle is more important than either the regular seasonal cycle or the random effects of weather in the SAT (Monteith 1977). Even more important for plant processes are the effects of microclimate since soil-surface temperature commonly exceeds 40°C in

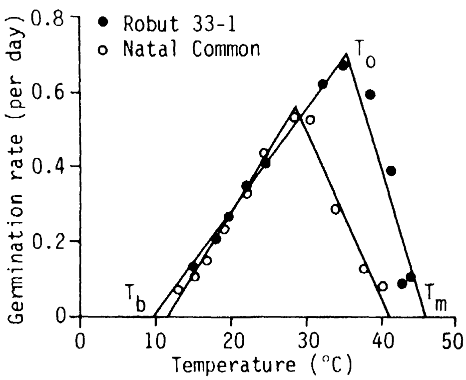

Figure 1. Germination rates for groundnut cultivar Robut 33-1 and Natal Common at various temperatures (°C). Base (Tb), optimum (To), and maximum (Tm) temperatures are indicated for Robut 33-1. (Source: Mohamed 1984.)

many parts of the tropics, especially when the soil surface is dry (Virmani and Singh, this symposium). The extremes of temperature over a period of days or hours may severely reduce the growth and development of many crops. For example, Garcia-Huidobro et al. (1985) found that exposure of imbibed pearl millet seeds to 50°C for 1 h reduced the germination rate and the percentage germination by 14%. However, similar information is not available for groundnut.

Thermal Time or Accumulated-Temperature Concept

The concept of thermal time is widely used for describing the temperature responses of many crops including groundnut (Gallagher 1979 for wheat, Angus et al. 1981 for many tropical species, and Yo[illegible]g et al. 1979 for groundnut). But there is still un[illegible]ainty concerning the choice of base temperature. Some workers (Weilgolaski 1974, and Angus et al. 1981) support the view that Tb is highest during the reproductive phase (3-10°C higher) than during the vegetative phase, and others suggest that Tb is highly variable even for the same phase. In contrast, Ong and his coworkers (Ong 1983a, 1983b, Leong and Ong 1983, Ong and Baker In press) obtained results that showed that Tb is conservative for the many processes and phases examined (see Table 2 for groundnut cv Robut 33-1). Reasons for the apparent variation in extrapolated value of Tb are discussed by Ong and Baker (1985). Values of Tb and the thermal time (*θ*) in °C d for each process in Table 2 are calculated from results at five temperatures between mean temperatures of 19 and 30°C. *θ* is the reciprocal of the slope of the rate/temperature relationship. Tb ranged from 9.5-11.4°C, which is close to the value of 10°C used by McCloud et al. (1980) for the PNUTS model. These results suggest that the value of Tb of one process, e.g., germination, could be used to calculate thermal time for other developmental processes for each genotype.

Table 1. Base (Tb), optimum (To), and maximum (Tm) temperatures of 14 groundnut cultivars

	Temperatures (°C)		
Cultivars	Tb	To	Tm
Valencia R2	8	35	43
Flamingo	8	34.5	42
Makulu Red	8.5	29	42
I[illegible]30	8	36	44
EGRET	9	29	43
ICG 47	9	36.5	47
Robut 33-1	10	36.5	46
TMV2	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 2. Values of base temperatures (Tb) and thermal time (O) in °Cd of several developmental processes of groundnut cv Robut 33-1. Results from 5-10 treatments.

Developmental process	Tb (°C)	O (°Cd)
Leaf production	10.0	56 per leaf
Branching	9.5	103 per branch
Time to first flowering	10.8	538
Time to first pegging	10.6	670
Time to first podding	11.4	720

Source. Leong and Ong 1983.

