Agrometeorology of Groundnut

Proceedings of the International Symposium
held at ICRISAT Sahelian Center, Niamey, Niger

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Cover: *Automatic weatherstation at ICRISAT Sahelian Center, Niamey, Niger (top) and general view of a drought-stress experiment employing the line-source sprinkler irrigation technique (bottom) at ICRISAT Center, India.*

Agrometeorology of Groundnut

Proceedings of an International Symposium

ICRISAT Sahelian Center
Niamey, Niger
21-26 August 1985

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Foreword

Groundnut is an important crop that can supply oil and protein to the peoples of Africa and give additional cash income to bolster the meager personal incomes of farmers. In the recent past groundnut was a crop of preeminence in the semi-arid tropics of Africa. Repetitive drought and diseases have reduced the farmers' ability to produce reliable and profitable yields; aflatoxin and other quality factors have made Africa's crop less attractive on the World market.

A resurgence of groundnut production is needed and this was clearly the basis for the International Symposium on Agrometeorology of Groundnut. Because weather-related factors were involved in the reduction of the groundnut crop, it is vital that research renew the crop's vigor based on a clear understanding of climatological settings where success may be achieved. Our knowledge has attained a level that will permit us to develop methods and models of groundnut that have strong predictive value.

It is now our task to use all of our knowledge of climate, water relationships, and soils in concert with other necessary research disciplines to discover new ways for successful groundnut culture. This symposium, involving as it did many disciplines, was an important event for Africa.

I hope these proceedings will be of help to both researchers and agricultural planners throughout the semi-arid tropics.

C.R. Jackson
Director, ICRISAT Sahelian Center
and West Africa Programs

Opening Session

Chairman: B. Coly **Rapporteur: M.C. Klaij**
Co-chairman: M. Boulama

Welcoming Addresses

L.D. Swindale

International Crops Research Institute for the Semi-Arid Tropics

I extend to you my welcome to this International Symposium on the Agrometeorology of Groundnut on behalf of ICRISAT and all the technical sponsors who have organized this meeting and brought this enlightened group together. The government of Niger will itself extend an official welcome at the conclusion of my address.

I wish to congratulate the sponsors on what has obviously been a well-organized and a well-arranged meeting. The response from the participants is very encouraging. I would also like to thank the local organizers, local ICRISAT, INRAN, and AGRHYMET staff for the arrangements that they have made to ensure the success of this conference.

This is a very important occasion for ICRISAT because it is the first time that we have been significantly involved in developing an international scientific conference here in Niger. Previously we have had internal ICRISAT meetings to which some people from outside ICRISAT have been invited, and we have also been responsible for helping to organize regional meetings here in the Sahelian region.

But this is the first time we have had the responsibility to help assemble people from all parts of the world to discuss an interesting subject that is relevant to all parts of the world and particularly to the Sahelian region. This is the first time, but certainly not the last, because when the ICRISAT Sahelian Center is fully developed, I expect that we will be able to have international meetings of this caliber, probably once a year. And I hope, Mr. Minister, that you will find it an interesting prospect that Niamey will become the Mecca for international scientific meetings concentrating particularly on agricultural problems of the Sahelian region.

As you well know, groundnut is a very important crop and I will not enlarge upon it's importance as it will be discussed by many of you over the next few days. It is one of ICRISAT's mandate crops. It is an important crop to the countries of the developing world, where more than about 80% of the crop is grown.

India and China are very large consumers of this crop. India is the largest producer of groundnut and they cannot satisfy their own demand. So the possibilities of South-to-South trade are very real for this crop. I think that this is an important consideration. In West African Sahelian countries, groundnuts have been a major agricultural export in the past. It is a great shame that the groundnut production has declined so significantly in recent years and that this source of foreign exchange is no longer available. In this country, about 200000 tonnes of exported groundnuts in 1967 has dropped to about 2000 tonnes in 1984. We would like to see that in the future this is changed and once again countries of the Sahelian region become major exporters of this very important income-earning crop. It is important not only for the countries' foreign exchange, but also important as a source of cash for farmers, to help them buy the products that they need. In order to solve the many problems that exist with this crop, a very serious multidisciplinary effort is going to be needed. You will need to integrate the knowledge of many different types of specialists into well-constructed research programs that focus on the major problems of this crop, and bring about production changes so that the farmers and ultimately all the people of these countries can benefit.

The organizing committee of this symposium, conscious of the importance of groundnut in the future of these countries, has decided to hold this meeting here, and the government of Niger has graciously supported our request. To decide on the future research focus is an urgent task, and I request all of you to work hard during the next few days of this symposium and on the final day to come forward with some very serious possibilities for research activities and programs. ICRISAT intends to be a significant contributor to these research efforts. We have a substantial program on groundnut research at ICRISAT Center in Hyderabad, India. The leader of that program, Mr. Gibbons, is here today along with some of his colleagues from the program to make sure that we contribute to this work.

In addition, we are constructing, with the permission and active support of the Government of Niger, a research center at Sador6 near Niamey. And I hope that most of you will have an opportunity while you are here to visit our Sahelian Center. The farm is fairly well developed this year. The experimental fields are doing well, and I am sure that we will have excellent results from our research this year. I hope that you will be able to see this work and understand how we are working in this region. At the moment we are not doing much with groundnut. But I can assure you that we will. We have received the authority to appoint three internationally-recruited scientists to the groundnut program at the ICRISAT Sahelian Center. For two of the posts, we have not only the authorization but also the funds and we are in the process of recruiting for these two posts. For the third one, we have only authorization, not the funds. We will have to see what our donors will contribute in 1986 to enable us to fill this post as well. We expect to have a groundnut breeder, pathologist, and an agronomist at the heart of this team working together with the millet team and the resource management team which we already have at the Sahelian Center. Two weeks from today we will have a meeting of all the donors, also here in Niamey, and we will talk to them about the results of this symposium and about our other work. We will ask them to come forward with the necessary funding so that we can continue with our work.

I am also very pleased to inform you that a man who is well known to the international fraternity of groundnut scientists, Dr. Curtis Jackson, has been appointed as the Director of the ICRISAT Sahelian Center and of all our West African programs. He will be coming here permanently in November of this year. Dr. Jackson is currently the Director for International Cooperation of ICRISAT itself. He is coming here to take over the responsibility for West African programs because we consider this a very important part of ICRISAT, and he will have my full confidence and support. He will be able to develop the programs here, as part of ICRISAT, but with a great deal of autonomy and self sufficiency so that they will really be able to serve this region and solve the problems of this region. These are things that we are willing to do and are going to do for groundnut in the Sahel in the future. We hope that other organizations present here today will be able to contribute very significantly to the future program and that this country and all the countries of the Sahel and of West Africa will benefit from the research efforts. Thank you.

Ouverture officielle du Symposium

Son Excellence Monsieur Illa Maikassoua, Ministre de l'Enseignement Supérieur et de la Recherche, Gouvernement du Niger

Messieurs les Ministres, Monsieur le Directeur Général de l'ICRISAT, Messieurs les Représentants de l'OMM, de la FAO et de l'USAID, Messieurs les chercheurs, Mesdames et Messieurs,

C'est pour moi un insigne honneur et un agréable devoir de vous souhaiter la bienvenue dans notre pays à l'occasion du Symposium international sur l'agrométéorologie de l'arachide. Nous sommes vraiment très heureux que vous ayez accepté de tenir à Niamey ce Symposium international. La question de l'agrométéorologie de l'arachide présentant pour nous un intérêt vital, nous prêterons la plus grande attention aux délibérations et aux résultats de votre Symposium.

Honorables délégués, Mesdames et Messieurs, l'arachide est une culture très importante en Afrique. Au Niger, avant la sécheresse de 1973, la production d'arachide occupait la troisième place, après le mil et le sorgho. La culture de l'arachide a été encouragée par l'établissement d'une société nationale de commercialisation, la SONARA, de trois usines de décorticage d'une capacité de 82 000 tonnes, et de trois huileries ayant une capacité de transformation de 105 000 tonnes d'arachide décortiquée en huile brute destinée à l'exportation.

La sécheresse de 1973 a changé dramatiquement cette situation. Les superficies cultivées en arachide ont diminué et la production est passée de 260 000 tonnes, en 1972, à 74 000 tonnes en 1978. Le pourcentage d'arachide exportée est passé de 45% en 1972 à 5% en 1975. En 1977, les décortiqueries de Dosso et Tchadoua n'ont fonctionné respectivement qu'à 8,5% et 3,2% de leur capacité.

Cette situation nous amène à considérer, avec une attention toute particulière, les différents facteurs agroclimatiques affectant la production d'arachide dans les pays semi-arides, particulièrement au Niger, et à mettre au point des stratégies visant à stabiliser la production d'arachide, afin d'éviter que ne se répète une situation catastrophique comme celle de 1973.

Pour atteindre cet objectif, la contribution de chercheurs travaillant dans différentes disciplines est essentielle : agrométéorologie, agronomie, sciences du sol, phytopathologie, entomologie, etc. La science contemporaine requiert que les problèmes soient examinés dans leur totalité pour que les solutions apportées soient réelles et durables.

J'ai été heureux de constater, en consultant le programme du Symposium, que plusieurs sujets importants seront abordés au cours des quatre prochains jours. Vos travaux, je n'en doute point, seront marqués par l'esprit de responsabilité et de dialogue enrichissant et fructueux. Je suis convaincu que les recommandations qui découleront de vos discussions permettront éventuellement de réorienter les programmes de production de l'arachide en Afrique de l'Ouest, et partout ailleurs où cela peut s'avérer nécessaire.

L'Institut international de recherche sur les cultures des zones tropicales semi-arides (ICRISAT), l'un des organisateurs de ce Symposium, a un important programme de recherche sur l'arachide. J'ai eu l'occasion d'apprécier les activités de cet institut, lors d'une visite que j'ai effectuée l'année dernière à son siège, en Inde. Les résultats des recherches conduites par l'ICRISAT seront très utiles aux paysans des zones tropicales semi-arides. Nous sommes heureux que l'ICRISAT ait établi son Centre sahélien au Niger et que ses chercheurs travaillent en étroite collaboration avec ceux de l'INRAN, notre institut national de recherches agronomiques. Nous attachons une très grande importance aux recherches conduites par l'INRAN et l'ICRISAT pour augmenter notre productivité agricole. C'est pourquoi nous ne ménagerons aucun effort pour stimuler et faire progresser cette recherche.

Honorables délégués, Mesdames et Messieurs, il me plaît encore une fois, de vous souhaiter la bienvenue dans notre pays et de vous souhaiter aussi un bon séjour. Je suis persuadé que vos conclusions refléteront notre souci à tous, de voir ce Symposium international sur l'agrométéorologie de l'arachide aboutir à des résultats positifs et judicieux qui se concrétiseront grâce à une inlassable action commune de nature à assurer la stabilité de la production de l'arachide.

Sur ce je déclare ouverts les travaux du Symposium international sur l'agrométéorologie de l'arachide.

Je vous remercie.

D. Rijks

World Meteorological Organization

On behalf of the Secretary General I am pleased to extend a welcome to you to attend this symposium on the Agrometeorology of Groundnut. I also wish to thank the Government of Niger for its kind invitation to hold this symposium in Niamey.

One of the principal tasks of WMO is the provision of support to national meteorological services for the organization, collection, analysis, exploitation, and application of meteorological and hydrological data. Among its programs, the World Meteorological Organization counts the 'Program on Applications of Meteorology*. Major application areas in this program are aviation, marine services, and agriculture. Other areas are the application of meteorological knowledge to energy matters and to water-resources management. The Applications Program is supported by the other Programs, notably the World Weather Watch, the Hydrology and Water Resources Program, and the World Climate Program.

The main objectives of the Agricultural Meteorology Program are the definition of requirement by users; the description of the agricultural potential of agroclimatic region; the definition of the requirement of different crops and cropping systems; the formulation of practical application techniques to help meteorological services to provide users with the information required; and the education, training, transfer of knowledge, and technical cooperation activities necessary to implement the above objectives.

I am convinced that this symposium will help the meteorological community to achieve these objectives and in particular to define the user requirements and practical application techniques. It is the wish of WMO that the results of this symposium will help national meteorological services to make their contribution to the increase of agricultural production in the world.

M. Frere

Food and Agriculture Organization

Excellencies, Directors General, Ladies and Gentlemen,

I wish on behalf of Mr. E. Saouma, Director General of FAO, to welcome all participants to this symposium on the agrometeorology of groundnut, jointly sponsored by ICRISAT, WMO, FAO, and the Peanut CRSP.

This symposium is the fifth in a series which considered wheat in 1973, maize in 1976, rice in 1979, and sorghum and millet in 1982. I wish also to recall that after the sorghum and millet workshop in November 1982 in India, this is the second meeting for which we have benefited from the beautiful local arrangements organized by ICRISAT. I wish to thank ICRISAT sincerely for these efforts.

I am sure that because of the diverse subjects which will be treated during the week, and the exchange of views we will have outside the meetings and during the field trip, everyone of us will go home with an improved knowledge of the groundnut crop and its agrometeorology.

I wish you a pleasant and fruitful week in Niamey.

Daouda Toukoua

Institut national de recherches agronomiques du Niger

Monsieur le Président, Messieurs les Directeurs des institutions organisatrices du présent Symposium,
Chers participants,

Au nom du Directeur Général de l'Institut national de recherches agronomiques du Niger (INRAN), il m'échoit l'honneur de vous souhaiter la bienvenue à l'occasion du Symposium sur l'agrométéorologie de l'arachide dans les zones tropicales semi-arides.

Autrefois considérée comme culture de rente, l'arachide est aujourd'hui perçue comme une culture vivrière transformée en grande partie artisanalement en huile et tourteaux utilisés pour la consommation locale. Après une augmentation très importante des productions entre 1950 et 1966, augmentation due non seulement à l'extension des superficies, mais aussi à une meilleure productivité à l'hectare, la chute a été brutale à partir des années 70; à tel point que le Niger, jadis exportateur net, ne s'autosuffit plus aujourd'hui en produits arachidiers.

Le rendement moyen à l'hectare qui était de l'ordre de 850 kg en 1966-67, est tombé à 440 en 1981. Cette chute très importante est à mettre en relation avec les sécheresses et le parasitisme.

De 1970 à 1974, il y a glissement des isohyètes vers le Sud. En 1973, seul l'extrême Sud du Département de Dosso reçoit plus de 500 mm, alors que cet isohyète passe normalement au Nord des zones de production.

En 1975, l'attaque de rosette anéantit la production. Depuis, les aléas climatiques et phytosanitaires encore observés font que cette culture reste à un niveau très bas à l'échelon national.

Outre la nécessité pour le paysan d'être d'abord autosuffisant en céréales, l'une des raisons essentielles de la baisse de production et des rendements est que l'arachide est devenue une culture à risques. Un déficit pluviométrique en début de saison retarde la date de semis parce que la priorité est donnée à la céréale et un déficit pluviométrique en fin de saison ne permet pas la pleine maturation de l'arachide, d'où une diminution de la qualité et de la quantité des semences.

Pour rétablir la production arachidière, un plan semencier national a été mis en place depuis 1972, mais la disponibilité de semences en quantité et en qualité reste le principal frein à la relance de cette culture à laquelle s'ajoutent les séquelles des maladies et parasites.

Aussi la tenue d'un tel symposium regroupant d'éminents spécialistes, vient à point nommé, car je suis convaincu que les résultats de vos travaux permettront de mieux cerner et de proposer des solutions à toutes les contraintes s'opposant à l'amélioration de la culture arachidière dans les zones sahéliennes.

Je vous remercie.

Agrometeorology of Groundnut in the Semi-Arid Tropics: Need, Relevance, and Objectives of the Symposium

S.M. Virmani[1]

I am honored to have been called upon to define broadly the purpose and objectives of this interagency symposium on the agrometeorology of groundnut, *Arachis hypogaea* L. You are aware that this meeting has been cosponsored by several international and national agencies, and let me at the outset recognize them. These are: the World Meteorological Organization (WMO); the Food and Agriculture Organization (FAO) of the United Nations; Peanut Collaborative Research Support Program (Peanut CRSP) of the United States Agency for International Development (USAID); Institut National de Recherches Agronomique du Niger (INRAN), the Agricultural Research Department of Niger; and our hosts AGRHYMET, the WMO regional center for training in agricultural meteorology and hydrology. ICRISAT is indebted to all the sponsors and others who have helped organize the symposium. We all have a common interest. It is to ensure that results of agricultural research are applied to increase and stabilize agricultural production in rainfed, dryland regions of the seasonally-dry tropics. In a broader sense, then, the overall objective of this symposium is to assist in the compilation of all the agrometeorology-related knowledge on the groundnut-based farming systems of the semi-arid tropics (SAT), and to put together recommendations for evaluation and adoption by the countries concerned.

The scientific aim of this symposium is to bring together researchers to discuss and review new ideas and perspectives related to groundnut-based dryland crop-production systems of the tropics, so that we can take away something that will enhance and sharpen our professional skills. The symposium, I am sure, will provide a forum to learn from each other's work so that a dialogue between interested workers is established on a continuing basis. Exchange of data, experimental plans, research methodologies and related materials, germplasm, etc., could follow. With this in view, the organizing committee of the symposium has tried to design the program in such a way that, as a result of this symposium, interdisciplinary research will get the necessary encouragement, and cooperative research efforts will be enhanced. From the program you will have noted that adequate time has been left for discussion in each session. We hope this will be conducive to the expression of different ideas. Let us all work towards creating a relaxed atmosphere in the meeting that we associate with timetables.

I would now like to read out the objectives of this symposium established by the organizing committee. These are:

- To provide a forum for the exchange of information about the agrometeorology of groundnut in the SAT;

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[1] Principal Agroclimatologist, Resource Management Program, ICRISAT Center, Patancheru, A.P. 502324, India.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502324, India: ICRISAT.

- *To review the present knowledge of agrometeorological factors that* primarily influence the growth and development of groundnut and identify research gaps;

- To review and evaluate techniques and methods (i) to describe and better understand the extent and intensity of weather risks to crop production, and (ii) to quantify the response of groundnut to its growing environments;

- To formulate a plan of action for national and international research institutions to identify priority research areas and collaborative work, and to disseminate research results; and

- To help apply operational agrometeorological information to improve groundnut production both quantitatively and qualitatively.

The time seems appropriate for a meeting of this type. The SAT countries are going through a difficult phase in so far as their agricultural production is concerned. The population pressure in many SAT countries is increasing. The crop yields are declining. Minor perturbations in climate and weather, variations that are normally characteristic of the climate of SAT ecologies, are currently causing a catastrophic impact on food production leading to hunger and starvation.

The important roles of agriculture and related activities in semi-arid agriculture are obvious when one considers that in excess of 80% of the population in many of the dry tropical countries derives its sustenance from agriculture. Some 60% of their gross national product comes from agriculture. As with any modern industrial operation today, agriculture faces demands for increased productivity which must be balanced by concerns for environmental protection. The problem is of serious concern in the groundnut-based farming systems, because it is the main cash crop of the small farmers. The agroclimatologists and agronomists have the ability to provide weather-related information as a management tool for decisionmaking to minimize this apparent conflict. We hope to cover this aspect adequately in the course of this meeting.

The intimate interrelationship between the climate, agriculture, and food production is well known. While other subject areas of agricultural sciences have developed fairly rapidly over the past 50 years or so, agricultural meteorology has not. There are several reasons for this discrepancy, but the major cause has been the lack of quantitative information on crop-environment interactions, particularly those related to soil moisture.

With the easy availability of microprocessors since the early 70s, the task of collection, assembly, and transmission of diverse and large volumes of weather data has become relatively simple. The construction of automated weather stations has been simplified due to their use. Thus, meteorological data can now be routinely collected on a regular time schedule from diverse areas representative of the tropics. This has led to the establishment of a large number of agrometeorological observatories where data relevant to agriculture are systematically collected.

The instrumentation and recording devices for monitoring plant growth over short to long intervals has vastly improved in the past two decades. This has led to increased weather-related research in agriculture. Our current understanding of relationships between meteorological factors and biological phenomena is fairly adequate. This process shall continue as new insights are gained from past experiments and as data acquisition and recording systems constantly improve. We now have the capability to computer-simulate crop growth and development based on the quantitative relationships between physiological response of crop plants and meteorological factors. Experimental evidence collected from actual field results has confirmed that the simulation techniques are robust and can be used as research and application tools.