Figure 1 illustrates the rate/temperature relationship for the germination of two contrasting groundnut cultivars (Mohamed 1984). The germination data were obtained at constant temperatures using a large thermal gradient plate in steps of 2-3°C. Genotypic differences in the rate of germination are greatest above To, but a 6-7°C variation in cardinal temperatures was also found. For example, results for 14 contrasting genotypes showed that Tb ranged from 8-11.5°C, To from 29.0-36.5°C, and Tm from 41-47°C (Table 1, Mohamed 1984).

Temperatures close to Tb and Tm produce a low rate of germination (Rg), but their influence on the proportion of seeds which finally germinated (Gm) is genotypically dependent (Fig. 2). For example, Gm of cv Makulu Red, a highland variety, is much more sensitive to a reduction in Rg caused by high (>28.5°C) rather than by low temperatures. This genotype is therefore poorly adapted to high temperatures compared to cv Plover, a Brazilian genotype, that is not greatly affected until the temperature reaches 40.5°C. The selection for a heat-tolerant groundnut cultivar is therefore possible in many tropical regions where soil temperatures regularly exceed 40°C.

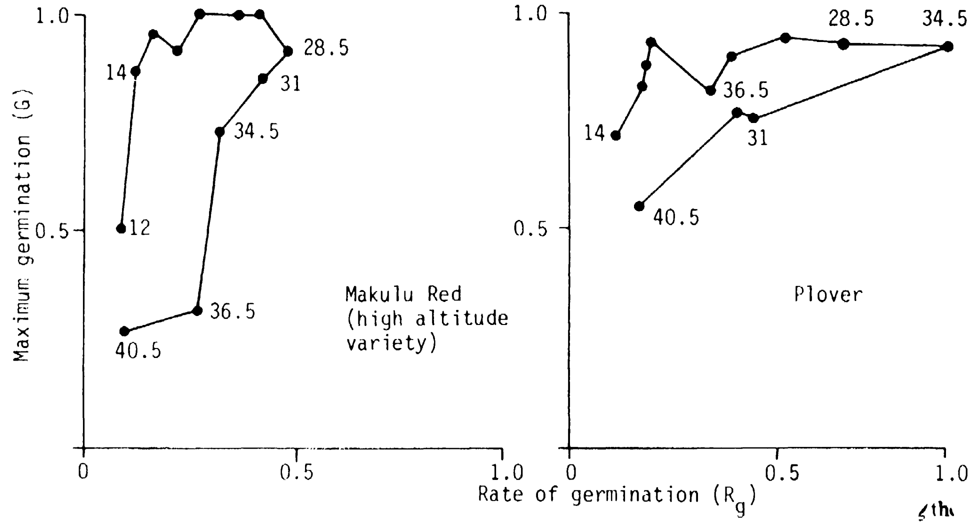

Figure 2. Relationship of maximum germination and rate of germination to temperature (°C) of groundnut cultivars Makulu Red and Plover. (Source: Mohamed 1984.)

Flowering and Growth

Work in growth cabinets (Fortanier 1957) shows that the flowering and growth responses of groundnut cv Schwarz 21 to temperature are remarkably similar to that described for germination (Fig. 3). The optimum temperature for both processes lies between 32-34°C, which is consistent with the values reported for germination and branching (Mills 1964, De Beer 1963). The flowering of groundnut does not indicate any thermoperiodicity and most species are day-neutral (Fortanier 1957).

There is little information on the effects of temperature on the phenology of groundnut in the tropics. Williams et al. (1975) reported that the growth of cv Makulu Red varied at mean air temperatures of 18, 20, and 23°C. Crops were harvested when 95% of their leaves were lost by natural defoliation or until 70% of the pods had matured. The total growing durations for these crops were 176 d at 18°C, 176 d at 20°C, and 151 d at 23°C. Growth-analysis results showed that only the 23°C crop reached physiological maturity, i.e., total pod dry weight reached constant value and estimates of thermal time (maturity index of 2000°C d and Tb of 8.5°C) indicated that the two other crops were harvested at least 68 and 15 d earlier than the 23°C crop. It is possible that the low temperature or disease build-up may have caused the substantial foliage loss in these crops.

At ICRISAT Center (17°N) the mean air temperatures during the rainy and postrainy seasons are very different. During the rainy season (Jun-Sep) the mean air temperature is 29°C for the first 6 weeks

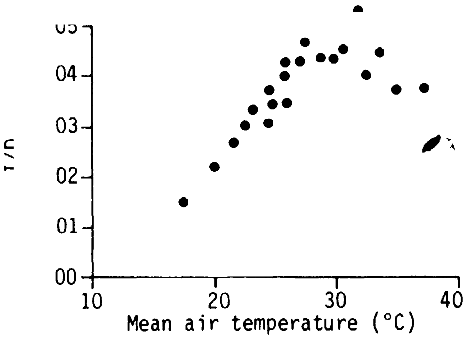

Figure 3. Rate of flowering (1/D) of groundnut cultivar Schwarz 21 as a function of mean air temperature (°C). Recalculated from Fortainier (1957). D is days for 50% of the population to produce the first flower.

and declines to 26°C for the remainder of the growing period. In contrast, the mean air temperature during the early postrainy season (Nov-Dec) is about 21°C and increases steadily to 29°C in April (ICRISAT 1984 pp. 183-185). Since plant development is predominantly controlled by temperature there are conspicuous differences in the time to flowering, podding, and the total duration of crop growth in the two seasons (Table 3). These results were based on actual observations of cv Robut 33-1, and are consistent with calculations based on thermal time (maturity index of 2000°C d and T of 10°C).

Daylength

Early studies in growth rooms showed that the phenology of groundnut is not affected by daylength (F[illegible]nier 1975). However, recent research has indicated that pod yield is greatly influenced by daylength (Wynne and Emery 1974, Ketring 1979) and genotypic variation in yield responses to short and long days has been reported by Witzenberger et al. (In press). The last group of workers reported yield increases of 36-106% under short days (11-12 h) in four cultivars but slightly increased yield in long days (15-16 h) in the remaining two cultivars. The differences in yield responses to daylength are mainly due to changes in the number and proportion of large kernels. Clearly, there is an urgent need to identify daylength sensitivity in the existing germplasm to match a specific daylength, especially when exotic cultivars are grown in new regions or when two crops are grown within a year in regions of high latitude.

It is well established that long days promote vegetative growth, e.g., increased stem length and leaf growth at the expense of reproductive growth (Ketellaper 1969), but there is some uncertainty about the influence of daylength on the duration of reproductive growth. In a study of several cultivars Sengupta et al. (1977) found that flowering was delayed by a daylength shorter or longer than 10 h, whereas in contrast, Ketring (1979) did not observe any effect of daylength (8, 12, 16 h) on flower initiation. Both these workers used different cultivars in their experiments and it is possible that genotypic variation in response to daylength may also be important.

Table 3. Crop phenology of cv Robut 33-1 rainy and postrainy seasons, ICRISAT Center.

Growth stage	Rainy season	Postrainy season
Days to first flowering	24-26	40-44
Days to pod filling	52-54	80-83
Duration of pod filling (d)	60-64	60-62
Length of growth (d) or 2000° Cd	110-115	135-140

Source: Diwakar, unpublished.

Humidity or Saturation Deficit

Saturation deficit (SD) is an important agroclimatic factor because it is a major determinant of potential evaporation. In many climates, SD is not an independent variable, but is closely coupled to the rainfall and temperature. Groundnut crops are often irrigated or grown on stored moisture during the postrainy season when SD exceeds 3-4 KPa. It is usually impossible to control SD effectively in the field, so physiological studies of SD have been restricted to controlled environments. However, not much is known about the influence of SD on the phenology of groundnut because attention has been drawn to the conservative way that stomata respond to SD to limit the actual rate of transpiration (Black and Squire 1979).