Today we are at a point where the following have been achieved:

- A network of agrometeorological observatories across the SAT manned by suitably trained meteorologists has been established;

- the ability to disseminate agrometeorological data for many locations on real-time basis exists;

- computer models are available for making weather- and climate-dependent crop management decisions; and

- a serious attempt is currently under way to gather meteorological data for operational purposes.

We need to harness the science and technology of weather and climate applied to agricultural production. This type of undertaking requires inputs from meteorologists as well as agronomists, plant physiologists, entomologists, pathologists, and others. Thus, experiences shared between and among these groups tend to highlight the interdisciplinary needs and provide perspectives for solving similar problems.

During the course of this symposium we will be discussing several applications of basic weather and climate data in such areas as:

- Global groundnut production: agroecological characteristics, crop zonation, review and appraisal of biological constraints to increased groundnut production in the SAT.

- Weather relations of the groundnut crop: adaptation studies, water use, and response of groundnut to drought stress.

- Climate requirements of groundnut: phenology and climate, physiological response, and selection for diverse environments.

- Climate and groundnut production: disease and pest incidence, postharvest and cropping systems techniques.

- Applications of agrometeorology to groundnut cultivation: agricultural monitoring and early warning systems, status of applied research and development, microclimate manipulation.

Dr. E.T. Kanemasu, I am sure, will refer to a number of potentially important applications of agroclimatic knowledge in crop production. I would like to bring to your attention a recent paper (Ruesink 1981) on insect pest management utilizing weather data that showed by making effective use of weather information, insect population dynamics can be accurately forecast. The amount of insecticide to be applied can be varied accordingly to produce economic yields. This research has resulted in less potential contamination to the environment, lower pesticide use, less money spent by farmers, and lower energy use (associated with the application of the pesticide). Similar benefits can be obtained for farmers by following weather-related information. We at ICRISAT have used rainfall climatology information in association with several countries of the Sahel for delineating the semi-arid areas, zones of isoclimes for the transfer of improved agricultural technologies, and for defining problems of interdisciplinary collaborative research (ICRISAT 1984 pp. 137-166). I believe that the knowledge of meteorological sciences as applied to agricultural research and development is currently adequate, however the procedures for disseminating information for agriculture are not adequate. In this context it may be interesting to recall the General Accounting Office Report (GAO 1979) which lamented that 'Agricultural weather information is not effectively communicated to users.'

I believe that the time has now come for an effective dialogue between the institutions located in the SAT and others interested in the problems of this area to operationalize weather-related information for use by our agricultural community. We need to collect weather and crop data on a uniform basis. We need to agree on a common format for the exchange of information and analytic procedures. Without this common ground, the ability to utilize the weather information for research, and to develop improved agricultural practices will not be fully realized. The benefits of modern climate data technology will not reach the small farm holders in the developing countries. These and other related questions will have to be resolved soon.

With that final thought, Mr. Chairman, I look forward to a week of useful meetings. And let me add my own welcome to you all. Thank you.

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Groundnut: The Unpredictable Legume? Production Constraints and Research Needs

D.G Cummins[1]

Abstract

A series of conferences in the United States on the culture of groundnuts resulted in the 1951 publication The Peanut—the Unpredictable Legume. Subsequent research, some of which will be discussed in the present symposium, has shown to the contrary that groundnut is a predictable legume. Because of its value as a food and oil source, an animal feed, and its adaptability to a wide range of soil and climatic conditions, groundnut has spread from its origin in South America to most countries within the boundaries of 40°N and 40°S latitudes. Groundnut is an important crop in the semi-arid tropics, that produces about 67% of the world crop. Production in the semi-arid tropics is constrained by socioeconomic, biological, and environmental factors. The future of groundnut in this region depends on the extent to which research provides solutions to these constraints, and the successful transfer of new technology to the user.

Résumé

L'arachide — une légumineuse imprévisible? Contraintes de production et besoins de recherche : *Une série de conférences aux Etats-Unis sur la culture de l'arachide a abouti en 1951 à la publication du livre intitulé The Peanut—the Unpredictable Legume. Les recherches subséquentes, dont un certain nombre seront discutées au cours du présent symposium, ont montré au contraire que l'arachide est une légumineuse prévisible. L'arachide s'est répandue de ses origines en Amérique du Sud, vers la majorité des régions à l'intérieur de la ceinture de latitude de 40° S à 40° N, à cause de sa valeur alimentaire, de son huile et de son adaptation à une grande variété de sols et de conditions climatiques. L'arachide est une culture importante dans les régions semi-arides tropicales, qui contribuent pour environ 67% à la production mondiale. Sa production dans les régions semi-arides est limitée par des facteurs socio-économiques, biologiques et environnementaux, et l'avenir de l'arachide dans ces régions dépend du succès de la recherche à fournir des solutions à ces contraintes et du succès du transfert des nouvelles technologies.*

Introduction

Before I proceed with the topic I have chosen for my talk today, I would like to add some other comments. I am pleased that the Peanut Collaborative Research Support Program (Peanut CRSP) is a cosponsor of this symposium on the influence of climate on the production of groundnut in the semi-arid tropics. The Peanut CRSP is a relatively new program, funded in July 1982 by the United States

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT.

Agency for International Development (USAID) and cost-shared by the United States and host-country collaborating institutions. It is designed to bring the expertise within the U.S. university agricultural research community to bear on food production and utilization needs in developing countries. This goal is accomplished through a collaborative research linkage between selected U.S. and host-country groundnut research programs and researchers. The University of Georgia manages the program, which includes four U.S. universities and nine host countries, with projects in breeding and cultivar improvement, pest management, aflatoxin management, soil microbiology, and food technology. I personally appreciate the opportunity to present the opening lecture to this symposium. I believe this symposium and planning workshop can have a great influence on the search for information that will aid the optimum use of the fragile semi-arid tropical environment for groundnut production, followed by an increase in the food supply and well-being of the human population of the region.

The Unpredictable Legume

The 'Unpredictable Legume' may seem an unusual title for my talk, but it does have some historical background. Diversification in crop production in the southeastern United States, especially following the lasting effects on the cotton industry of the boll weevil epidemics in the early 1920s, led to increased production and commercialization of groundnuts. Subsequent research information was compiled in a book titled The Peanut—The Unpredictable Legume published in 1951 by the National Fertilizer Association, Washington, D.C., and sponsored by the Plant Food Research Committee of that association. Authoritative information was brought together on the crop from a mass of data, often contradictory, inconsistent, and erratic. Nevertheless, it presented a consolidation of then current ideas that formed a sound foundation for economic production of the crop and identified research needs.

The development of the book began in 1937 when the problem of varying results involving fertilizer field trials with groundnuts engaged the attention of the Plant Food Research Committee of the National Fertilizer Association. The need for more research was presented to and approved by the Southeastern Agronomy Research Committee of the Southeastern Experiment Stations in January 1939. A series of annual conferences of research workers followed from 1939 through 1948. These scientists contributed data and observations which stimulated new research and clarified previous findings. Sometime in these series of conferences someone appropriately referred to groundnut as an 'unpredictable legume', hence the book title. Many distinguished authorities were involved in the conferences. One of the conference chairmen was Dr. Ralph W. Cummings, North Carolina Agricultural Experiment Station, and later Director General of ICRISAT (National Fertilizer Association 1951).

Why the question mark in the title I selected, The Unpredictable Legume? In view of the inconsistencies in the early research data, I am sure this was an accurate statement. But what has happened since 1951? I believe just a casual look at our progress will quickly answer the question.

Advances in genetics have brought about an understanding of groundnut that has enabled breeders to greatly increase the yield potential of cultivars; to introduce disease, insect, and drought resistance into adapted germplasm; and to develop early-maturing or short-cycle cultivars that extend the crop into the short rainy-season semi-arid tropical areas. Remarkable accomplishments have been made in pest management, aflatoxin detection and control, understanding the symbiotic role of rhizobia, unlocking uncertainties in mineral nutrition such as calcium absorption through the shell, physiological processes, and accomplishments in postharvest handling, storage, and utilization that have greatly expanded the utility of the groundnut.

As an example of what has happened to commercial production based on research information that has been disseminated through the extension system to the farmer, let us take a quick look at what has happened in the state of Georgia in the U.S. In 1947, the estimated yields were about 780 kg ha^{-1}. In 1984, a record yield of 3800 kg ha^{-1} was obtained on an area of over 250 000 ha.

The groundnut research community has grown to where we have very capable groups in both the developed and developing countries. ICRISAT was established to provide an international focus on SAT problems and has groundnut as a mandate crop. The American Peanut Research and Education Society (APRES) was developed to foster research and education on groundnut, and publishes Peanut Science, a scientific journal devoted solely to groundnut. One of the organizers of APRES, Dr. C. R. Jackson, is present today in his position of Director for International Cooperation at ICRISAT. A second edition of a comprehensive book on groundnut, Peanut Science and Technology (Pattee and Young 1982) was published recently by APRES. ICRISAT hosted an international workshop on groundnuts in 1980 and published the proceedings (ICRISAT 1981). The Peanut CRSP in cooperation with ICRISAT will soon initiate a research periodical for short, preliminary articles. Many other examples could be cited on groundnut research and information dissemination.

I am sure that many more research accomplishments will be cited during this program to further show the progress that has been made. Do you now agree with me that we can rephrase the statement to The Peanut: The Predictable Legume? I believe we will all answer in the affirmative.

Origin, Spread, and Uses

Groundnut has spread from its origin in South America to most tropical, subtropical, and warm temperate zones of the world. The spread can be attributed to its adaptability to a wide range of soil and climatic conditions, and to its value as a food crop, an oil source, and an animal feed.

The exact origin of groundnut is still unknown and will remain a subject of scientific inquiry. Hammons (1982) summarized the present knowledge on the origin of groundnut. There is general agreement that the center of diversity of *Arachis is* in the Mato Grosso State of Brazil near the borders of Paraguay and Bolivia. Most of the sections into which the genus has been divided are found in this area. The cultivated groundnut is thought to have originated in southern Bolivia-northwestern Argentina in the eastern foothills of the Andes. An important center of variability for the *hypogaea* species exists in this area.

There is no evidence for pre-Columbian spread of *Arachis hypogaea* to the Old World. Spanish, Portuguese, and Dutch explorers and traders apparently transported the species to Africa, Spain, Portugal, the Western Pacific, China, and India. In all these lands, the groundnut readapted and became specialized. It returned again from Africa to tropical America and the United States, probably with the slave trade and afterward. These areas of readaptation and specialization away from the center of origin have been important sources of germplasm for groundnut improvement programs.

Diverse uses of groundnut were observed in the area of its origin. In the foothills of the Andes, the kernels were eaten at one of several stages from immature to ripe, either raw or cooked. They were boiled, roasted, crushed, or ground and mixed with other food. The whole young pods were used in soups after boiling. Beer and a nonalcoholic drink were made from groundnuts, and the oil made into soap.

Similar uses for groundnut have developed in the areas around the world where it has been introduced. The major use worldwide is as a source of cooking oil. The oilcake is often used as an animal feed. The oilcake is also used in various dishes, especially when the oil is pressed out in small-scale home or village processes. A number of high-protein and milk-type products have been developed from groundnut. Whole-roasted groundnuts are a delicacy worldwide. The major use in the United States and some Western European countries is as a butter or spread.

Commercialization of groundnut has made it an important cash crop in many countries. West African production developed because of the oil market in Britain and France. Groundnut became the primary source of foreign exchange in countries such as Senegal. It is an important cash crop in eastern and southern African countries such as Sudan and Malawi. The production in India is used mainly for oil. Groundnut is an important crop in China, and Southeast Asian countries such as Indonesia, Burma, and Thailand. Most of the United States' crop is converted into butter for domestic consumption, but significant quantities are exported, primarily to Western Europe.

World Production and Distribution

Estimates of world groundnut production vary from year to year, but over the last 10 years harvested area has averaged about 18 million ha. Production estimates generally averaged just under 18 million t, or an average of just under 1 t ha^{-1} (USDA 1975-84).

An examination of the distribution of world production shows that of the total production, Asia produces about 58%, Africa 27%, North America 10%, South America 5%, Australia 0.2%, and Europe 0.1%. It is interesting to note that only about 5% of the total world production is in South America where the groundnut originated. Leading producers are India, China, the United States, Senegal, Sudan, Brazil, and Argentina.

A very significant point about the distribution of world production emphasizes the importance of this symposium. As pointed out by Gibbons (1980, p. 12), approximately 67% of the production comes from the seasonally-dry, rainfed areas of the semi-arid tropics. Furthermore, about 80% of the production comes from the developing countries.

Groundnut is adapted and grown in many countries where serious food shortages exist, especially the SAT region. I do not believe there is enough awareness in many countries of the importance of the high protein and calorie content of groundnut for feeding a population faced with food shortages and starvation. A major objective of the Peanut CRSP is to increase the food utility of groundnut.

Constraints to Production in the SAT

In keeping with the regional emphasis of this symposium I will confine most of my remaining remarks to problems and needs of the semi-arid tropics. Also, I will use as my source of information to support my views on production constraints in the SAT the data compiled during the planning phase of the Peanut CRSP. The information is summarized in two publications: Peanut CRSP Planning Report (Cummins and Jackson 1982a), and World Peanut Production, Utilization and Research (Cummins and Jackson 1982b). Data were collected from about 120 people through personal interviews during 13 in-country site visits; published information (primarily the proceedings of the International Workshop on Groundnuts (Gibbons 1981); and responses to a widely-distributed survey questionnaire. Such data can be biased due to the interest and expertise of respondents, but this sampling was distributed widely enough to minimize these personal biases. With few exceptions the responses summarized were from people in the SAT region or areas with distinct wet-dry seasons with climates near to that defined as SAT. Northeast Thailand would be an example of such an area. The elimination of these responses would have little or no effect on the basic conclusions of the major constraints to groundnut production in the SAT.

The following factors were most frequently cited as constraints to production:

- Low yield potential of cultivars because of lack of resistance to drought, diseases, and insects.
- Yield losses due to drought, diseases, and insects.
- Low yield due to cropping systems and cultural practices that are not adequate to take advantage of yield potential of cultivars.
- Toxicity of groundnuts from aflatoxin which endangers the health of humans and animals and lowers market value.
- Groundnuts often are not regarded as a major food source with high nutritional value, but exist in a restricted array of food preparations with low sensory values.
- Low yields from lack of complete physiological adaptation of groundnuts and associated microorganisms to the environment.
- Prices, markets, and farmer and consumer interest limit production and utilization.

Obviously, all of these constraints are not specifically production constraints, but each one has a direct or indirect implication in production.

For example, drought is a specific production constraint, while toxicity from aflatoxin contamination decreases market value, thereby reducing the farmer's incentive to produce groundnuts.

Also, what affects the groundnut acreage more than expected market price following harvest? The first three factors were the most frequently cited constraints.

To discuss these constraints in more detail, I will divide them into three major categories: environmental, biological, and socioeconomic. I will also suggest research areas that should provide solutions to these constraints.

Environmental

- Yield losses due to drought, diseases, and insects.
    - low rainfall compounded by high temperatures
    - leaf spots
    - rust
    - rosette virus
    - root, stem, and pod rots
    - foliage insects
    - root, stem, and pod insects
- Toxicity of groundnuts from aflatoxin endangers the health of humans and animals and lowers market value. This is categorized as an environmental factor because of the ubiquitous nature of the causal organism *Aspergillus flavus* and the universal occurrence of the resulting toxin.

Biological

- Low yield potential of cultivars from lack of resistance to or tolerance of drought, diseases, and insects.
    - lack of inherent resistance to drought

  - short-cycle cultivars not available for drought escape
  - cultivars susceptible to diseases and insects
- Low yields due to cropping systems that are not adequate to take advantage of yield potential of cultivars.
  - inadequate mineral nutrition
  - improper seeding dates and rates
  - low soil pH
  - competition from weeds
  - incompatible intercrops
- Low yields from lack of complete physiological adaptation of groundnuts and associated microorganisms to the environment.
  - inadequate nitrogen fixation due to unadapted rhizobia, or rhizobia species incompatibility
  - suboptimum leaf area and flower numbers
  - low photosynthetic efficiency
  - inadequate root invasion by mycorrhizal fungi

Socioeconomic

The socioeconomic constraint is often elusive and difficult to deal with, but can easily be the determining factor in production. For example, a breeder may release a new, high-yielding, drought-tolerant cultivar, but farmers may not grow it because of some factor such as seed size or taste or the risk factor of trying a new unproven cultivar.

- Groundnuts often are not regarded as a major food source with high nutritional value, but rather as a restricted array of food preparations with low sensory values.
- Postharvest handling and storage inadequate to maintain high-quality products.
- Prices, markets, and farmer and consumer interests limit production and utilization
  - market prices too low for profitable production
  - market prices too uncertain at seeding time to provide production incentive
  - input costs too high
  - other crops more profitable
  - too much labor required to produce and harvest crop
  - lack of equipment makes production and harvest difficult and laborious
  - farmers aspire to other occupations or migrate away from farms
  - farmers will not risk new technology
  - lack of confidence in crop after losses due to disease or drought
  - relative cost to consumer too high
  - markets inadequate
  - seed production and distribution systems lacking
- Insufficient number of properly trained research and extension personnel.

Future Work

I could list more constraints facing groundnut production in the SAT, but I believe I have emphasized to this symposium that there are problems and challenges facing groundnut researchers. I believe we will meet these challenges with the same determination that researchers met the 'Unpredictable Legume' 30-40 years ago.

We will develop or accelerate research programs to:

- Breed for drought-, disease-, and insect-resistant or tolerant cultivars.
- Breed short-cycle cultivars to mature within limited rainy periods and escape drought.
- Develop efficient systems for low-cost disease and insect control.
- Develop practices to minimize aflatoxin contamination.
- Develop more efficient cultural systems and fertilizer application practices.
- Improve nitrogen fixation by rhizobia.
- Increase awareness of food value of groundnut and develop food products acceptable to the population.
- Develop markets, labor-saving equipment, and improve overall production incentives to farmers.
- Train more and better research and extension personnel.

I believe this symposium will contribute to the recognition of problems facing us, whether environmental, biological, or socioeconomic, and present ways to solve them, and thus help to take better advantage of the potential that groundnut has as a food and cash crop in the SAT.

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Agrometeorological Research in Developing Strategies for Improved Food Production

E. T. Kanemasu[1]

Abstract

Agrometeorological research in food production systems deals with the quantification of crop plant responses to their environment. This is a complex biophysical and biochemical system, and requires multidisciplinary teams to adequately identify and prioritize the issues limiting food production. Agrometeorological knowledge can be used advantageously for increasing and stabilizing crop production in different environments. In the semi-arid tropics, a strategy of stabilizing yields rather than maximizing yields is preferred. What is the role of the agrometeorologist in developing new strategies for these stressful environments? Basic information about the climate, soils, and crops is required. It is not sufficient to have monthly averages of temperature and rainfall. The meteorological data must be carefully edited and evaluated in relation to the crop being grown and the soil in which it is being sown. Because water is a major limiting factor to production in the semi-arid tropics, the development of the crop in relation to rainfall events and potential evapotranspiration rates is a major consideration. This paper will examine strategies for food production in stressful environments.

Résumé

Recherche agrométéorologique sur la mise au point de stratégies visant à accroître la production alimentaire : *La recherche agrométéorologique sur les systèmes de production alimentaire vise à quantifier la réponse des plantes à leur environnement. Il s'agit là d'un système biophysique et biochimique complexe et des équipes multidisciplinaires sont requises pour déterminer et classer par ordre d'importance les facteurs limitant la production alimentaire. Les connaissances agrométéorologiques peuvent être utilisées avantageusement pour accroître et régulariser la production agricole dans des environnements variés. Dans les régions tropicales semi-arides, on cherche plus à régulariser la production qu'à la maximiser. Comment l'agrométéorologiste peut-il contribuer à mettre au point de nouvelles stratégies dans ces environnements difficiles? Des informations de base concernant le climat, les sols et les cultures sont nécessaires. Connaître les moyennes mensuelles des températures et des pluies n'est pas suffisant. Il faut analyser et évaluer avec soin les données météorologiques en fonction des cultures implantées et des sols. L'eau étant un des principaux facteurs limitant la production dans les régions tropicales semi-arides, le développement des cultures en fonction des événements pluvieux et des taux d'évapotranspiration potentielle est un sujet d'étude majeur. Cet exposé considère les stratégies de production alimentaire dans des environnements difficiles.*

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT.