Saturation deficit may have an early effect on crop establishment by its direct influence on the evaporation of seed-bed moisture. For example, work in controlled-environment greenhouses showed that seedling establishment of groundnut declined by 20% when the maximum SD increased from 1.5 to 2.5 KPa (Ong et al. In press). Once the plants are fully established the influence of SD is dependent on the rate of water uptake by the roots, the foliage area, and the soil-moisture content (Simmonds and Ong. In press). The interaction between SD and the water-storage capacity of the soil will obviously be a major factor in determining whether crop phenology is affected. In addition, the early phenological stages and processes during early growth are less likely to be affected than the late processes such as pod filling. For instance, the start of flowering of cv Robut 33-1 is unaffected by mean SD ranging from 1.0 to 2.5 KPa (Ong et al. In press). The influence of SD on crop growth and phenology will continue to be poorly understood unless more controlled-environment facilities are available to vary the SD and the temperature diurnally in the natural environment.

Rainfall

Rainfall is the most significant climatic factor affecting crop production in the SAT because most crops are rainfed. A low and highly variable rainfall coupled with soils of low water-holding capacity are cited as the major constraints to crop production in these regions (Virmani and Singh, this symposium), but the relationship between groundnut yield and seasonal rainfall is often poor (Popov 1984). Figure 4 illustrates the highly variable yields in Bambey, Senegal, between 1932 and 1964, and shows fourfold changes at a seasonal rainfall of 800 mm. Similarly, groundnut yields at ICRISAT Center are poorly correlated with total rainfall and there is considerable variation in the harvest index (Table 4). It is not clear whether such yield fluctuations are due to the distribution of rainfall, waterlogging, or the magnitude of the disease damage.

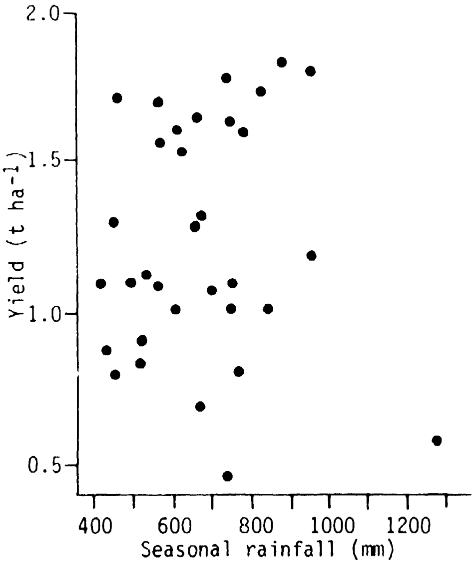

Figure 4. Comparison of groundnut yields (t ha^{-1}) and seasonal rainfall for 32 years (1932-1964), Bambey, Senegal. (Source: Popov 1984.)

Table 4. Comparison of pod yield (t ha^{-1}) and harvest index of groundnut cv Robut 33-1, ICRISAT Center, rainy seasons 1978-1983.

Year	Seasonal rainfall (mm)	Pod yield (t ha^{-1})	Harvest index
1978	1077	1.19	0.21
1979	631	3.00	0.37
1980	733	1.76	0.54
1981	1072	4.41	0.46
1982	656	1.62	0.60
1983	1022	2.44	0.43

M. S. Reddy, unpublished data

The importance of rainfall distribution to groundnut yield is well appreciated, but experimental evidence is poorly documented. In Oklahoma, Murdock et al. (1961) reported a yield of 2.7 t ha^{-1} with supplementary irrigation of 75 mm on 21 July, but only 1.8 t ha^{-1} when the same irrigation was applied on 31 July. Few drought studies have attempted to distinguish the effect of the amount, frequency, and the distribution of rainfall on groundnut yield. Work in controlled-environment greenhouses at Nottingham University, UK, showed yield which was four times greater than the yield of crops which used the same amount of water, but was irrigated during the vegetative phase only (ODA 1984).