Introduction

Smith (1920, p. 304) in his book, 'Agricultural Meteorology', described agrometeorology as that branch of science relating 'climate to vegetation and farm operations'. Smith examined the weather and the yield of potatoes in Ohio between 1883 and 1909. He plotted the departure from normal of the yields, June and July rainfall, and June and July temperatures on the x-axis, and years on the y-axis. He then visually compared the lines and concluded that in a general manner rainfall and yield were positively correlated, and temperature and yield were negatively correlated. While the sophistication of data analysis has greatly increased, the same type of analysis and massaging is still continuing today. In fact, it is not uncommon to find similar figures in our current professional journals.

Agrometeorological research seeks to develop quantitative understanding from among the environmental parameters and crop production over a wide range of climates. Thus, the types of problems addressed are varied and include incidences of insect pests and diseases, pollution, drought, soil and water conservation, hydrologic problems, episodic events, risk analysis, and disaster relief. It is not difficult to see the kinds of complexities that are involved. We are dealing with a complex biological and biophysical system where interrelationships and feedback mechanisms are prevalent in a highly dynamic nature.

An important part of an agrometeorologist's role is data collection. An agrometeorologist is used to dealing with large data bases; however, a thorough familiarity with the data and those who collected the data is required. It is important that there is consistency within data sets. Since the agrometeorologist must relate the physical with biological systems, both meteorological and biological data sets must be critically edited and scrutinized.

One of the strategies for food production in a stressful environment is to reduce the risk. Therefore, stability in yields rather than maximum yields is sought. This may be done unknowingly by the subsistence farmer in his traditional planting method. For example in many droughty regions, stand establishment is a major problem. The farmer may plow his seeds into the soil as a means of planting, thus the seeds are placed at different depths. Germination and seedling survival are dependent upon the soil moisture and the timing of rains. Delayed germination due to deep seed placement may be desirable in a situation where rainfall is also delayed, because early germinated plants will die. The farmer can also spread his risk by planting over a period of several months.

Agrometeorologist's Role

How can the agrometeorologist aid these types of farmers? These droughty regions are usually characterized by coarse-textured soils with low water-holding capacity, susceptible to compaction, runoff, and surface crusting. Some of the possibilities for stabilizing crop yields under these conditions are:

- Surface organic mulching to reduce evaporation, surface-soil temperature, and soil-surface crusting, and to increase infiltration. However, in some situations, termites and/or farm animals will quickly eliminate the residue.

- Water harvesting is a possible alternative in many areas. It is possible to conceive of a technique of harvesting water from one microwatershed to another. For example, planted and nonplanted strips alternated on a gentle slope so the water moves from the nonplanted strip to the lower planted area is one technique. The soils are usually naturally self-sealing so water does not penetrate the nonplanted area. Care must be taken to prevent serious soil erosion where there are heavy rains. Weeds in the nonseeded area must also be controlled.

- Planting the crop/cultivar at the best date is a major farmer decision. It is in this research area that I will address my remaining comments.

Water Availability and Crop Choice

Dancette and Hall (1979) reported an interesting study where they computed the probabilities of satisfying the water requirement of a 75-day millet crop compared to a 90-day millet. They showed an increase in the region in which a short-season crop could be successfully grown. There was about 8 cm less water used by the short-season crop; thus, the 15 days averaged 5.3 mm per day. Dancette and Hall's (1979) analysis demonstrates matching water availability with crop development. Monteith (1984) illustrated this concept with his coined 'water time' and 'temperature time' diagram. He emphasized the need to match the length of growing season, which at any location is principally driven by temperature, with water availability. This water availability is a combination of within-season precipitation and water stored in the profile. The ontogeny of the crop can be estimated from the calculation of thermal units. Most tropical crops have a base temperature of 10℃, an optimum of 33°C, and a maximum of about 45°C. Cultivars can have a range of base temperatures as well as a range of thermal units required for development of the various morphological events (e.g., phyllochron interval, anthesis, grain filling, etc.). In addition, it appears that with a fairly narrow genetic pool (e.g., a population) there can be a range of thermal units. A consequence of this is that the crop canopy will be composed of plants developing at different rates. In addition, some cultivars are photosensitive, therefore, their development will be dependent upon photoperiod.

Stewart and Burnett (1985) suggest a similar approach. They plotted the weekly rainfall amounts that were exceeded 50% of the time, and the weekly thermal units. Superimposed on these patterns were the temperature-driven developmental stages of sorghum. They attempted to adjust the planting date of sorghum to match the peaks in rainfall with the critical stages of sorghum. It is important that rainfall dependability instead of mean rainfall values be considered. In some unpublished preliminary analysis Virmani (at Kansas State University on sabbatical leave from ICRISAT) has computed the weekly probabilities of receiving one-third of the potential evapotranspiration (Penman) as precipitation (R/PE=0.33) for Botswana (37 stations) and Niger (86 stations). The data set consisted of 6-35 years of data for Botswana and 6-63 years for Niger (Figs. 1 and 2). According to the Hargreaves' (1982) classification of R/PE=0.33, the growing season in Botswana (typically, October to April) is characterized by low probability of sufficient rainfall to grow a crop. Because of this low probability, the Botswana farmer is faced with multiple planting dates to

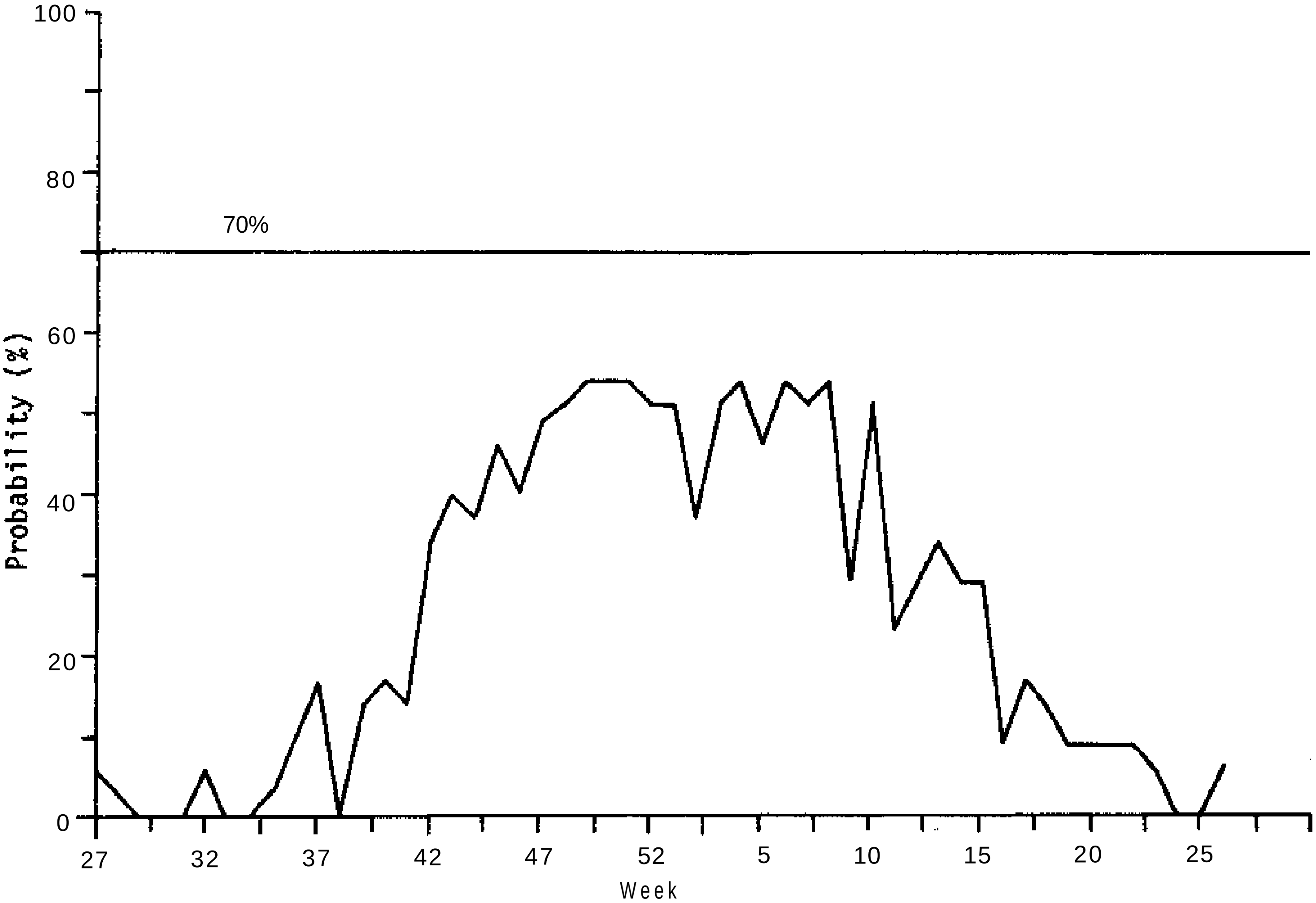

Figure 1. Weekly probabilities of receiving precipitation amounts greater than 33% of the potential evapotranspiration at Gaborone, Botswana.

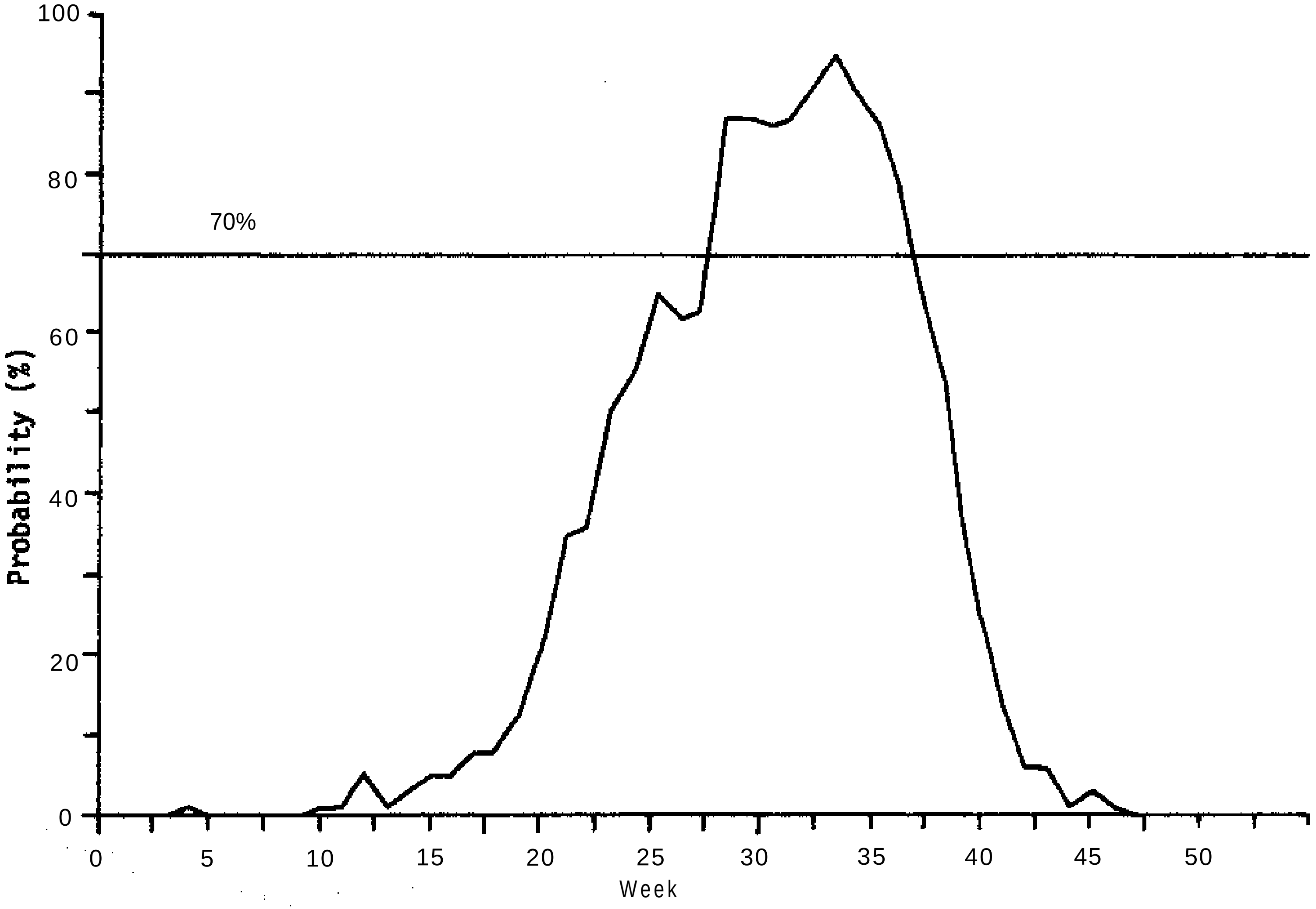

Figure 2. Weekly probabilities of receiving precipitation amounts greater than 33% of the potential evapotranspiration at Niamey, Niger.

spread his risk. If the farmer plants in November, there is a risk of a drought at anthesis (Fig. 3); therefore, it may be desirable to delay planting until December. The Niamey data (Fig. 4) illustrates the risk involved in planting sorghum because its longer season than millet exposes the crop to drought during grain filling.

Genotype Selection

Varieties can be selected on a basis other than maturity. Finley and Wilkinson (1963) outlined a technique of comparing genotypes across environments. Some varieties do well in good environments and very poorly in adverse environments. Other varieties are relatively stable across environments. At the Evapotranspiration Laboratory of Kansas State University, we have developed a technique for selecting drought-resistant genotypes on the basis of canopy temperature and vapor pressure deficit. While we are aware that several environmental factors affect leaf temperature, canopy temperature comparisons can be made across genotypes when made with certain precautions. The infrared thermometer permits a rapid method of obtaining surface temperatures. The measurements should be made in a manner to assure leaf temperatures and not soil temperatures; therefore, an oblique view of the canopy is usually required. The radiation environment should be relatively constant over the time period of the measurements. We hypothesize that a drought-resistant genotype would be characterized by warm canopy temperatures under well-watered conditions and with relatively high stomatal sensitivity to relative humidity.

Results from over 200 sorghum lines indicate that the above hypothesis related well to those genotypes that performed well in a very dry environment at Yuma, Arizona, in a 2-year study. The above technique provides selection of genotypes that have low transpiration rates and consequently, low photosynthetic rates. This is usually translated into low yield. If that yield, even though low, can be made stable over very good to very poor environments, then that genotype has a place in a technological package. This is only one strategy for production in semi-arid environments. The above technique can also be used to select 'cool' genotypes that are rapidly transpiring and photosynthesizing. If the environment is such that a strategy of a short-season genotype is preferred, then an early-maturing, cool-canopy-temperature genotype may be the most desirable.

Crop Modeling and Remote Sensing

The use of models to assess risk and to evaluate management and cropping strategies has been an active research area. Evapotranspiration (ET) models have been developed to the extent that we feel relatively comfortable with them, but some questions still remain. While there may be technical questions about advection, topography, rootzone depth, etc., there is a major concern about rainfall (quantity and intensity) and runoff. The measurement of rain is a point measurement, and the true nature of its spatial variability is difficult to obtain. Thus, any model using average meteorological data for predicting ET and soil moisture will be difficult to use for extrapolation either regionally or even to a neighboring farm. This can be especially true in semi-arid regions of Africa. The point is that a major component of the water balance is assumed to be an accurate representative quantity, and there is little regard for its highly spatial nature.

Because transpiration and photosynthesis are inextricably connected, evapotranspiration and yield have been correlated with reasonable success. To avoid or minimize the nonuniqueness between years and locations, researchers have normalized the relationships to obtain:

$$(1-Ya/Ym) = Ky\,(1-ETa/ETm) \quad \text{(Equation 1)}$$

where

Ya = actual yield
Ym = maximum yield
Ky = yield-response factor

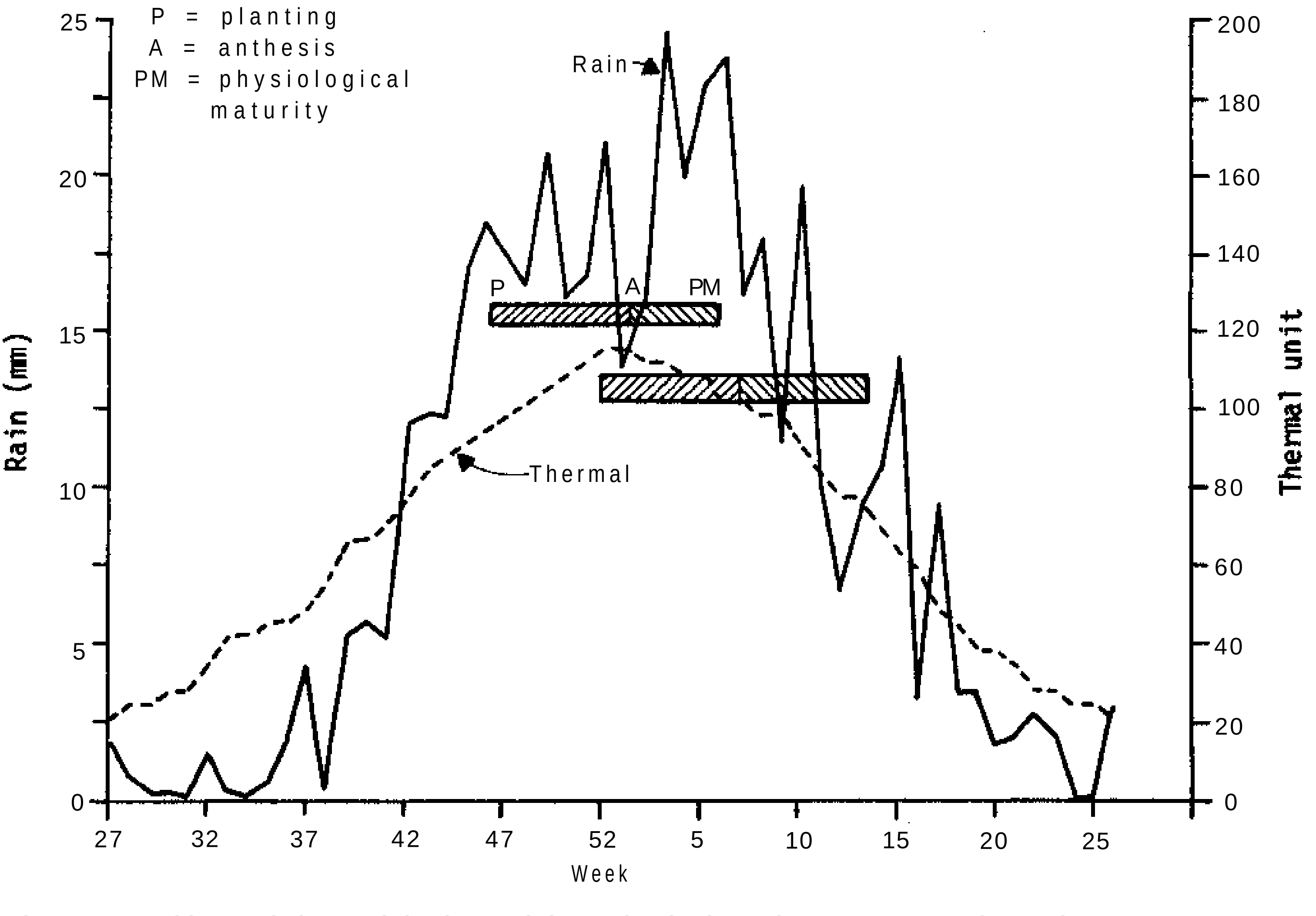

Figure 3. Weekly trends in precipitation and thermal units (10°C base temperature) at Gaborone, Botswana. Growing seasons for sorghum are illustrated.

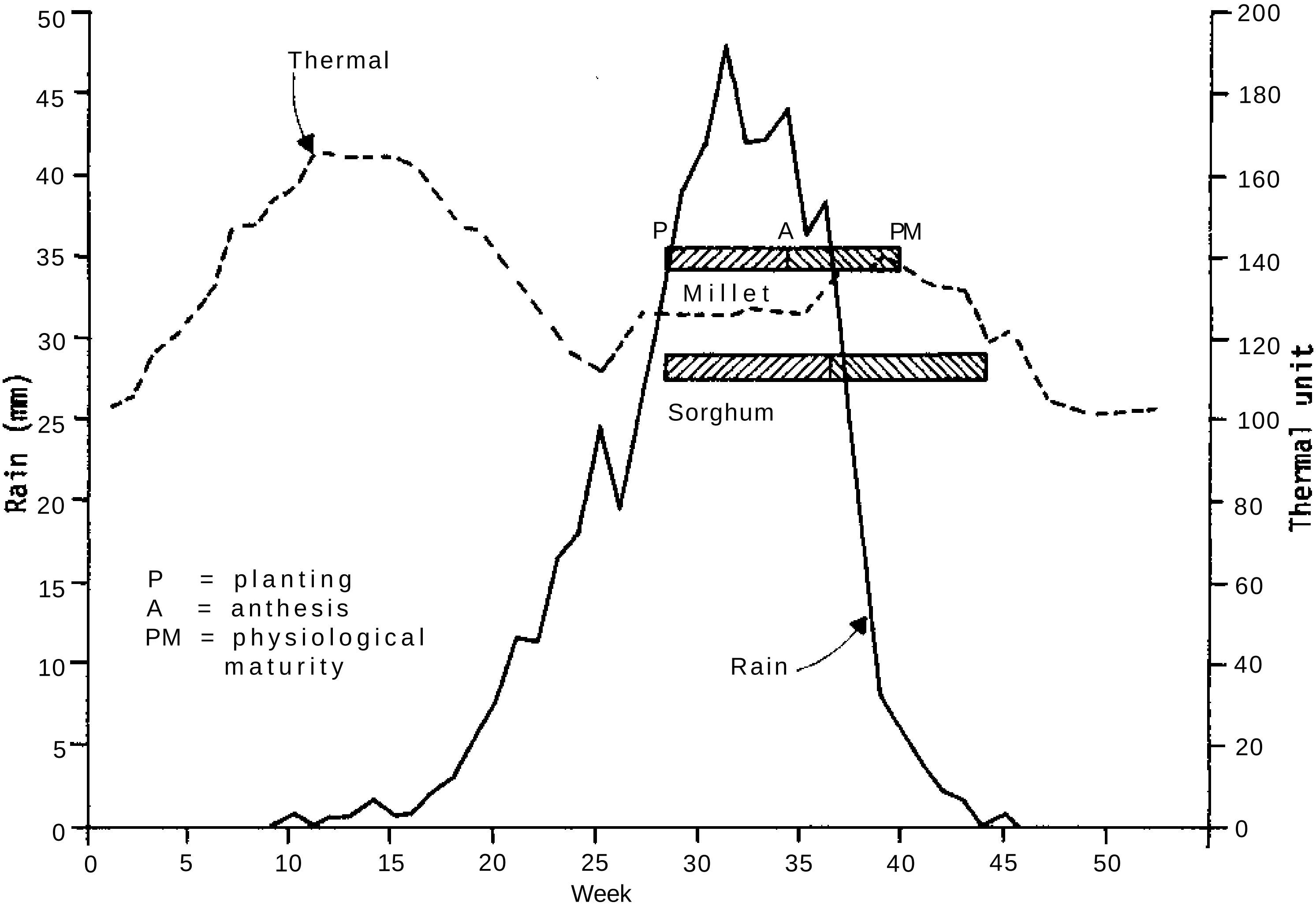

Figure 4. Weekly trends in precipitation and thermal units (10°C base temperature) at Niamey, Niger. Growing seasons for sorghum and millet are illustrated.

ETa = actual evapotranspiration
ETm = maximum evapotranspiration

The actual and potential values are equal when the water requirements are fully met. Doorenbos and Kassam (1979) provide Ky values for a number of different crops. Because crops have sensitive growth periods, they have listed values of Ky for the total season and also for various growth stages. Clearly from the above equation, one can see that the decrease in yield is proportional to the decrease in ET. However, to obtain the actual yield, one must estimate the potential yield. While procedures have been suggested for estimating Ym, it is obviously not a straightforward procedure.

The estimation of actual ET requires the knowledge of leaf area index (LAI). This is necessary in order to estimate evaporation from the soil surface and transpiration from the plant surfaces separately. These processes are different physically and physiologically, therefore they cannot be estimated together. Evaporation can be a major component of ET in the semi-arid regions where plant stands can be low. Thus the management of the soil surface can play a major role in evaporation and infiltration, crusting, and soil erosion. In addition, it should be recognized that the heated soil surface between plants becomes a source of sensible heat and increases the transpirational demand. This is usually more prevalent in coarse-textured soil. Because of lower thermal conductivity surface temperatures can elevate substantially under high insolation conditions.

Most ET models use crop cover or LAI as a means of separating evaporation and tranpiration. The model will use LAI as a measured input or will have a submodel for the growth of leaves. The simulation for leaf growth and senescence is extremely difficult even under the best growing conditions. Thus, some researchers have examined the possibility of using remotely-sensed satellite data for estimating LAI; however, problems have been encountered in obtaining adequate satellite coverage with Landsat (overpass every 18 d). The National Oceanographic and Atmospheric Administration Advanced Very High Resolution Radiometer (NOAA AVHRR) daily data are of a coarse resolution (1 km x 1 km at the subsatellite point) and therefore undesirable for many applications. However, a thorough evaluation of AVHRR data to determine its usefulness in assessing LAI is in order. It must be recognized that soil reflectance, plant geometry, viewing geometry, and solar angle effect the AVHRR scene. In addition, the vegetation within the pixel is usually not uniform.

Researchers have also found that spectral indices obtained from multispectral radiometer data were linearly correlated with the interception of light by the canopy. Thus, using the relationship between light interception and yield (Monteith 1977) to obtain potential yield and an ET model with remotely-sensed input of LAI, one can use equation (1) to predict yield.

I do not want to leave the impression that models are an end result. They are only tools and still very limited by our inability to fully understand the biological system. Thus, the challenges to agrometeorologists are many and only limited by our vision and imagination.

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Opening Session

Discussion

A. Ndiaye:

The representative of INRAN mentioned the case of leaf spot attack in Niger in 1975 which significantly reduced the production. I do not know the progress in research at INRAN on leaf spot, but in Senegal we have developed a variety (69-101) that is resistant to leaf spots. Seed of this variety can be made available through Institut Senegalais de Recherche Agricole (ISRA). Unfortunately this variety is late maturing '110-115 days' in Senegal.

A. Tekete:

Under experimental conditions mycorrhizal infection is known to be a yield-increasing factor, particularly under low-fertility conditions. Has quantification of mycorrhizal influence been carried out on groundnut under practical conditions?

D. G. Cummins:

The Peanut CRSP has a project led by Mrs. Ruth A. Taber of Texas A&M University in cooperation with research groups in Thailand and the Philippines related to micorrhizal fungi invasion into groundnut roots and the subsequent influence on plant growth. A number of species of mycorrhizal fungi have been collected, isolated, and spores multiplied on a trap crop. Preliminary results on groundnut growth following inoculation with these spores have shown an increased growth due to mycorrhizal infection of the groundnut roots. In effect, the mycorrhizal fungi hyphae increase root surface area, allowing increased nutrient (phosphorus) and water uptake into the groundnut plant. A major problem to overcome for this to become practical in groundnut production, in a way similar to inoculation with rhizobia for nitrogen fixation, is in the process of spore multiplication and inoculation of groundnut roots in a field.

R. W. Gibbons:

I would like to add to the comments made by Dr. Cummins on the role of mycorrhiza in groundnut production. This area is underresearched. We are doing some work on it at ICRISAT and work has also been done by Institut Francais de Recherche Scientifique pour le Developpment en Cooperation (ORSTOM) in Senegal where they demonstrated not only the useful interactions of mycorrhiza and rhizobia but also the effect of these organisms on root growth and attack by nematodes.

D. Smith:

Dr. Ruth Taber made a discovery that is quite interesting and has potential significance. She found that mycorrhiza can occupy weed seeds in the soil. The potential significance is that perhaps this could be a way eventually to distribute mycorrhiza in the soil. This has not been exploited but the potential is there.

S. M. Virmani:

I was pleased to see Dr. Cummins emphasize drought and diseases of groundnut as major yield-reducing factors in the SAT. Our survey of the major problems affecting groundnut production in the sub-Saharan countries showed drought, instability of the onset of rainfall at planting time, and diseases as the major yield-reducing factors.

D. Rijks:

Dr. Kanemasu talks about the relationship between the actual yield and evapotranspiration, and a formula in which he says because crops are sensitive at various stages, the crop coefficients vary with season and at various growth stages. That clearly is an area where application techniques could make a contribution to agricultural planning. To solve the formula for the whole season should not be difficult. It will be interesting to estimate yields a little before the end of the season. Could you please give an idea about how this technique can be used if we use the yield-response factors for the various stages of growth?

E. T. Kanemasu:

The figures that I showed were taken out of the FAO publication describing the crop-coefficient values that could be used for different stages of growth. Your suggestion as to prediction of yield before the end of the season is somewhat difficult to achieve.

People have tried using a truncated part of the formula; others put in speculated weather data for the rest of the season. Neither have met with a great deal of success. You come out with an average yield in any case, but what one would like to do is to predict the weather ahead of time and that is a problem.

D. Rijks:
To me the problem of using this formula is not the weather data. I think you can follow the ratio of ET_a/ET_m throughout the season fairly easily. It has been done with reasonable success in various instances. It would seem to me that the real problem is to get the Y_m values for various stages of growth. We need to find solutions to this.

E. T. Kanemasu:
If you would like to use this data more for the forage crops, and therefore rely upon the dry matter, one could use the amount of intercepted light to predict what the potential yield could be. That is the method I would use, but there is some danger in trying to extrapolate the weather. You could say the weather is somewhat predictable, but there is still a problem.

N. R. Yao:
a. Thermal units were used to describe both germination and shoot development in sorghum. Is there any significant difference in using hourly temperature data or daily maximum and minimum temperatures for the computation of those thermal units?
b. You reported that resistant crops have higher canopy temperatures and this is associated with lower evapotranspiration. Is this high temperature associated with stomatal closure and/or canopy structure, or with the genetic behavior of the crop?

E. T. Kanemasu:
a. The data shown were from a thermal gradient plate in which the temperature at any given point was held constant. In an environment in which the temperature is changing it would be more appropriate to use hourly temperature data; however, for more practical studies the daily maximum and minimum temperatures give satisfactory results.
b. The higher canopy temperatures appear to be a result of higher leaf-stomatal resistance, however, canopy structure certainly enters through the boundary-layer resistance, and therefore is included in the overall canopy resistance.

We found that the canopy temperatures for sorghum were greater than those for millet, which would indicate that sorghum was transpiring at a lower rate than millet. If one looked at the seasonal data, sorghum had a higher water use than the millet. In looking at the stomatal resistance, water use, and other water-relations measurements for the two crops, we concluded that the water use for millet was lower than that for sorghum because of the shorter growth cycle.

J. H. Williams:
The screening based on canopy-air temperature differential identifies lines with water-conservation mechanisms. How often does this confer an advantage and how often does it work the other way by causing plant stress?

E. T. Kanemasu:
This screening is applicable to situations of water exploitation when the crop is thriving on stored soil water. There may be other screening techniques where the situation is different.

A. Ndiaye:
a. In addition to the elements you have brought up in comparing sorghum and millet resistance to drought, there is also a difference in the cell structure (protoplasmic resistance) that makes millet more tolerant to drought than sorghum.
b. I would like to comment on the basic principle in using infrared thermometer to determine plant tolerance to drought and plant temperature. A plant containing more water has better temperature regulation displaying thereby lower temperatures than a plant with less water content. An infrared thermometer (or infrared films) is then used to evaluate plant temperatures in relation to the quantity of water in the plant and thus plant tolerance to drought.

C. K. Ong:
I would like to produce a more simplistic view of the relationship between stomatal conductance, leaf temperature, and the balance of water between supply and demand. Recent work at ICRISAT Center shows that stomatal conductance has a universal relationship with relative leaf-water content. And I would like to take up the remarks of Dr. Kanemasu that there are genetic differences in stomatal behavior. I think we are not looking at stomatal behavior but the response of the plant to the relative water content of leaves. This is a very simplistic view of how stomata, water content, and the atmosphere respond to changes in both supply and demand for water.

Session I

Global Groundnut Production

Chairman: L.D. Swindale
Co-chairman: B. Neasmiangodo

Rapporteur: K. Anand Kumar

Agroclimatological Characteristics of the Groundnut-Growing Regions in the Semi-Arid Tropics

S.M. Virmani and Piara Singh[1]

Abstract

*Groundnut (*Arachis hypogaea *L.) is grown in many diverse agroenvironments. It is cultivated in some 90 countries around the world. In semi-arid tropical (SAT) areas it is an important cash crop in subsistence farming systems, as well as an important food source. The total output of groundnuts in SAT countries is about one-half of the total world production.*

Within the SAT, India has the largest groundnut production area. It produces 52% of the combined output of all the SAT countries. Other SAT countries producing significant amounts of groundnut are Senegal, Nigeria, Sudan (each producing between 5-7.5% of combined SAT production); Zaire, Brazil, Burma, Argentina (2.6-5%); and Thailand, Malawi, Zimbabwe, Cameroon, Central African Republic, Chad, Mali, and Gambia (1-2.5%).

Groundnuts are grown primarily in rainfed dryland conditions. In India, the crop is cultivated in soils ranging from coastal sands to Vertic Inceptisols. In the African subcontinent it is grown on Alfisols and Oxisols. Groundnut soils have generally low (≤ 100 mm) to medium (≈200 mm) available-water holding capacity (AWC) in the root profile.

In the Indian groundnut-growing areas the annual rainfall varies from about 400-1500 mm, usually received between 2-4 rainy months. the crop is grown from 8-32°N latitudes. In northern India, where the rainfall is unimodal, groundnuts are grown during the rainy season from June to September. In south India, below 10°N, the rainfall tends to be bimodal and temperatures are suitable for groundnut cultivation almost the whole year; two crops are raised. The first crop is grown from July to September/October (first rainy season) with another crop in October/November to January/February during the second rainy season with some supplemental irrigation.

In the Sahelian West Africa, the groundnut crop is cultivated in a narrow belt between 10-15°N latitude. It is sown in July and harvested in October. The total seasonal rainfall varies between 300 and 1200 mm. The main rainy season lasts 2-3 months beginning in late June.

The groundnut-growing areas in the SAT have short (75-110 d) growing seasons and are characterized by intermittent drought periods. We have examined the probability estimates of moisture adequacy for a few selected locations in relation to crop-water needs. This study showed that the amount of soil moisture in the surface soil is fairly restricted at the time of seed formation and maturity, thus leading to pod development and harvesting problems. Our data also showed that groundnut yields are likely to be significantly reduced once in every 3 years due to failure of seasonal rainfall in the SAT.

Résumé

Caractéristiques agrométéorologiques des régions où l'on cultive l'arachide dans les tropiques semi-arides : *L'arachide (*Arachis hypogaea *L.) est cultivée dans près de 90 pays, dans*

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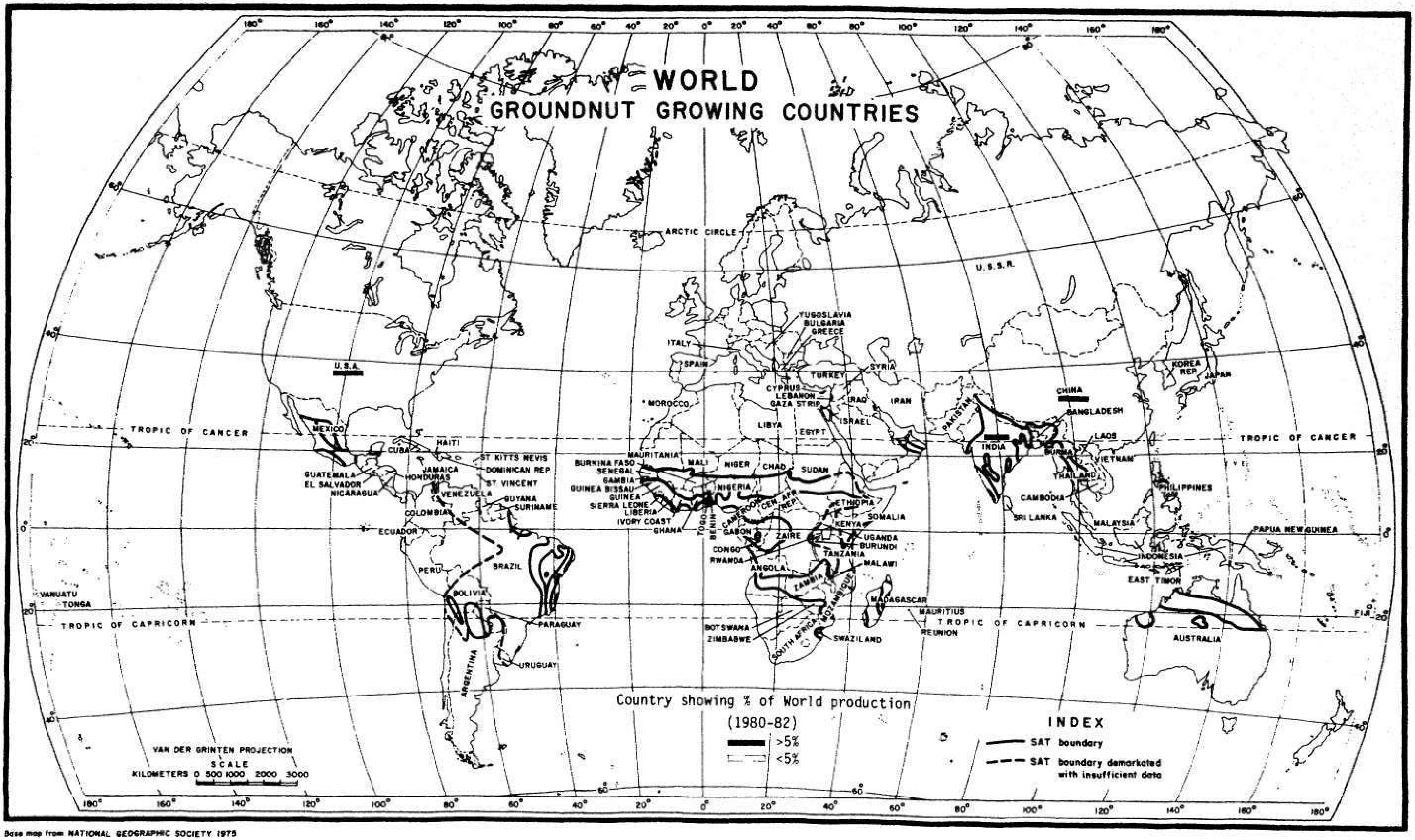

Base map from NATIONAL GEOGRAPHIC SOCIETY 1975

Figure 1. World groundnut-growing countries.

plusieurs milieux agro-climatiques différents. Dans les zones tropicales semi-arides, il s'agit d'une importante culture de rente au sein des systèmes agricoles de subsistance. Il s'agit également d'une importante source alimentaire. La production totale d'arachide dans les pays tropicaux semi-arides représente environ la moitié de toute la production mondiale.

Parmi ces pays, c'est l'Inde qui consacre la plus grande partie de son territoire à la culture de l'arachide. Sa production représente 52% de celle de tous les pays tropicaux semi-arides. Suit le Sénégal, le Nigeria et le Soudan (la part de chacun étant de 5 à 7,5% de la production d'ensemble de ces pays), le Zaïre, le Brésil, la Birmanie et l'Argentine (de 2,6 à 5%), et la Thaïlande, le Malawi, le Zimbabwe, le Cameroun, la République centrafricaine, le Tchad, le Mali et la Gambie (de 1 à 2,5%).

La culture de l'arachide a lieu principalement en terre aride non irriguée. En Inde, l'arachide est cultivée dans des sols qui varient des sables côtiers aux Vertic Inceptisols. Dans le sous-continent africain elle pousse dans des Alfisols et des Oxisols. En général, les sols propices à la culture de l'arachide présentent une capacité pour l'eau disponible de basse ($\lesssim$100 mm) à moyenne ($\simeq$200 mm) dans le profil racinaire.

En Inde, dans les régions de culture de l'arachide, les précipitations annuelles varient entre 400 mm et 1500 mm. Elles ont lieu habituellement au cours d'une période de pluie qui couvre de deux à quatre mois. La zone de culture est située entre 8°N et 32°N de latitude dans une grande variété de modèles de précipitations. En Inde du nord où les précipitations ont un caractère unimodal, les arachides croissent pendant la saison des pluies qui s'étend de juin à septembre. En Inde méridionale où les précipitations sont bimodales et où la température est propice à la culture de l'arachide presque tout au long de l'année, deux récoltes ont lieu. La période qui va de juillet à septembre/octobre (première saison des pluies) est la première consacrée à la culture de l'arachide, alors que la deuxième période, qui va d'octobre/novembre à janvier/février se situe au cours de la deuxième saison des pluies, nécessitant une irrigation additionnelle.