A severe water deficit can delay the onset of flowering and rapid pod growth (Billaz and Ochs 1961, Billaz 1962). Yield is often reduced by drought even when plant stress is relieved by irrigation because pod maturation is delayed, and it is not always possible to delay harvesting. Boote and Hammond (1981) reported a delay of 11 d in flowering when drought was imposed between 40-80 days after sowing (DAS). Stansell and Pallas (1979) found that the percentage of mature kernels of the same cultivar was reduced to only 34% of the control when drought was imposed 36-105 DAS. Detailed information on the irrigation, water use, and water relations of groundnut is reviewed by Boote et al. (1982).

Integration of Phenology and Growth

Agroclimatic factors that influence crop phenology may also have a major effect on crop-growth rate and the partitioning of dry matter. It is useful therefore to integrate phenological and growth responses. For example, temperature affected the dry-matter production of pearl millet by governing the rate of formation and the duration of canopy rather than the efficiency of solar energy conversion (Squire et al. 1984). A similar analysis of the information on groundnut shows that the duration from sowing to the end of pod filling (defined as 2000° C d) increased from 95 d at 31°C to 222 d at 19°C (Fig. 5). Unpublished data (B. Marshall, Nottingham University, personal communication) shows that rapid canopy formation starts at 300°C d and reaches canopy closure at 800°C d at a leaf area index (LAI) of 3. Assuming a maximum growth rate of $20\ g\ m^{-2}\ d^{-1}$ (Duncan et al. 1978) at all temperatures for the remainder of the growing period, the total dry-matter production is $12.8\ t\ ha^{-1}$ at 31°C and $32.2\ t\ ha^{-1}$ at 22°C (Fig. 5). However, field observation shows that the crop-growth rate is lowered by temperatures below 23°C (Williams et al. 1975, for Makulu Red) and the total dry matter is reduced by 60% at 18°C and 40% at 20°C (Fig. 5). The effect of high temperature (>31°C) on crop-growth rate is unknown although the apparent photosynthesis of individual leaves is reduced by 25% when temperature increases from 30 to 40°C (Bhagsari 1974).

Temperature also has a profound effect on the partitioning of dry matter to pods in groundnut (Cox 1979, Ong 1984). Pod-growth rate of Florigiant groundnut is reduced by 45% when the temperature is increased from 24°C to 32°C and the final kernel weight is reduced by 30% (Cox 1979). The optimum temperature for pod yield is therefore considerably lower than that for the rate of developmental processes. Robut 33-1 has an optimum temperature for pod growth of 24°C (Ong 1984) while Makulu Red has T_o of 20°C (Williams et al. 1975). There are several other reasons why higher temperatures are detrimental to reproductive growth: pollen death is reported to occur at 33°C (De Beer 1963); fewer pegs and pods are produced; greater stem growth may compete directly with reproductive organs for assimilates (Fortanier 1957); and tall stems may prevent pegs from reaching the ground (Williams et al. 1975, Leong and Ong 1983).

High soil temperature (>30°C) may also be an important limitation to groundnut pod yield in much of the SAT because local heating of the pod zone resulted in major reduction in pod yield when temperature exceeded 24°C (Dreyer et al 1981).

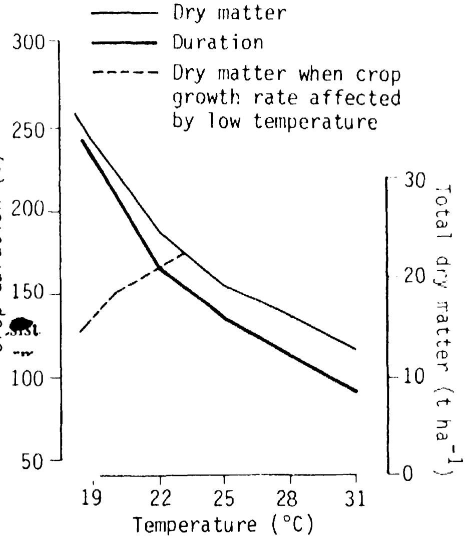

Figure 5. Temperature effects on the duration from sowing to end of pod filling and the final dry matter produced. The duration is calculated using a maturity index of 2000°C d and Tb of 10°C.