Dans la région sahélienne de l'Afrique occidentale, la culture de l'arachide a lieu dans une frange étroite située entre 10°-15°N de latitude. Le mois de juillet est celui de semis et la récolte a lieu en octobre. Dans cette zone, l'ensemble des précipitations saisonnières varie entre 300 et 1200 mm. La principale saison des pluies dure de deux à trois mois et commence vers les derniers jours de juin.

Les zones de culture de l'arachide des pays tropicaux semi-arides connaissent une brève saison de croissance (de 75 à 100 jours) et se caractérisent par des périodes de sécheresse intermittente. Nous avons procédé à l'examen des estimations probables sur l'adéquation de la teneur en eau de quelques emplacements sélectionnés aux besoins en eau de cette culture. Cette étude a montré que l'importance de l'humidité du sol dans les terres arables est assez limitée à l'époque de la germination et de la maturité, ce qui provoque des problèmes de développement des gousses et de récolte. Nos données ont également démontré qu'il est probable que le rendement de l'arachide diminue nettement une fois tous les trois ans, en raison de l'absence de précipitations saisonnières dans les pays tropicaux semi-arides.

Introduction

Groundnut *(Arachis hypogaea* L.) is a widely grown crop. It is cultivated in some 90 countries around the world. It requires tropical, subtropical, or warm temperate climates for optimum production. The approximate limits of its current commercial production lie between 40°N and 40°S (Fig.1). According to FAO (1982) 18.8 million ha were sown, and 19 million t of groundnuts in shell were harvested in 1980-82. The average yield was a little over 11 ha^{-1}.

Groundnuts are produced predominantly in developing countries. About 90% of total world production comes from this region. India and China produce about one-half of world production. The United States of America is also a major producer. In the developing world SAT countries account for over 60% of production (11 million t from 14 million ha).

Groundnut yields average 805 kg ha^{-1}, but vary widely in the SAT countries. In Brazil, yields exceed 1450 kg ha^{-1}. In Nigeria, Burma, Sudan, India, and Mali, the yields vary between 800-1000 kg ha^{-1} (FAO, 1982). In Malawi, Senegal, and Zaire yields range between 673-716 kg ha^{-1}. With the sole exception of Brazil, in all other SAT countries the per hectare yield is lower than the world average (Fig.2 and FAO 1982).

The groundnut crop is an important component of the mixed cropping patterns of the small farms of the dry tropics. It is a cash crop. It is a legume. Farmers depend on the extra cash it produces to

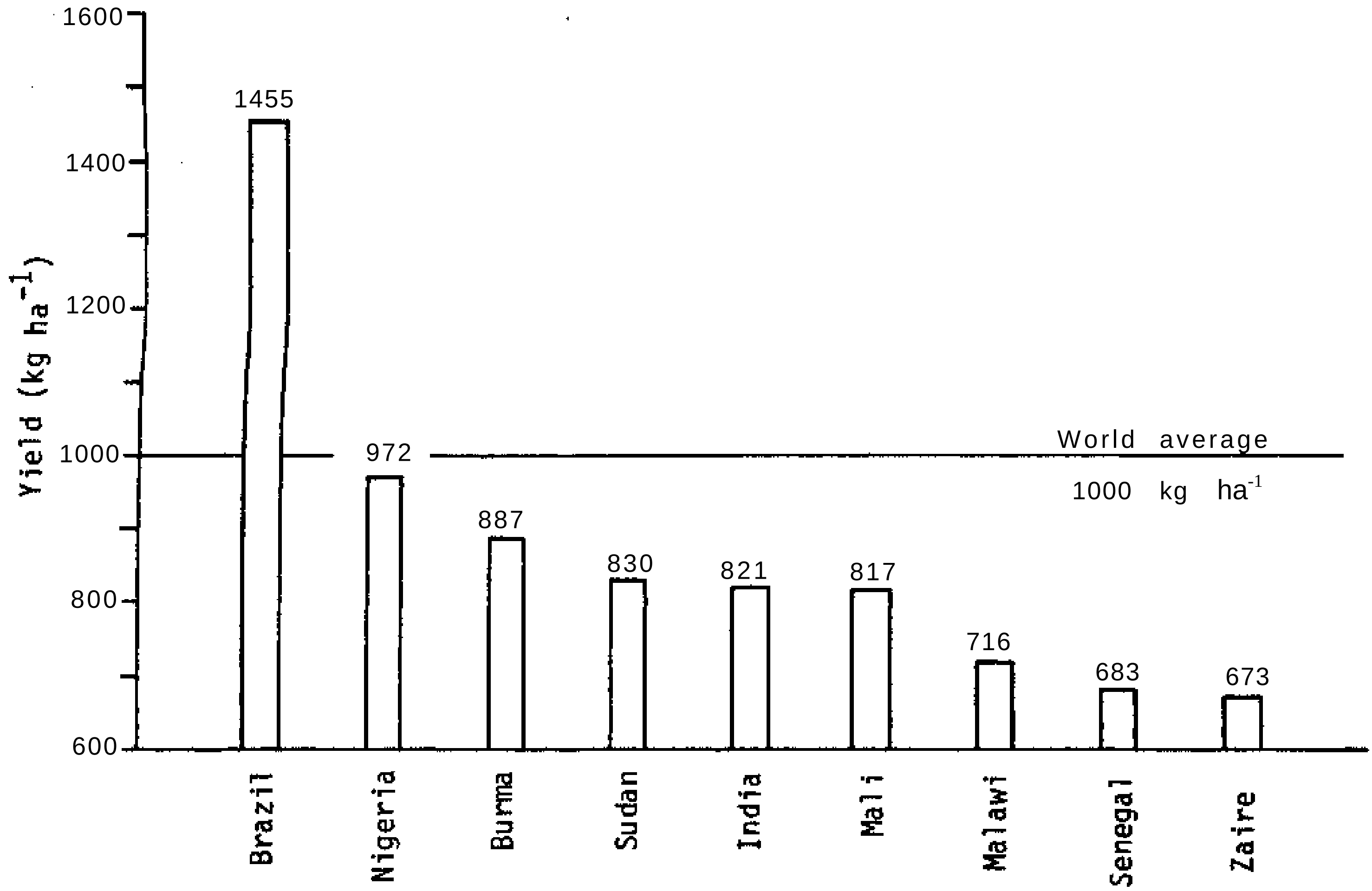

Figure 2. Groundnut yield in selected SAT countries. (Source: FAO 1982).

purchase inputs for cereals in the cropping systems. Groundnut not only produces oil for human food, but it also fuels the change of traditional low-input farms to modern agriculture. High and stable groundnut production is an essential element for the introduction of efficient farming systems in the SAT.

In many of the groundnut-producing countries the crop is consumed locally. India, the world's largest producer, is also one of the largest importers of vegetable oils. The countries of sub-Sahelian West Africa have been traditional exporters of groundnuts, but production there has declined recently. There is thus an urgent need to increase the productivity of the groundnut crop for sustained growth of semi-arid agriculture.

In this paper we will present:

- the ecological features of some important groundnut-producing areas of the SAT;
- agroclimatic analyses of some selected locations for identifying the soil and climatic constraints for increased groundnut production in different regions; and finally
- the analysis of rainfall environment for quantifying changes that have occurred in the groundnut-growing areas of sub-Sahelian West Africa in recent years.

Ecological Features of Principal Groundnut-Growing Areas of the SAT

South America

The SAT groundnut-growing area in this continent is in Brazil between 19° and 23° 5'S, with the major producing area between 20° and 23° 5'S. The total annual rainfall in this region varies from 1000-1400 mm. The crop is grown on Ustic-Ultisols (Ustults) that are dry for more than 90 d a^{-1}. The relative humidity of the area averages 73% for the year, but is higher during the groundnut cropping season. The main rainy season lasts 5 months—from November to March, but significant amounts of rainfall may be received in October and April. Less than 20% of the annual rainfall is received during the dry period from May to August. Total number of sunshine hours in the groundnut-growing area vary from 2200-2700 h a^{-1}. During the crop growing season the duration of sunlight hours is around 6 h d^{-1}. Annual potential evapotranspiration of the groundnut-growing areas of Brazil averages around 2000 mm. The annual rainfall meets about 50-60% of the annual climatic water demand (WMO 1971). During the rainy season, however, the rainfall more or less equals the potential evapotranspiration (PE) demand (1250 mm). Mean annual temperature is 24°C.

West Africa

In the West African region between 5-15° N, there is an extensive area in Senegal, Gambia, Mali, Burkina Faso, Niger, and Nigeria where groundnuts are grown. Senegal cultivated over 1 million ha of groundnuts in 1982 (FAO 1982). Other major groundnut-growing areas are in northwestern Mali, southeastern Burkina Faso, southern Niger, and northern Nigeria (Fig.l). The crop is sown in this region in June or July and harvested in September-October. The growing period lasts about 2-4.5 mo. The annual rainfall in the region ranges between 600 and 1000 mm, with an evapotranspiration rate (ET) of about 1700 mm a^{-1}. The ET for the growing season is about 550 mm. The average annual temperature is about 25°C, but it is generally about 30°C during the groundnut-growing season. The relative humidity during this period averages 80% (WMO 1971). In Sahelian West Africa groundnuts are grown primarily in sandy Alfisols and Oxisols.

Central and Southern Africa

The groundnut-growing countries in Central Africa are Central African Republic, Chad, Sudan, Uganda, and Zaire. In southern Africa groundnuts are grown in Malawi, Mozambique, and Zimbabwe. Some other countries have small areas under the crop (Fig.l). In Malawi the crop forms a significant part of the national agricultural production. It is cultivated on Ustic Oxisols and Alfisols (Ustoxs and Ustalfs) and some Udic Ultisols. The rainfall varies from 500-1500 mm. In Central Africa groundnuts are grown from June to September, while in Southern Africa these are sown in November/December and harvested in March. In Malawi the annual average temperature of the groundnut-growing areas is about 16℃. Total number of sunshine hours annually in the Malawian groundnut-growing areas is about 2550 (WMO 1971).

India and Southeast Asia

Over 7 million ha of groundnuts are cultivated annually in India. The total production is about 6 million t. Burma and Indonesia are also significant producers in the SAT (FAO 1982).

In India, groundnuts are cultivated on Ustic Alfisols, Oxisols, and Usterts (the dry Vertic soils), from 7-30°N. The major groundnut-producing areas are located in western India. The crop is raised primarily under rainfed dryland conditions. In northern India (20°N) groundnuts are sown with the onset of the rainy season in late June or July and harvested in October. In the eastern coast of southern India, where the rainfall is bimodal, two crops are raised per year. The second crop is raised with some supplemental irrigation. The first cropping season is from June to September or October, and the second from October/November through February. The average temperature during the growing season is 27°C, with total sunshine hours per annum in the groundnut-growing areas varying between 2381 and 2900 from south to north. The relative humidity during the cropping season is generally around 70%, with annual rainfall from 500-1500 mm (WMO 1971).

Agroclimatic Analysis of some Selected Locations

It is apparent from the ecological data that groundnuts are cultivated over a variety of soils and agroclimatic environments within the SAT. However, some generalizations can be made:

- in the groundnut region the rainfall is seasonal;
- the evapotranspiration rates are high;
- the rainfall is variable from year to year;
- the soils are mostly sandy and do not have adequate moisture-holding capacity; and therefore,
- the key factor affecting groundnut growth and yield is the characteristic and length of the moisture environment during the crop-growing season.

At ICRISAT Center we have collected extensive

Table 1. Locations selected for detailed agroclimatic analysis.

Region	Country	Location	Geocoordinates	
South America	Brazil	Campo Grande	20° 28'S	54° 40'W
West Africa	Senegal	Dakar (Yoff)	14° 44'N	17° 30'W
	Nigeria	Kano	12° 03'N	08° 32'E
Southern Africa	Malawi	Lilongwe	13° 58'S	33° 42'E
South and Southeast Asia	India	Ahmedabad	23° 04'N	72° 38'E
		Madras	13° 00'N	80° 11'E

climatological data sets for several groundnut-growing countries. For example, we have rainfall data for over 100 locations of Brazil extending back 30 years or more. Monthly values of potential evapotranspiration have been calculated for these locations. For West and Southern Africa, we have access to meteorological data for over 200 locations. In the case of India, we have a library of climatic data sets including daily rainfall, temperature, and open-pan evaporation for about 70 locations. For some locations in India, West and Southern Africa, we have also collected extensive micrometeorological data for some representative groundnut-based cropping systems.

We used the clustering procedure available in the statistical analysis system (SAS) package at Kansas State University, USA, to select a few representative locations from each of the major groundnut-growing regions for detailed analysis. We used the monthly and annual rainfall, moisture-availability index (MAI), and annual temperature as variables for clustering different locations. Our aim was to select one or two locations from each of the major groundnut-growing regions of the SAT which would represent about 80% of the sites within a given region with a unit ± standard deviation for the selected agroclimatic characteristics. By following these procedures, we identified locations for which we had at least 30 years of data (Table 1).

The moisture environment for these locations has been assessed by calculating the MAI at different probability levels. The amount of expected rainfall has been calculated using an incomplete gamma statistical procedure (WMO 1971). The potential evapotranspiration was calculated following modified Penman's procedure (Rao et al. 1971). Values of MAI less than 0.33 reflect a moisture environment insufficient for active plant growth, while values between 0.34-0.99 show adequate rainfall to meet plant-water needs. Values of MAI above 1.00 show that water is present in excessive amounts (after Hargreaves 1971). The values of MAI and the length of the growing season obtained at different probability levels for each of the locations studied are shown in Table 2. A brief description for the different locations follows.

Table 2. Moisture-availability index (MAI) and growing-season length of some selected groundnut-growing locations in the SAT,

Brazil: Campo Grande
20° 28'S 54° 40'W
Annual rainfall: 1437 mm

Soil: Ustult AWC' 175 mm
Data: 1931-60

Probability	Moisture-availability index						Growing season
(%)	Oct	Nov	Dec	Jan	Feb	Mar	(days)
80	0.29	0.24	0.58	0.69	0.58	0.50	135
Mean	0.69	0.54	0.99	1.19	0.97	0.61	200
40	0.85	0.58	1.09	1.36	1.15	0.77	+200

Continued.

Table 2. *Continued*

Senegal: Dakar (Yoff)
14° 44`N 17° 30'W — Soil:Ustalf AWC 75 mm
Annual rainfall: 578 mm — Data: 1931-60

Probability	Moisture-availability index				Growing season
(%)	Jul	Aug	Sep	Oct	(days)
80	0.21	0.95	0.80	0.06	70
Mean	0.54	1.76	1.14	0.33	135
40	0.55	1.90	1.15	0.37	+ 142

Nigeria: Kano
12° 03'N 08° 32'E — Soil: Ustalf AWC 75 mm
Annual rainfall: 872 mm — Data: 1931-60

Probability	Moisture-availability index				Growing season
(%)	Jun	Jul	Aug	Sep	(days)
80	0.55	1.11	3.05	0.60	140
Mean	0.66	1.46	2.53	1.02	154
40	0.70	1.52	2.60	1.03	161

Malawi: Lilongwe
13° 58'S 33° 42'E — Soil: Ustox AWC 75 mm
Annual rainfall: 849 mm — Data: 1931-60

Probability	Moisture-availability index					Growing season
(%)	Nov	Dec	Jan	Feb	Mar	(days)
80	0.13	0.44	0.84	0.79	0.39	120
Mean	0.39	0.76	1.26	1.37	0.77	160
40	0.45	0.85	1.28	1.62	0.85	+160

India: Ahmedabad
24° 04'N 72° 38'E — Soil: Ustert AWC 150 mm
Annual rainfall: 804 mm — Data: 1931-60

Probability	Moisture-availability index					Growing season
(%)	Jun	Jul	Aug	Sep	Oct	(days)
80	0.10	1.03	0.74	0.18	0.00	50
Mean	0.43	2.41	1.78	1.12	0.01	135
40	0.46	2.46	1.82	1.22	0.01	+135

India: Madras
13°00'N 80° II'E — Soil: Ulstalf AWC 50 mm
Annual rainfall: 1233 mm — Data: 1931-60

Probability	Moisture-availability index							Growing season
(%)	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(days)
80	0.12	0.27	0.44	0.47	1.10	1.28	0.18	120
Mean	0.28	0.52	0.80	0.89	2.12	2.85	1.18	180
40	0.29	0.54	0.90	0.95	2.03	3.17	1.50	+187

1. AWC = Available-water holding capacity of root profile.

Brazil: Campo Grande

The MAI values exceed the lower threshold value of 0.33 in all the rainy months at the various probability levels studied except October and November at 80% probability. The data for the length of the growing season show that it is at least 135 d in 8 out of 10 years. In 2 years out of 10, the rains will be insufficient at sowing time. Sowing may be delayed to late November in such cases. In this groundnut-growing area, soil fertility and its physical limitations are likely to be more important constraints to increased groundnut production compared to the soil-moisture adequacy for crop growth.

Senegal: Dakar (Yoff)

The MAI values (Table 2) at the 80% probability level are below the lower threshold of 0.33 for July and October. This means that in 1 out of every 5 years the growing season is likely to be restricted to about 70 d; it would be in the order of 135 d or more for many of the years (6 out of 10). Since the soils have low available-water holding capacity (75 mm) in the root profile, and the rainfall is low (578 mm), soil-moisture conservation would be an important component of improved groundnut-management systems in this West African region.

Nigeria: Kano

The rainfall at this location is 872 mm. Most of the precipitation occurs in the 4 months from June to September. At the 80% probability level (Table 2) the MAI values exceed the lower threshold values of 0.33 for each of the rainy months, thus ensuring a growing season of at least 140 d in most years (8 out of 10). The groundnut crop is raised on Alfisols in this region. This soil has about 100 mm AWC. Improved management of soil fertility and adequate water-conservation techniques would be important technology elements to increase groundnut production in this region.

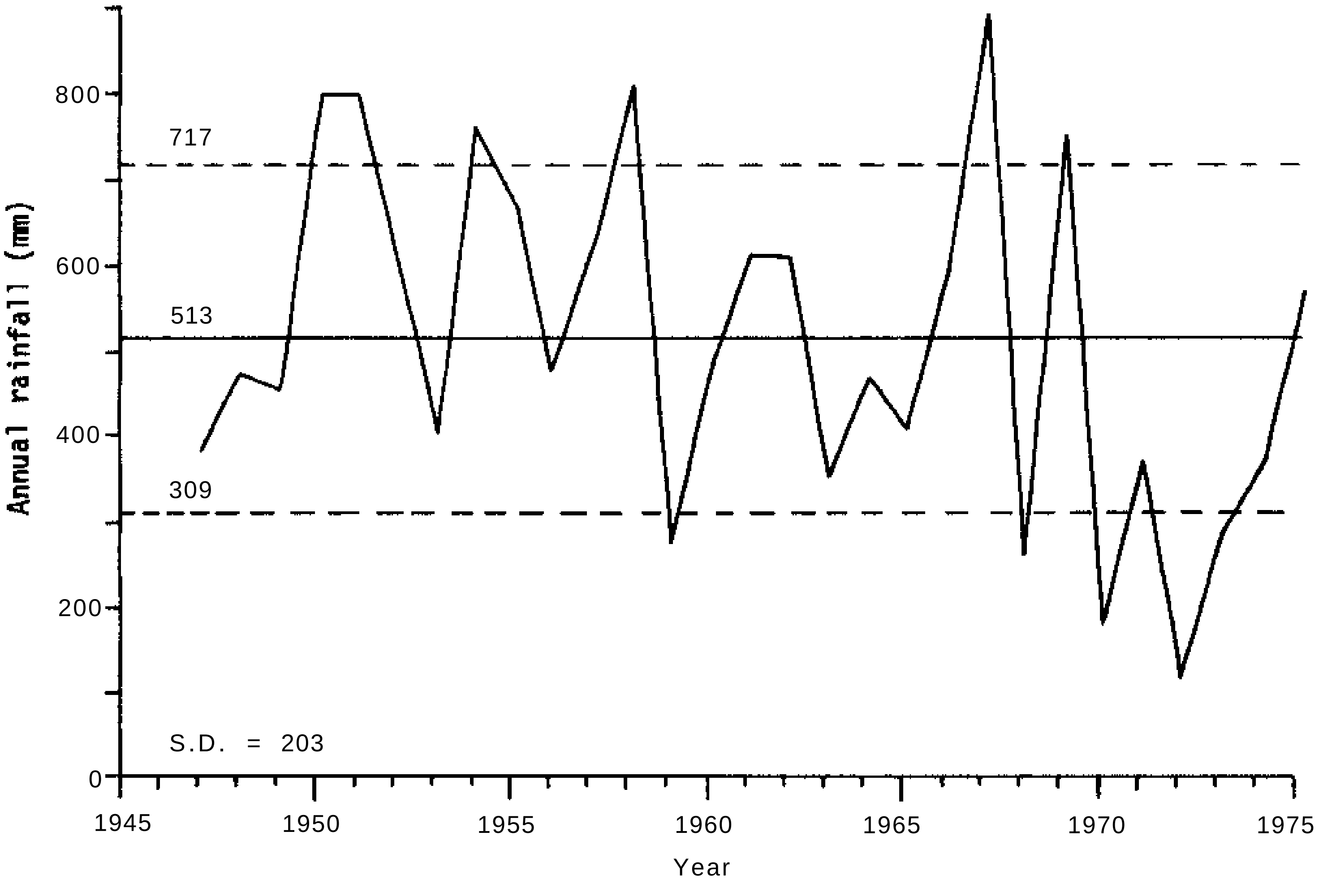

Figure 3. Annual rainfall trend at Dakar (Yofl), Senegal.