Daylength and Saturation Deficit

There is a dearth of information on the effects of these factors on the phenological and growth responses of groundnut. As previously pointed out, the importance of daylength on phenology and yield is probably dependent on variety. Workers at ICRISAT Center are investigating this aspect.

Saturation deficit will have a major effect on the water-use rate and the growth of groundnut grown on stored moisture. The water-use efficiency (WUE), defined as the amount of dry matter produced per unit of water transpired, is inversely proportional to SD (Simmonds and Ong In press) but much less is known about the way in which dry-matter production is related to SD. Work in controlled-environment greenhouses shows that large SD (>2.5 KPa) accelerates the depletion of soil-moisture reserves and greatly reduces LAI by lowering the turgor potential of the expanding leaves (Ong et al. In press).

Because expanding leaves are more sensitive to moisture deficit than pods, the partitioning of dry matter is likely to be affected by SD. For instance, comparison of the rates of peg production and leaf expansion at four levels of SD shows that pegs are

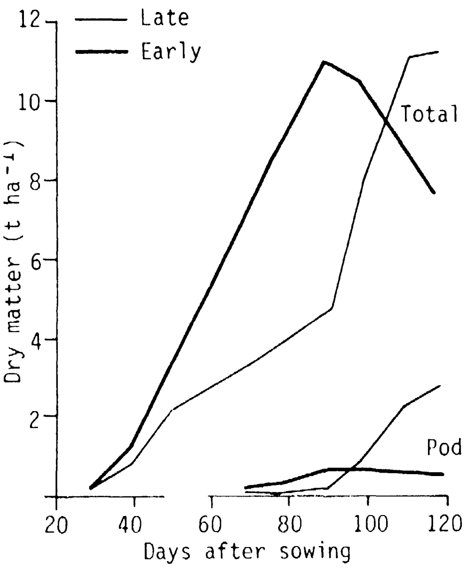

Figure 6. Comparison of the dry-matter production (t ha^{-1}) of groundnut cultivar Robut 33-1 with early and late irrigation. Both crops received the same amount of irrigation. (Source: ODA 1984.)

relatively unaffected by drought stress until predawn water potential reaches -0.8 MPa (Fig. 6).

These observations are consistent with the finding that when the major sinks are sensitive to water deficits, dry matter is preferentially distributed to other parts of the plant (Wardlaw 1969).

Rainfall

In contrast to the poor correlation between the amount of rainfall and groundnut yield (Fig. 4, Table 4), field studies show that yield is proportional to the amount of water applied when rainfall is low (Boote et al. 1982, for review on irrigation effects). The postrainy season at ICRISAT Center provides an ideal rain-free environment to study the interaction between phenology and drought. Results from a series of experiments there (ICRISAT 1984) show that:

- early stress (29-57 DAS) does not influence pod yield greatly,
- pod yields are increased by 15 g m^{-2} cm^{-1} of water applied 93-113 DAS, i.e., seed-filling phase, and
- cultivars differ widely in their recovery when drought stress is relieved (Williams, this symposium).

The analysis of Kowal and Kassam (1974) illustrates the strong connection between the length of the growing period (as determined by total rainfall), and the yield of a 120-d groundnut crop in northern Nigeria (Table 5). The delay in the start of the rainy season with increasing latitudes reduces the length of the growing period, which results in lower yields when the growing period is less than 90 d. This analysis highlights the importance of the interaction between phenology and the rainfall pattern.

The importance of variation in rainfall distribution on groundnut yield is not well understood because research has concentrated on withholding water at different times of the growing season (Pallas et al. 1979, Stansell et al. 1979). Unfortunately, in many of these experiments the amount of water applied changed with the treatment so that the effects due to the timing and amount of water applied could not be separated. Detailed analysis of the experiments conducted at Nottingham University (ODA 1984) shows that the dry matter accumulated before pod filling is not available for retranslocation to pods and the partitioning of subsequent assimilates is unaffected by the treatments. The crops which received early or late irrigation used the same amount of water and produced the same amount of dry matter, but loss of leaves was observed in the late-irrigation treatment only (Fig. 7). This experiment demonstrates the substantial effect of rainfall distribution on groundnut yield and provides one

Table 5. The effect of variation in the length of growing period and rainy season on groundnut yields with latitude in northern Nigeria.

Length of rainy season (d)	Length of growing period (d)	Latitude (°N)	Yield reduction (%)
115	120	11.2	0
110	120	11.2	0
100	120	11.2	0
90	110	11.3	0
80	100	11.5	8
70	90	11.8	28
60	80	12.0	40
50	70	12.3	56

Source: Kowal and Kassam 1974.

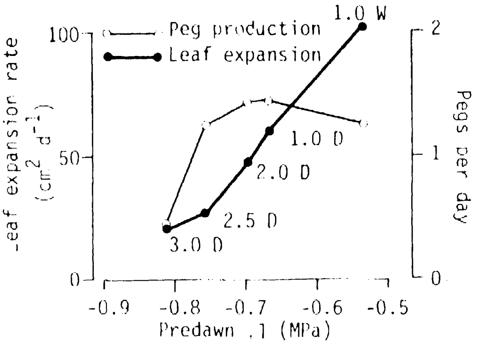

Figure 7. Relationship between predawn leaf-water potential (MPa) and rates of leaf expansion (cm^2 d^{-1}) and peg production. Treatments are identified by the maximum saturation deficit (KPa) and the soil regime: W for wet and D for stored moisture.

explanation for the large variation in the harvest index observed from year to year (Table 4).

Further work is needed to determine whether the observed pattern is typical of the responses to the variation in rainfall distribution. There is a possibility that cultivars that have the ability to retranslocate much of the stored dry matter to pods would be less sensitive to variation in rainfall distribution.

Conclusions and Research Needs

Although temperature is regarded as the dominant factor affecting the phenology of groundnut, there is no information on whether high temperature (>40° C) for only a few hours in the day has a major effect on crop development. It is evident that high soil temperatures can reduce seedling establishment and limit reproductive yield in many areas of the tropics. Laboratory studies show that sources of resistance to high or low temperatures exist in the germplasm (Mohamed 1984), and these cultivars should be utilized to ensure better yield stability. It is vital that agroclimatologists collect information on soil temperatures throughout the groundnut-growing areas to predict the phenology of groundnut. Differences in microclimate may explain the reported differences in the yield of sole and intercropped groundnuts (with a tall cereal such as sorghum) during the dry season. Unpublished data show that shading by the sorghum leaves reduces the temperature of the groundnut leaves by 5-10°C during the day.

Recent studies at ICRISAT Center have demonstrated the importance of genotypic differences in the sensitivity of groundnut yields to daylength. The effect of daylength on the duration of the reproductive phase is still uncertain and further work is needed to assess the extent of genetic variability.

Saturation deficit is likely to affect the duration of late developmental stages. SD interaction with soil-water content should be examined further. Such studies must be carried out in controlled-environment greenhouses so that the SD and the temperature can be varied diurnally as they do in the natural environment.

The influence of rainfall on groundnut yields is complex because of its major effect on the partitioning of dry matter, changes in pod maturation, and the incidence of foliar diseases that may lower crop growth rate.

Finally, progress in understanding crop-weather relationships necessitates a closer integration of crop phenology and growth responses. For example, the survival or final number of grains produced in maize and millet is dependent on the growth rate of the whole plant as well as on temperature (Hawkins and Cooper 1981, Ong and Squire 1984). The concept of a thermal growth rate has proved useful to understand how yield components are determined in cereals, and it should be evaluated for groundnut.

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