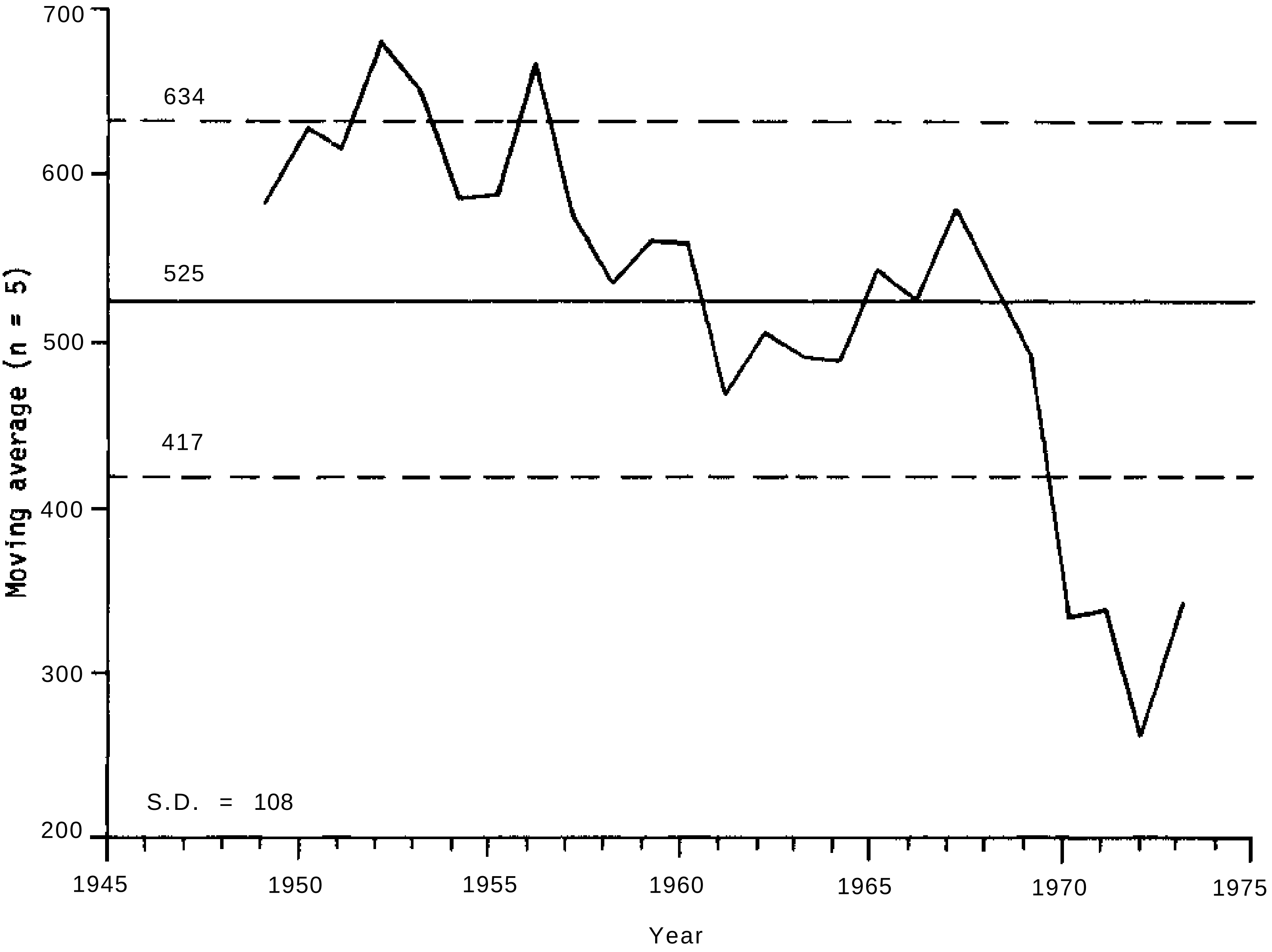

Figure 4. Five-year moving average of annual rainfall at Dakar (Yoff), Senegal (14°44'N, 17°38'W), 1947-1975.

Malawi: Lilongwe

In this Southern African country, the rainfall is fairly dependable except that sowing may be delayed due to low rainfall in the month of November in 1 out of every 5 years. The growing season exceeds 120 d in 8 out of every 10 years (Table 2). On average, it is 160 d. The soils on which groundnuts are grown have 75 mm AWC. Management of soil chemical properties would be important to increase groundnut production in this area.

India: Ahmedabad

In this north Indian groundnut-growing location, the crop is grown during the southwest monsoon. Average length of the growing season is 135 d. In 2 out of every 10 years, the growing season is likely to be highly restricted (to less than 50 d). October has very low MAI values (Table 2). Since the crop is grown on Vertic soils in this region, harvesting groundnut may present serious problems in most years. Water conservation would be an important aspect of improved dryland groundnut production in this area.

India: Madras

This southern Indian coastal location receives rainfall from both the southwest and northeast monsoons. Two growing seasons are utilized for raising groundnuts—the first from June to October and the second from October to January or February. However, two groundnut crops are rarely grown sequentially on the same dryland field. The data on MAI (Table 2) show that a 120-day crop could be raised in

8 years out of 10 in this area. The average growing season there is 180 d. Groundnuts are raised on Alfisols and Oxisols in this region. These soils have low AWC (≤ 50 mm). Soil and water management would be an important component of the improved groundnut-management systems in this region.

Changes in Rainfall Environment in Groundnut-Growing Areas of Sub-Sahelian West Africa

The West African sub-Sahelian zone is characterized by high evapotranspiration rates, low to medium seasonal rainfall, and sandy soils. The average rainfall barely meets the climatic water demand represented by high potential evapotranspiration rates. Any negative change in the amount of rainfall in this region could have serious consequences for increased and stable crop production. In order to quantify any changes in the rainfall of this region, we studied the precipitation records for 1947-1975 for Dakar (Yoff), Senegal. A plot of annual rainfall (Fig. 3) shows that precipitation has been highly variable from year to year over the past 30 years. The number of years of below-average rainfall has increased somewhat in the 1960-75 period. This observation is further confirmed by the 5-year moving-average data shown in Figure 4. In order to evaluate the agricultural significance of this trend we analyzed the probabilities of weekly rainfall (R/PE ≥ 0.33) for the periods 1947-1955, 1956-1965, and 1966-1975 (Table 3) which are shown in Figure 5. Since a crop-growing season of

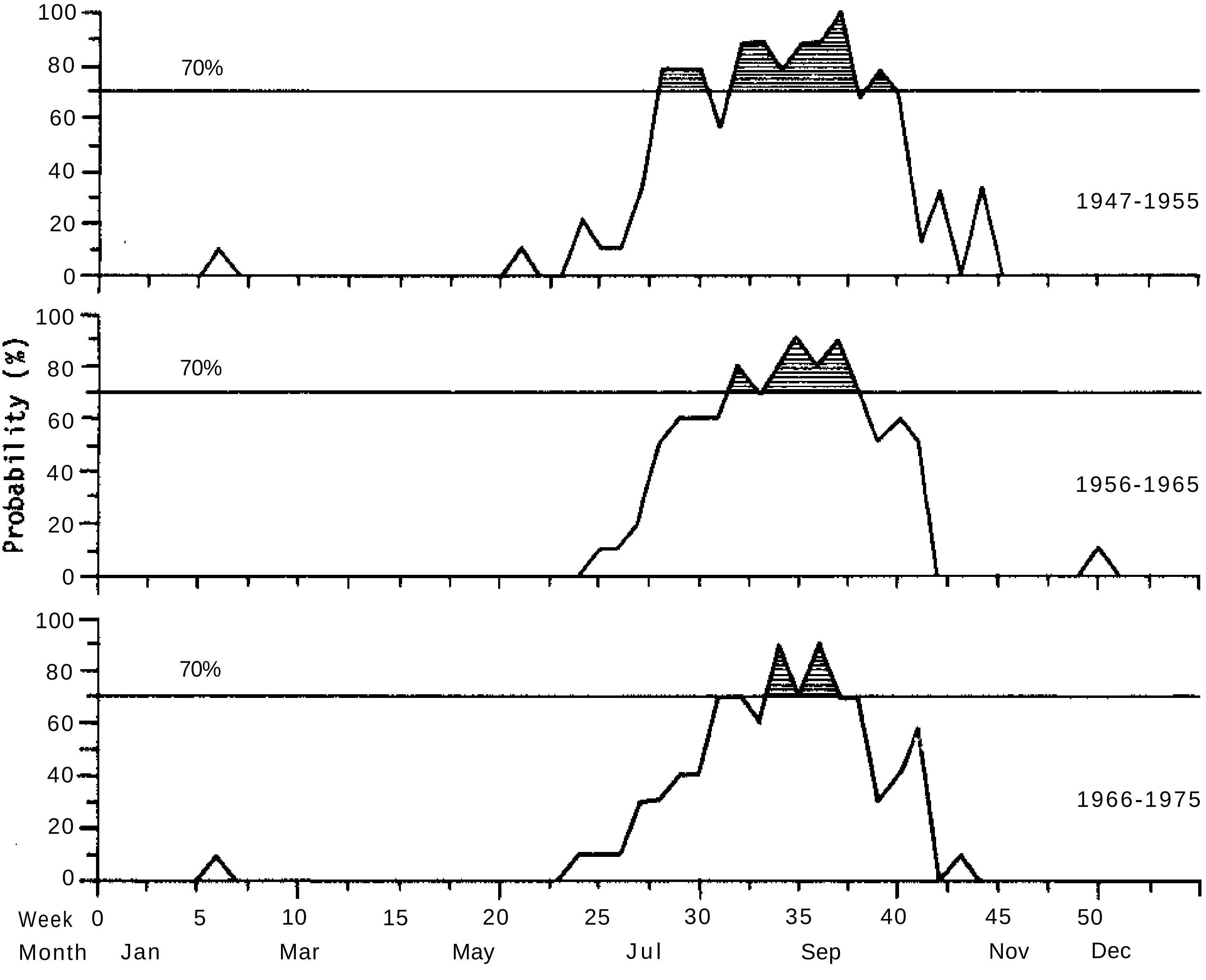

Figure 5. Rainfall probability estimates of R/PE ≥ 0.33 for three selected datum periods, Dakar (Yoff), Senegal (14° 44'N, 17°38'W).

Table 3. Probabilities (R/PE > 0.33) of weekly rainfall in Dakar (Yoff), Senegal.

Data-collection period	Weeks rainfall probability exceeded 70%	Probability of having a growing season of 10-12 weeks (%)
1947-1955	10	80
1956-1965	7	60
1966-1975	6	40

about 84 d is required for optimal groundnut production in western Senegal, the constraint imposed by shortening the length of the growing season could have grave consequences on crop yield.

We have also analyzed, on a similar basis, the precipitation data of a few other African groundnut-growing locations. We observed a similar trend. These results show that the agroclimate of the groundnut-growing areas is fragile. The rainfall of these areas is low and seasonal, and preliminary indications are that it decreased in the past few decades. The growing season is getting shorter. Further, the groundnut-growing soils are sandy, shallow, and in many cases highly prone to erosion. A serious interdisciplinary farming systems research effort must be continued and further intensified to evolve new and improved groundnut-production systems to increase and stabilize yields in the SAT.

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Biological Constraints to Increased Groundnut Production in the Semi-Arid Tropics

R. W. Gibbons[1]

Abstract

Groundnuts, wherever they are grown, are subjected to a wide range of destructive organisms that can reduce yields. Fungal pathogens are common, and on a global scale the leaf spots, rust, and the toxin-producing Aspergillus flavus *are regarded as important, and can drastically reduce yields or the quality of the crop. Other fungi are regionally or locally important, and there are instances where new pathogens have recently become serious. In general, viruses are restricted in distribution, but on a regional or national basis can be devastating in years when epidemics occur. At least one virus, the seed borne peanut mottle virus (PMV), is found in most groundnut-growing countries and is often overlooked because it produces mild symptoms. Only one bacterial disease, caused by* Pseudomonas solanacearum, *is economically important, and is a problem in certain areas, particularly China and Indonesia.*

Many pests attack groundnuts, but relatively few cause consistent and serious yield losses on a worldwide basis. Aphids are, however, important globally and are vectors of several important viruses. Direct yield losses caused by species of thrips are usually not serious, but Frankiniella schultzei *is very important as the main vector of bud necrosis virus in India. Locally, leafhoppers, millipedes, leaf miners, and various sucking bugs can be serious pests.*

Over the last decade there has been an increasing effort to utilize host-plant resistance, or integrated management schemes, to overcome many of the more serious yield reducers.

Aspects of poor nodulation due to inefficient native strains, or poor application techniques, are discussed in the light of current research findings.

Résumé

Contraintes biologiques à l'accroissement de la production d'arachide dans les régions tropicales semi-arides : *L'arachide, partout où elle est cultivée, est soumise à une large gamme d'organismes destructeurs qui peuvent réduire la production. Les champignons pathogènes sont communs, et à l'échelle mondiale, les taches foliaires, les rouilles, et la toxine produite par* Aspergillus flavus *sont considérées comme importantes et peuvent radicalement réduire la production et la qualité de la récolte. D'autres champignons sont régionalement ou localement importants et il y a des cas ou de nouveaux agents pathogènes sont devenus récemment dangereux. En général, les virus ont une distribution restreinte, mais régionalement ou localement ils peuvent être dévastateurs durant les années d'épidémies. Un virus, au moins, le "peanut mottle virus" (PMV) porté sur les semences est présent dans la plupart des pays producteurs d'arachide; il est souvent sous-estimé parce qu'il produit des symptômes légers. Seule une maladie bactérienne causée par* Pseudomonas solanacearum *est économiquement importante et pose un problème dans certaines zones, particulièrement en Chine et en Indonésie.*

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De nombreux insectes nuisibles attaquent l'arachide mais relativement peu sont responsables de pertes de production graves à l'échelle mondiale. Les aphidés sont cependant importants car ils sont les vecteurs de divers virus importants. Les pertes de production directes causées par diverses espèces de thrips ne sont pas graves en général, mais Frankiniella schultzei *est très importante puisque c'est le vecteur principal du virus de la nécrose du bourgeon en Inde. Localement les cicadelles, les mille-pattes, les mineuses des feuilles et diverses cochenilles peuvent être des insectes nuisibles dangereux.*

Durant la dernière décennie, un effort important a été mené pour utiliser des plantes hôtes résistantes ou des schémas de gestion intégrée afin de combattre les principaux réducteurs de rendement.

Des aspects de faible nodulation dus à des souches originelles inefficaces ou à de mauvaises applications techniques sont discutés à la lumière de résultats de recherche récents.

Introduction

The cultivated groundnut, *Arachis hypogaea* L., is grown in many countries of the semi-arid tropics (SAT). In the SAT the groundnut, with its high protein and oil content, is important both as a human food and a source of cooking oil. Groundnut hay is used extensively in the SAT as cattle fodder, particularly in the dry season after the crop has been harvested. The hay is often sold for cash in Africa, but the yield and quality may be affected by foliar diseases which can cause extensive defoliation before harvest. To many farmers of the SAT, groundnuts are a major source of cash income when sold for local consumption, or for export to developed countries.

Yields in the SAT are low, averaging 800-900 kg ha^{-1}, compared to the average yield of over 2500 kg ha^{-1} produced in developed countries such as the United States. The low yields can be attributed to three major constraints: unreliable rainfall, pests, and diseases. In the United States similar constraints are present, but are overcome by capital inputs of mechanization, irrigation, fertilizer application and pest-control systems.

Biological constraints are not independent of abiotic constraints. Pests and diseases are affected by each other, and by climate and soils in very complex interactions. For simplicity, biological constraints can be conveniently discussed under the headings of diseases, insect pests, and factors affecting symbiotic relationships with nitrogen-fixing bacteria. In this review weeds will not be discussed, although their importance as yield reducers is well recognized.

Diseases

Groundnuts are affected by many diseases caused by fungi, viruses, and bacteria. Diseases may be distributed worldwide, or of only regional or restricted significance.

Foliar Fungal Diseases

Three foliar diseases exist worldwide and cause significant losses annually, particularly in the developing countries of the SAT. The leaf spots (early and late) have long been regarded as serious diseases of groundnut, while the third major disease, rust, has only been of worldwide significance over the last 15 years.

Leaf Spots

Early leaf spot, caused by *Cercospora arachidicola,* and late leaf spot, caused by *Cercosporidium personatum,* are probably the most serious diseases of groundnut worldwide (Jackson and Bell 1969). The diseases have often been collectively referred to as *Mycosphaerella* leaf spots, Cercospora leaf spots, brown leaf spots, peanut cercosporiosis, viruela, and tikka (Jackson and Bell 1969). Although both leaf spots are commonly present together, the intensity and severity of each disease varies over localities and seasons, and there can be both short- and long-term fluctuations in their relative proportions. Early leaf spot was the predominant disease in the southeastern United States from 1967 until 1976, but since then late leaf spot has become dominant (Smith 1984). In the groundnut-producing states of southern India late leaf spot is very severe, and early leaf spot is much less important (Subrahmanyam et al. 1980). In Nigeria, late leaf spot predominates in the low-rainfall areas of the north, but early leaf spot is more important in the higher-rainfall areas (D. McDonald, ICRISAT, personal communication 1985). In Malawi early leaf spot regularly causes almost complete defoliation of the crop in the main producing areas (1000-1500 m elevation) of the central region. Late leaf spot is common in the low-altitude areas where it is hot and humid (Sibale and Kisyombe 1980). Late leaf spot is more important in the Casamance region of southern Senegal (Gautreau and De Pins 1980). In many countries of the SAT detailed information defining which leaf spot predominates, and the climatic conditions affecting spread of the diseases, is lacking. Care also has to be taken in identifying the leaf spot fungi by symptoms alone, as symptom expression is affected by cultivar and environment (Subrahmanyam et al. 1982a).

It has been estimated that leaf spots can reduce pod yields from 10-50% when fungicides are not applied (Jackson and Bell 1969). Losses of 10% have been reported in the United States, even under regular fungicide-application regimes (Jackson and Bell 1969). However many peasant farmers in the SAT cannot afford or lack access to modern fungicides, sprayers, and even adequate sources of clean water for high-volume spraying on their crop. In northern Nigeria application of fungicides in certain low-rainfall seasons has extended the growing season of cultivars adapted to the region, leading to drought stress and aflatoxin problems due to late harvesting (D. McDonald, 1CRISAT, personal communication 1985).

There are at present no released cultivars resistant to either of the leaf spot fungi, but in the last few years more intensive research programs on breeding for resistance have begun in several countries. Breeding lines with moderate resistance to both leaf spots and with desirable agronomic traits are being bred (Smith 1984). Many rust-resistant cultivars, mainly from South America, also have moderate levels of resistance to *C. personatum* (Subrahmanyam et al. 1982b). Sources of resistance to early leaf spot in A *hypogaea* have been reported from the United States (Sowell et al. 1976, Hammons et al. 1980). However, Subrahmanyam et al. (1983) failed to find resistance to early leaf spot in some 2000 genotypes screened in Malawi, even though the collection contained genotypes reported resistant elsewhere. Strains of both fungi resistant to the fungicide benomyl have been reported (Clark et al. 1974). Variation in the pathogens could make breeding for resistance more location-specific. Sources of resistance and immunity to the leaf spot fungi also occur in the wild *Arachis* species. Interspecific breeding programs utilizing this resistance are underway in the United States, and at ICRISAT Center in India (Stalker 1984, Moss 1980).

Rust

Rust, caused by *Puccinia arachidis,* was largely confined to South and Central America and the Caribbean prior to 1969, with occasional outbreaks occurring in the southeastern groundnut-producing areas of the United States. The disease was also recorded in the USSR in 1910, Mauritius in 1984, and the Peoples' Republic of China in 1937, but did not become permanently established in these countries (Hammons 1977, Subrahmanyam et al. 1979). In recent years rust has spread, and has become established in most groundnut-growing countries in Asia and Africa (Subrahmanyam and McDonald 1983). Yield losses from rust can be substantial. In Texas, Harrison (1973) reported losses of 50-70%, and in India Subrahmanyam et al.(1983) reported losses of 50%. When rust occurs in conjunction with the leaf spot fungi, yield losses can be even higher.

The reasons for the rapid spread of rust over the last 15 years are not clear. Groundnut rust can spread by long distance dissemination of urediniospores, by the movement of infected crop debris, or by the movement of pods or seeds surface-contaminated with urediniospores or infected crop debris. There is no reliable evidence of groundnut rust being internally seedborne (Subrahmanyam and McDonald 1983). Urediniospores are short-lived on infected plant debris. It is therefore unlikely that the fungus is perpetuated from season-to-season in crop debris under the hot climatic conditions often encountered in the SAT, particularly if only one groundnut crop is grown in a year (Subrahmanyam and McDonald 1982). Perpetuation could be in several ways. The pathogens could survive from season-to-season on volunteer groundnut plants. No authentic alternate host species are known outside the genus *Arachis* (Subrahmanyam and McDonald 1983). Continuous groundnut cropping without any break appears to be the most likely factor in the perpetuation of rust. This happens in the SAT regions of India, particularly in the southern states, where rainy-season crops are followed by crops grown on residual moisture and under irrigation (Subrahmanyam and McDonald 1983). Double cropping of groundnuts also occurs in the wetter, humid areas of China (Zhou et al. 1980) and Thailand (A. Patanothai, Khon Kaen University, Thailand, personal communication).

In the SAT areas of southern Africa rust was reported in March 1974 from Zimbabwe, and in Zambia and Malawi in 1975. It is also present in Mozambique and Tanzania. Cole (In press) in a recent review of the rust situation in southern Africa states that although the initial outbreaks caused concern, and the disease is now endemic to the region, serious outbreaks are now confined to specific groundnut-growing areas and it is sporadic in the rest of the production areas. Cole (In press) has related altitude and humidity to rust outbreaks. Where groundnuts are grown in Malawi below an altitude of 750 m rust is serious, as in the lakeshore areas of the country which all lie below 500 m. Similar situations occur in the lower altitude areas of Zimbabwe, Zambia, Tanzania, and South Africa. All these countries, except Mozambique, grow a single crop of groundnuts in a year. Planting is from Nov-Dec, and the main production areas are at altitudes above 1000 m. In southern Mozambique groundnuts are planted from Jul-Oct and the main crop in more northerly areas is planted in Nov-Dec. Cole (In press) suspects that spores are blown from southern Mozambique to the main growing areas which are planted later. This could explain the late development of infections even in the rust-prone areas of Malawi. In Zimbabwe also, rust appears only on isolated plants a month before harvest.

In West Africa, rust was first reported in Nigeria during October 1976. The disease was widespread but not serious in the northern states, and occurred only near harvest time. It was suspected that the arrival of rust was from the east (Fowler and McDonald 1978). In early 1977 rust was found on volunteer groundnuts at Mokwa, in the higher-rainfall riverine areas to the south. It appeared in Zaria in late August 1977, and later appeared further north in Kano and Bornu states. Fowler and McDonald (1978) estimated yield losses at not more than 5%. Salako and Olorunju (In press) later reported that rust is highly dependent on the amount and spread of rainfall. In the wetter, more southern areas, where the rains last from 7-9 months, this disease is serious and occurs regularly. In the drier, main production areas, it is not economically important. Sankara (In press) reported that rust appeared in Burkina Faso in 1977 and is economically important in the 1000-1100 mm rainfall zone, particularly when temperatures are low (19-25°C), and the relative humidity is high (80%). Gautreau and De Pins (1980) regarded rust as a potential, rather than an actual, threat to groundnuts in Senegal and introduced rust-resistant material as a precaution. If the observations on high rainfall and long season length are indeed well correlated with rust outbreaks, then the main production areas in the drier zones of the SAT are not going to be seriously affected by rust.

Excellent sources of resistance to rust exist both in the cultivated groundnut and in wild *Arachis* species, with breeding programs underway in several countries to incorporate these resistances. Agronomically acceptable, high-yielding, rust- resistant cultivars may become available soon (Subrahmanyam et al. 1984). Present evidence indicates that resistance to rust is stable over widely separated locations in the Americas, India, and the Peoples' Republic of China (Subrahmanyam et al. 1983).

Other Foliar Diseases

Many other foliar diseases caused by fungi have been reported from the SAT and other regions of the world. They are usually of local or of no economic importance at present, and they have been reviewed recently by Porter et al. (1984). Sometimes these diseases may become important if changes occur in cultivars or climate. Web blotch, caused by *Phoma arachidicola* is also known as Ascochyta leaf spot and muddy spot. This disease was first recognized in the USA as serious in 1972, although described earlier in several other countries (Smith 1984). It has also become more important recently in Malawi and Zimbabwe, particularly during cool and wet seasons in the higher-altitude areas. In Zimbabwe breeding for resistance has begun after promising resistant cultivars were identified (Hildebrand 1980).

Soilborne Diseases

Two recent reviews list up to 20 soilborne diseases affecting groundnuts (Porter et al. 1982, 1984). Stem rot, caused by *Sclerotium rolfsii,* also known as white mold or stem blight, is listed as the most important yield-reducing disease in the United States. It has been recorded in all groundnut-growing areas of the world (Feakin 1973), but has not received or been given much prominence in the SAT. This is not surprising because rapid disease development requires warm, moist conditions, particularly under a very extensive, lush canopy. Mercer (1978) reported 5. *rolfsiias* being a disease seen on research stations in Malawi, and Rothwell (1962) mentions the fungus as causing slight damage in Zimbabwe which could become more serious under intensive cultivation. The fungus overwinters on organic matter in the soil. At ICRISAT Center the disease is serious on groundnuts grown on Vertisols but not on Alfisols. Control measures include deep burial of crop residues by ploughing.

Pod Breakdown and Pod Rots

Many fungi attack pods, but two fungi, *Pythium myriotylum* and *Fusarium solani,* are responsible for serious economic yield losses in many countries (Porter et al. 1982). They have been studied intensively in the United States but little research has been done on them in the SAT. Mercer (1977, 1978) described F. *solani as* causing a wilt and pod breakdown in Malawi. Yield losses caused by these, and other similar fungi, have probably been underestimated in the SAT. At ICRISAT Center detailed studies have shown that susceptible cultivars had 20-25% of their pods rotted at harvest time. Disease levels in germplasm lines ranged from 4-72% (Subrahmanyam et al. 1980).

Macrophomina phaseolina causes a dry root rot, a stem rot, wilting, and 'blacknuts'. The disease is cosmopolitan and soilborne. M. *phaseolina* is particularly serious in the Gambia. Intact pods and seeds may appear healthy but if climatic conditions are favorable for fungal growth, or the harvest is delayed, blacknut symptoms occur. Infection starts between the cotyledons and eventually the white mycelium turns gray and then black. The symptoms are often hidden and become apparent only when the seed is split open. Apart from appearance, the quality of the seed is spoiled, making them unsaleable (Feakin 1973).

Seed and Seedling Diseases

Groundnut seed and seedlings are highly susceptible to disease because they present a rich source of stored nutrients useful to numerous fungi. If the delicate testa, which protects the seed against invasion by fungi, become damaged then the underlying cotyledons become susceptible to attack. Species of *Rhizopus* and *Penicillium, Aspergillus niger* and A *flavus* are commonly isolated from germinating seed. Adverse soil temperatures and moisture conditions delay seedling emergence, and increase the probability of invasion by pathogenic soil inhabiting fungi (Sullivan 1984).

Aspergillus niger causes a crown rot and a collar rot as well as a seedling blight, and is a worldwide problem. It is very prevalent on the lighter tropical soils in the SAT because it can tolerate low soil-moisture conditions. It develops most rapidly at 30-35°C (Feakin 1973).

Many countries in the SAT have developed control measures for seed and seedling diseases, usually involving rotations and chemical seed dressings. Without these measures losses caused by *A. Niger* have been estimated at more than 50% in areas of continuous groundnut cultivation in India (Chahal et al. 1974).

Yellow Mold and Aflatoxin

Mycotoxins of *Aspergillus flavus* came into prominence in the early 1960s when they were found in groundnut meal, and killed 100 000 young turkeys in the United Kingdom. Mycotoxins are toxic fungal metabolites and the toxin produced by *A. flavus* group of fungi are known as aflatoxins. They are powerful carcinogens and have been implicated in both animal and human deaths from liver cancer (Pettit 1984). This discovery has caused great consternation among world health authorities and importers or users of groundnut products. The literature on *A. flavus is* now voluminous and has recently been reviewed by Diener et al. (1982).

As the role of the environment on the incidence of aflatoxin is discussed by two other scientists at this conference (Picasso and Pettit) only some general remarks are made in this review of biological constraints.

A. flavus is found throughout the world. In the SAT the groundnut crop is very vulnerable to invasion before harvest because pods are commonly damaged by insects and fungi, which facilitates invasion by *A. flavus.* As the crop is grown mostly by small farmers, often using hand tools, there is a high possibility of damage to pods and seeds at lifting and shelling. There is always a great chance of droughts occuring in the SAT, and droughts have been strongly linked with the occurrence of aflatoxin in groundnuts. Rapid drying of the seeds to 7-9% moisture content, below which levels the fungus cannot grow, is difficult in the SAT because drying is often done in the field. Late rains can rewet the pods and the moisture content rises, thus allowing the fungus to regrow. The SAT countries often lack the stringent inspection systems that have been set up in the United States, and moldy, infected seed is often eaten when the fields are gleaned after harvest. These overmature seeds are likely to have high levels of aflatoxin.

In addition to cultural methods, there are alternative approaches to reduce aflatoxin contamination. One of these is to breed cultivars with resistance to seed invasion by *A. flavus.* Several germplasm sources have been identified whose seed is not invaded by

A. flavus as long as the testa remains intact (Mixon and Rogers 1973, Mixon 1979, Mehan et al. In Press). Field trials in the United States with these breeding lines from Georgia failed, however, to show any reduction in aflatoxin content of their produce compared to the commonly grown cultivar Florunner (Blankenship et al. In press, Davidson et al. 1983). Another approach being taken at ICRISAT Center is to screen germplasm lines to determine the ability of their seed to support production of aflatoxin when inoculated with an aflatoxin-producing strain of A. *flavus* (Mehan et al. In press). Initial screening took place in 1979, and significant differences in the rate and accumulation of aflatoxin between cultivars were found (Mehan and McDonald 1983). Further studies have shown that the genotypes U4-7-5 and VRR 245 produced less than 10 μg g^{-1} seed of aflatoxin B_1 compared to the control cultivar TMV 2, that produced more than 150 μg g^{-1} seed. These genotypic differences in aflatoxin B_1 production were consistent over seasons, although levels were slightly lower in seed from the rainy-season crop than in seed produced in the irrigated postrainy-season crop (Mehan et al. In press).

So far no cultivar has been found that resists invasion when the testa is intact, and is also a low aflatoxin producer when the testa is removed. Attempts are now being made at ICRISAT Center to breed genotypes with low aflatoxin-production levels and resistance to seed invasion.

The solution to the aflatoxin problem will not be dependent on any one approach, whether it be genetic, cultural, or chemical. There will have to be an integrated management approach including good husbandry, correct harvesting and curing practices, good storage methods, genetic character utilization, improved sorting procedures, and detoxification techniques.

Bacterial Diseases

Bacterial wilt, caused by *Pseudomonas solanacearum,* is regarded as the only serious bacterial disease of groundnuts and is extremely serious on tobacco, potatoes, eggplants, and other solanaceous crops (Feakin 1973). Consistent heavy yield losses in groundnuts occur in the humid regions of southern China, Indonesia, and Uganda. Although a serious outbreak occurred in Georgia in 1931 it is now regarded as a minor disease in the United States (Gitaitis and Hammons 1984).

The disease flourishes in the warmer tropical and temperate areas. It is soilborne, and survives best in soils with high moisture levels. At present it does not seem to constitute a threat to groundnut production in the SAT.

Virus Diseases and their Vectors

There are several virus diseases affecting groundnuts, many of which have not been precisely characterized (Reddy 1980). Four viruses are of particular economic importance in the SAT, and they differ widely in their distribution, characteristics, and mode of transmission. These four viruses have been more extensively studied than many of the minor ones, but there are still many gaps in our knowledge because of the lack of virologists and well-equipped laboratories in the developing world (Reddy 1980).

Peanut Mottle Virus

Peanut mottle virus (PMV) was first discovered as the causal agent of a mottle disease in 1961. Since then it has been reported in all major groundnut-producing regions of the world (Kuhn and Demski 1984). Positive identification of PMV has been made in the United States, East Africa, Australia, Europe, Japan, Philippines, South America, Malaysia, and India (Ghanekar 1980). It has probably not been identified positively in many other countries of the SAT because of the very mild symptoms produced, and the lack of plant stunting usually associated with viruses.

Yield losses have been estimated as high as 30% in Georgia, USA (Kuhn and Demski 1975). PMV is a polyvirus and is transmitted by several species of aphids, including *Aphis craccivora,* in a nonpersistent manner.

This virus occurs in nature on several important legume crops of the SAT, including *Glycine max, Phaseolus vulgaris,* and *Vigna unguiculata.* Transmission through groundnut seed appears to be the most important source of PMV in groundnut, and the free exchange of seed around the world has probably helped to spread the virus. Aphids are efficient vectors of PMV, and will transmit the virus to other plants. Any climatic conditions that favor a rapid buildup of aphid populations could result in an epidemic. The epidemiology of the disease has been studied in the United States (Kuhn and Demski 1984). Little is known about the role of wild legumes in the SAT that could sustain the virus, and the aphid vectors, during the dry season.

Tomato Spotted Wilt Virus

A ringspot disease caused by Tomato Spotted Wilt Virus (TSWV) was first reported in Brazil in 1941 (Costa 1950). It was subsequently recorded in South Africa, Australia, United States, India, and Nigeria (Reddy 1984a). The disease has only reached epidemic proportions in India, and this has only happened in the last two decades. It is now regarded as one of the most important groundnut diseases in India where it is known as Bud Necrosis Disease (BND), because one of the typical symptoms is death of terminal buds (Ghanekar et al. 1979). The virus has a wide host range, including some common weeds of groundnuts in India, and unlike PMV, it is not seedborne.

Over 7000 germplasm lines have been screened at ICRISAT Center for resistance, but without success. Some germplasm lines and a number of released cultivars do, however, show lower-than-average incidence of the disease under field conditions (Reddy et al. 1983). The disease is transmitted in India by two species of thrips, *Frankliniella schultzei* and *Scirtothrips dorsalis.*

The virus is only acquired by the vectors in the larval stage. Adults cannot acquire it but they can transmit (Reddy 1984b). Studies in India by Amin and Mohammad (1980) have shown that epiphytotics are associated with an abundance of the major vector, *F. schultzei* Populations of the vector are at their lowest during the summer months when they survive on wild plants, cultivated crops, and ornamentals. Migration occurs after the monsoon showers start. At Hyderabad large-scale migrations to groundnuts occur in August and January. The thrips are carried by the prevailing winds, mainly in the early evening. Disease incidence is associated with immigrant thrips and secondary spread seems to be less-important (Amin and Mohammad 1980).

Control measures include early planting to promote plant growth before the major immigrations occur, and high plant populations to dilute the percentage of infected plants. Planting less-susceptible cultivars, such as Robut 33-1, is also a part of the integrated management system.

BND has become more important in India over the last decade, and this is possibly due to double cropping of groundnuts and planting highly-susceptible cultivars. Further research on the epidemiology of the disease on a national scale is required. As this disease can build up rapidly, vigilance should be exercised in other countries where the vectors and the virus are known to occur.

Peanut Clump Virus

Peanut clump virus (PCV) has been reported from Senegal, Burkina Faso, and the Ivory Coast in West Africa (Thouvenel et al. 1976), and from several locations in India. Early-infected plants in India produce few pods and yield losses of up to 60% have been observed in late-infected plants (Nolt and Reddy 1984).

The disease occurs in patches in the field, and reappears in progressively enlarged patches in later years. Infected plants are dwarfed and dark green with darkened roots, the epidermal layers of which peel off easily. The physical properties and morphology of the rod-shaped particles of West African and Indian PCV-isolates are identical. Local lesions produced by the Indian and West African isolates are identical on *Chenopodium quinoa,* but the West African isolates have a wider host range. Serologically, the isolates from within different regions of India are different (D.V.R. Reddy, ICRISAT, personal communication).

PCV is soilborne, and the vector in West Africa is a fungus, *Polymyxa graminis.* In India, the vector for PCV has not yet been confirmed, but P. graminis has been isolated from graminaceous hosts in PCV-infected soils (D.V.R. Reddy, ICRISAT, personal communication).

PCV is the first soil-transmitted virus to be identified in groundnuts. The actual distribution of PCV has not yet been fully determined in either West Africa or India. Visual observations of plants infected with PCV could be confused with the symptoms of 'green rosette', which is common in West Africa. The only control method at the moment is the use of biocides that destroy the soilborne vector, and hence the virus.

Groundnut Rosette Virus

Groundnut rosette, first reported from Africa in 1970, is recognized as the most economically important virus disease of groundnuts. It is now believed that rosette is confined to the African continent, south of the Sahara. Earlier reports of rosette in Australia and Indonesia were not substantiated, and in India the reports were based only on visual symptoms (Gibbons 1977). Several of the Indian reports probably confused clump and bud necrosis viruses with rosette (D.V.R. Reddy, ICRISAT, personal communication).

'Green rosette' (GGR) and 'chlorotic rosette'

(GCR) are recognized on the basis of symptoms. GGR is commoner in West Africa, whereas GCR is commoner in East and Southern Africa. Depending on time of infection the disease can cause yield losses of up to 80%. Rosette is transmitted in a persistent manner by *Aphis craccivora* (Reddy 1984c). Recent research has confirmed earlier reports that rosette virus consists of at least two components, one of which causes the symptoms of rosette, and the other is an assistor virus that is required for transmission by aphids (D.V.R. Reddy, ICRISAT, unpublished).

Limited tests have shown that no naturally-occurring hosts of the aphid, apart from groundnut volunteer plants, are alternate hosts of the virus as well (Gibbons 1977). In Tanzania, Evans (1954) stated that groundnut volunteers can survive the dry season and act as reservoirs of the virus and the aphid. In Malawi, volunteer groundnuts are difficult to find after the long dry season of 7 months begins in April (K.R. Bock, ICRISAT, personal communication). In Nigeria, Booker (1963) found that a weed, *Euphorbia hirta* was the principal host of the aphid, but not the virus, during the dry season. He also noted that in Nigeria the incidence of rosette increases from north to south, and is lowest in the comparatively dry Sudan zone where the bulk of the crop is grown. However, in 1975 a rosette epidemic occurred in the main-production, drier, zones of the country, not in the high-rainfall areas where it is usually endemic, but in the Sudan zone (Yayock et al. 1976). Out of an estimated 1.3 million ha planted to groundnuts in 1975, about 0.7 million ha were severely damaged at an early growth stage. Yayock et al. (1976) believed that an unusual combination of weather and sowing dates led to this disaster. Early sowing of groundnuts in the south was followed by dry weather after germination. Aphid colonies on these plants in the south developed many winged adults, which were blown northward by the prevailing winds, and reached the northern zones where the crop was just emerging. During subsequent dry weather in the north, winged adults were formed and dispersed to other areas. This led to a massive disease spread.

Resistance to rosette is available in germplasm from West Africa, and resistant cultivars have been bred in Senegal, Niger, and Malawi (Gillier 1980, Misari et al. 1980, Sibale and Kisyombe 1980). At the time of the 1975 epidemic in Nigeria all the resistant cultivars had been bred for the wetter, longer-season rosette-prone areas of Nigeria and they were not adapted to the Sudan zone. More detailed studies on the epidemiology of rosette are now being carried out in Nigeria and Malawi in conjunction with the Peanut CRSP, Ahmadu Bello University, and ICRISAT.

Nematode Diseases

The groundnut plant is attacked by a variety of plant parasitic nematodes. In some areas of the world cultivation of the crop cannot be maintained without nematode control. Depending on the genus of nematode involved, root systems, pods, and seeds may be directly damaged. Affected plants lack vigor and have reduced drought resistance. Nematode damage can also affect nodulation and make the plant more vulnerable to invasion by diseases (Porter et al. 1982).

The root-knot nematodes {*Meloidogyne* sp.) are probably the most important in limiting groundnut yields (Porter et al. 1982, Rodriguez-Kabana 1984). M. *arenaria, M. hapia,* and *M. javanica* are distributed in all parts of the world between latitudes 35°N and 35°S. Other important cosmopolitan nematodes are species of *Pratylenchus, Aphelenchus,* and *Aphelenchoides.*

Many attempts have been made to find sources of resistance to nematodes in groundnuts. Particular attention has been paid to the species of *Meloidogyne,* but no resistance has been found so far (Porter et al. 1982), thus chemical control of nematodes is commonly undertaken in the United States. In the SAT, Germani (1979) has demonstrated dramatic pod and hay yield increases with nematicide treatments in Senegal to control *Scutellonema cavenessi* Some of the chemical treatments also had very significant residual effects. In India, a parasitic nematode, *Tylenchorhynchus brevilineatus,* was shown to be the cause of a disease that had become known as 'Kalahasti Malady' in farmers' fields of Andhra Pradesh, India. The disease had been seriously affecting groundnut yields on sandy soils since 1976 (Reddy et al. 1984). Yields were again significantly increased by the use of soil chemicals. Misari et al. (1980) have recorded at least 11 species of nematodes on groundnuts in Nigeria, but consider that only two species may be potentially important. Due to the lack of trained nematologists in the SAT, damage caused by nematodes has probably been underestimated. Furthermore, many of the nematicides are both costly and toxic, so it is unlikely that farmers would readily use them. More work needs to be done on finding nematode resistance in groundnuts, as has been successfully done in other crops.

Arthropod Pests

Smith and Barfield (1982) have listed more than 360 soil- and foliage-inhabiting arthropod pests of groundnuts. This large number is not unique, and Van Emden (1980) considers this large diverse array of pests as typical of legume crops. Fortunately most of them are not serious pests, and although some of them are cosmopolitan in distribution, many of them are restricted to certain areas. Many of the groundnut pests are also pests of other crops.

The arthropod pests can be generally grouped into two major divisions, those attacking the foliage, and those inhabiting the soil. In this review the major pests are discussed under these headings. Foliage pests are subdivided into those that consume the plant parts, and those that are intracellular feeders.

Foliage Consumers

Most of the important foliage feeders are *Lepidoptera.* Serious pests in India include *Spodoptera litura, Aproaerema modicella,* species of *Amsacta,* and to a lesser degree, *Heliothis armigera.* Amin and Mohammad (1980) reviewed the Indian literature and concluded that *Aproaerema modicella* and species of *Amsacta* had been long recognized as pests of groundnuts, whereas *Spodoptera litura* and *Heliothis armigera* had only come into prominence in the last two decades. This is possibly due to the spread of groundnuts into new areas, and the expansion of groundnuts as an irrigated crop in the dry season. *Aproaerema modicella* is also listed as a pest in Indonesia, under the earlier name of *Stomopteryx subsecivella* by Feakin (1973). In Nigeria, Misari et al. (1980) only record various beetles that consume flowers as being important foliage feeders. Lepidopteran pests in Senegal include *Amsacta* sp., and *Spodoptera littoralis,* according to Gautreau and De Pins (1980). The two-spotted spider mite *(Tetranychus* sp) is widespread and can be important when groundnuts are grown in light, sandy soils that become drought stressed. Populations can build up rapidly, particularly if predators are controlled by insecticides (Campbell and Wynne 1980, McDonald and Raheja 1980).

It is generally agreed that groundnuts are most susceptible to defoliation from 70-80 days after emergence (DAE), and can in fact withstand preflowering and near-harvest defoliation without severe effects on yield (Smith and Barfield 1982). Therefore unless defoliators build up during the most susceptible period, there is little need to spray insecticides to control them. Low to moderate levels of resistance to several defoliators have been recorded (Campbell and Wynne 1980, Leuck and Skinner 1971, Rao and Sindagi 1974).

Intracellular Feeders

Intracellular feeders cause damage by removing sap, by injecting toxins, and most importantly by acting as vectors for plant pathogens, particulary viruses.

Aphids are generally considered more important as vectors of viruses than causing direct damage. Smith and Barfield (1982) list six aphid species as vectors of virus diseases. Undoubtedly *Aphis craccivora* is the most important of these, as it is a vector of rosette, peanut mottle, peanut stunt, and groundnut eyespot virus. *A. craccivora* is widespread throughout the groundnut-growing areas of the SAT. In India, where rosette does not occur, direct damage by *A. craccivora* has been recorded in northern India by Rai (1976). As a direct pest aphids cause leaf curling and stunted growth, and during droughts the plants may suffer stress due to loss of sap (Feakin 1973). Misari et al. (1980) also reported that high aphid populations in northern Nigeria result in wilting and death of the crop during periods of hot weather.

Seventeen species of thrips have been listed as pests of groundnuts by Smith and Barfield (1982). As with aphids, their most important role is as vectors of tomato spotted wilt virus (TSWV). *Frankliniella schultzei,* and to a lesser extent *Scirtothrips dorsalis,* are the vectors of TSWV on groundnuts in SAT India (Amin and Mohammad 1980).

Thrips rasp leaf tissues, particularly young leaflets in the terminal buds, and when fully opened, the leaves are malformed and puckered. Particularly heavy damage can result in defoliation. Some reports from SAT countries, where TSWV is absent or rare, state that thrips are serious pests of groundnuts. Feakin (1973) records *Caliothrips indicus* as a serious pest in south India, and *C. impurus* and C. *sudanensis* as pests in Sudan. Misari et al (1980) mention that thrips are becoming more important in northern Nigeria. In Malawi the large-seeded cultivar, Chalimbana, appears to be very susceptible to damage by thrips and leaves of this cultivar are more malformed and puckered than other cultivars (R.W. Gibbons, ICRISAT, unpublished).

According to Smith and Barfield (1982), the detrimental effects of direct thrips feeding on yield have been very controversial for many years. Many recent reports from the United States have failed to identify increases following chemical control with insecticides. Hill (1975) has also questioned the economic importance of thrips control in Africa. There appear to be sources of resistance to thrips in both the cultivated groundnut and in wild *Arachis* (Campbell and Wynne 1980, Amin and Mohammad 1980). This would be useful as part of an integrated management system where thrips are vectors of TSWV because genetic resistance to the virus has not yet been found.

Leafhoppers, particularly species of *Empoasca,* are pests of groundnuts in many countries. Adults and nymphs suck sap from the leaves, and the leaves become burnt and yellowed at their tips, because of the toxic saliva injected into the plants. In India, *E. kerri* is the dominant species and can cause irreversible wilting in seedlings according to Amin and Mohammad (1980). *E. facialis* is important in many parts of Africa, while *E. dolichi,* the cotton jassid, is an important pest of groundnuts in Nigeria (McDonald and Raheja 1980). There is little information on the economic returns of using insecticides to control leafhoppers, but there are reports of good levels of resistance to the leafhoppers in cultivated groundnuts (Campbell and Wynne 1980, Amin and Mohammad 1980).

Soil Pests

Important soil pests of groundnuts in the SAT include termites, wireworms, and various insect larvae. McDonald and Raheja (1980) considered that termites and millipedes are the most important soil pests in Africa, but termites are not listed as pests of groundnuts in the United States by Smith and Barfield (1982). Feakin (1973) lists 16 species of termites as pests of groundnuts in the SAT and many drier areas of the world. The damage caused can be divided into those species that scarify the pods, and those that enter the plant in the root region and mine the stems and roots.

The pod scarifying termites include species of *Odontotermes, Microtermes,* and *Amitermes.* After scarification the pods become weak and more vulnerable to breaking and cracking, which facilitates invasion by *A. flavus and* other fungi (Feakin 1973). In Nigeria, Johnson and Gumel (1981) found that pod scarification was caused by *Microtermes lepidus,* and more damage was caused in the drier zones of the Sudan savanna than in the wetter Southern Guinea savanna zones. Scarification was also more common in dead plants which had been killed by termites invading the roots. In market samples, Johnson and Gumel (1981) found the number of scarified pods rarely exceeded 5% of the total pods, but over 85% of the seed from scarified pods was infected by the fungi *Macrophomina, Fusarium,* and *Aspergillus.*

Termites can be controlled by chemicals, but those that are most efficient are usually very toxic to humans, and also persist in the soil for many years. Feakin (1973) advocates repeated mechanical cultivation over years, the use of less toxic chemicals, mulching, and good crop husbandry as possible control measures. Amin and Mohammad (1980) reported cultivar differences in the numbers of pods scarified by soil-inhabiting termites in India. Newer methods of termite control are currently being investigated by entomologists in Britain. These methods are based on the control of the fungi which termites cultivate as sources of food in their nests (T. Wood, Tropical Development and Research Institute (TDRI), London, personal communication).

Millipedes are common pests in many parts of Africa (McDonald and Raheja 1980). Immature forms of the genus *Peridontopyge* feed on young pods and developing seeds in Nigeria. Misari et al. (1980) estimate that pod losses can be as high as 30% due to millipede damage, but attacks vary over years and locations in northern Nigeria. Gautreau and De Pins (1980) reported that millipede damage to seedlings and pods has increased in Senegal over the last few years. In the Sudan, Ishag et al. (1980) reported that damage at the beginning of the rains when millipedes appear in great numbers.

Various other soil pests are important in the SAT. White grubs *(Lachnostera consanguinea),* the polyphagous larvae of beetles, are particularly important in the northern states of India. In some of these areas farmers have been compelled to stop growing groundnuts because of white grubs (Amin and Mohammad 1980). White grubs are of minor importance in Nigeria (Misari et al. 1980) and Malawi (Mercer 1978). *Hilda patruelis,* a Hemipteran sucking pest, causes groundnut wilting in Malawi and Zimbabwe. Adults and nymphs live in association with black ants in earth tubes at the bases of the groundnut stems. Control measures include insecticides that kill the pest or the ants (Feakin 1973). Reliable economic threshold limits for *Hilda,* and many other pests, are lacking in the SAT.

Biological Nitrogen Fixation

Groundnuts form symbiotic associations with soil bacteria of the genus *Rhizobium.* The *Rhizobium* infecting groundnuts is a member of the cowpea-cross inoculation group that nodulates other legumes, including cowpeas. Most groundnut-growing soils of the world have sufficient numbers of rhizobia present to form nodules on the crop. It has long been known, however, that not all rhizobial strains are effective in fixing nitrogen in symbiosis with groundnuts.

In recent reviews (Cox et al. 1982, Ketring et al. 1982, Wynne et al. 1980, Nambiar and Dart 1980) many factors have been shown to affect both nodulation and fixation, including soil nutrient status, diseases, insect pests, soil moisture, light, temperature, cultivar, and intercropping with cereals.

Recent evidence has shown that it should be possible to select specific strains of *Rhizobium* that can effectively increase yields of specific cultivars even when they have to compete with local, inefficient, native strains in a range of environments and soil conditions (Nambiar and Dart 1980). One such strain, NC 92, which was collected in South America and isolated in North Carolina, has shown significant yield increases with two released Indian cultivars, Robut 33-1 and JL 24, over a number of sites and seasons (Nambiar et al. 1984). Strain NC 92 shows promise in Cameroon with the locally recommended cultivar, 28-206 (T. Schilling, USAID, Maroua, Cameroon, personal communication).

Wynne et al. (1980) also believe strains can be selected after they have shown broad adoption with a number of host genotypes, or single genotypes. They suggest that sufficient variability exists for selection and manipulation of host genotypes and strains to produce greater nodulation, and greater fixing potential.

Direct application of rhizobial cultures to seed is the most common method of legume inoculation. However, groundnut seed is very fragile and easily damaged. Furthermore seed is often treated with fungicides, which may be toxic to the rhizobial cells. Nambiar et al. (1984) have shown that liquid cultures of *Rhizobium* were best applied to the soil in a furrow, just prior to planting the groundnut seed. They suspected that many of the bacteria applied to the cotyledons before planting may be moved out of the root zone during germination. When placed below the seed the inoculant was able to compete better with native strains already in the soil. These results may explain why inoculation trials in the past have failed to show yield increases.

Looking Ahead

A great deal is known about the biology of many of the harmful organisms that reduce yields of groundnuts in the SAT. However, detailed epidemiological studies of many pests and diseases are lacking on a national level, and very few studies have been made on a regional or international scale. Plant scientists need much more assistance from agroclimatologists to study the effects of climate on insect pests and diseases, and to forecast epidemics.

More studies are needed on the economic threshold of pest control. The timing and types of effective pesticide applications must receive more consideration because of the economic plight of the small-scale farmers of the SAT.

Breeding for resistance to insect pests and diseases must be regarded as the most effective and economic method of reducing biological constraints. In the long term, multiple resistances should be sought according to the needs of the country or region. The ultimate goal would be to put together a package of practices involving resistances, good agronomy, and extension advice. It must also be remembered that biological constraints are not static. Vigilance is needed to watch for new problems that may arise, particularly if the farming systems change.

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Global Groundnut Production

Discussion

A. Tekete:
You have talked about the influence of soil-water availability on the growth and yield of groundnut. I would like to know the influence of nutrient availability on water availability, growth, and yield of groundnut in the Senegal region.

S. M. Virmani:
That was not the brief of my paper. But I have some knowledge of changes in the nutrient availability in the soils of these regions. In the sandy soils the nutrient levels are both lower and much less available. In these areas the fixation of nutrients, particularly phosphorus, is very high. I think that because of soil erosion and other problems associated with less water availability, the problem of nutrient availability has increased or has intensified. I believe that water and nutrients are equally important in increasing and stabilizing groundnut production in this region.

L. D. Swindale:
Thank you, but I think you will agree that climate has relatively minor effect upon nutrient supply. It may have some effect on nutrient availability because of the interactions with water and some of the other factors that climate affects. But in terms of nutrient supply climate has a relatively minor effect. To some extent nutrients have been left out of this conference because the emphasis is on climatic effects.

A. Ndiaye:
I would like to have some idea about the criteria for the choice of the stations used as sites representative of groundnut-growing zones.

S. M. Virmani:
I could have taken the data for many other locations. We have data for about 500 locations. I simply wanted to demonstrate the dramatic effects of rainfall reduction. This study can be extended to cover all 500 locations if we wish to look further. But as I showed, I was not sure about Dakar, so I looked at another location in Dakar itself. That showed a similar trend. I looked at another location 700-1000 km inland, which is Dosso. Then I also looked at Nioro du Sahel. The trends were similar. I have not looked at many other locations, but I think the study can be extended to look at other locations as well.

J. S. Kanwar:
This is a very interesting study by Dr. Virmani. If I understand correctly, you mentioned that in the case of Kano you have sufficient moisture and 120-day duration varieties can be grown there. Still in that area the groundnut production is falling. I wonder if you would like to analyze that situation also?

S. M. Virmani:
There is a paper by Drs. Yayock and Owonubi on the same subject. I do not have data for Kano to look at this kind of situation but I would be interested.

J. J. Owonubi:
Which years do you have data for? If the data are mainly for 1950s and 60s the type of results you gave will certainly be correct. But if it includes the last 20 years, certainly it will be way off. You can no longer sow groundnut beginning in June. You have to wait until the beginning of July. So the growing season is no longer quite as long as it used to be.

S. M. Virmani:
I used the data between 1930-1960 which have been published by WMO and could have a bearing on the results.

A. Ba:
Taking into account the deficiency in rainfall recorded in Senegal, the low water-holding capacity of soils, and the lack of irrigation facilities, do you think that techniques such as mulching or incorporation of organic matter can contribute to increased water availability to groundnut?

S. M. Virmani:
I anticipated this question. There could be two solutions. One is to increase the water retention in the soil to increase the water availability. The second is to adopt intercropping of millet and groundnut to

stabilize the production. We may have to increase the proportion of millet grown in the groundnut regions of Senegal. This is one of the ways in which farming systems research can alleviate the problem of decreased rainfall and increased rainfall variability in these areas.

D. Smith:
It has been a retrospective study. Do you see anything in the retrospective analysis that will allow you to forecast rainfall patterns for the next 30 years?

S. M. Virmani:
We have been trying to see if there are any cycles in rainfall. One of the problems is that I took a short data set of the last 30 years available to me. The reason I used the last 30 years is because much of the research that is relevant today has been conducted in the last 20 or 30 years. But we believe, and some of the work done on cycles of rainfall in this region shows, that it is a 11- or 14- or 17-year cycle. The problem is that reliable rainfall and evapotranspiration records for a long period are not available.

J. S. Kanwar:
From the trend analysis that you presented, it appears that there is a need for short-duration varieties. How short could it be? From 140-150 days we came to 110 days, now we come to 90 days and from the analysis you gave, it appears it is 70 days. I think the job of the breeder is most difficult. I wonder if this group of climatologists can give us some idea of what type of varieties and what duration we need for different crops. It is not just the question of groundnut, because in the same area you are also growing millet, sorghum, and sometimes intercrops of these.

L. D. Swindale:
The biologists here should give much thought to this question; this is a very important question.

W. Hoogmoed:
You showed very clearly that soil and water management will be a tool for improving yields. In this respect, I have two questions. One, in your studies you compared annual or seasonal rainfall and moisture availability index to get possibilities for seasons. Since many of the soils on which groundnut is grown are prone to crusting, and hence runoff, did you take into account, may be over seasons, that not all precipitation will enter into the soil and be used ? My second question is, if you would improve the moisture-holding capacity of soil, you may have a better moisture availability over the season. Do you emphasize to calculate these in your studies to see the magnitude of impact of improving the moisture-holding capacity to see if it is worthwhile attempting to do this?

S. M. Virmani:
Let me respond to Dr. Kanwar. Is the situation still dynamic or has it stabilized? Most of the meteorologists believe that the trend that was set up between 1966 and 1975 or so, has established itself and that the variability will be of the same order as in the past 10 years. Whether that is true for the next 10 years is very difficult to predict.

To respond to Dr.Hoogmoed, I took the WATBAL program of Nix and coauthors of Australia as the methodology. We assumed that all the rainfall is stored in the soil before any runoff takes place. This is not basically correct, but as a first approximation this is the methodology we used. When I say that soil-water management is the key, I mean that at the time of crop establishment it is a very important factor for establishing the stand. Dr. Sivakumar is attempting Ritchie's soil-water balance model for many of the locations that I mentioned today and 1 think some responses on a model basis would be available. One of the problems at the moment is that we do not have access to a groundnut growth and development model. I am looking forward to Dr. Boote's presentation here. Once that model is available, we will be able to respond to your questions better.

M. V. K. Sivakumar:
A word of supplement on what has been said with regard to runoff. I think one cannot look at runoff without considering crop cover. A soil-water balance model such as the Commonwealth Scientific and Industrial Research Organization (CSIRO) WATBAL model mentioned by Dr. Virmani which does not use any input of crop cover cannot provide answers to questions on soil management. Ritchie's water balance model has the capacity to take into consideration the crop cover and so such computations can be facilitated. This of course needs some estimate of leaf area index of the crop for the locations in which you are interested.

P. Sankara:
a. Sometimes both diseases (rust and leaf spot) can be observed on the same plant. What are the interactions between these two fungi on the same plant?
b. I would like to know if the propagation is only by

wind. I am asking this question because in 1982 we observed a farm in the southwestern part of Burkina Faso which was totally destroyed by rust. If the propagation is by wind is there any means of conservation?
c. We have also observed certain hyperparasites such as *Tuberculina* in fields attacked by rust. What are the possibilities of using these as a biological control?

R. W. Gibbons:
a. Most of the propagation of rust is by wind. As the uredospores are viable for upto 40 days under ambient conditions, they could also be carried on pods or plant fragments when they are transported by man. It is not thought that rust is internally seedborne as are other diseases.
b. Hyperparasites may have promise but they may be difficult to manipulate and use effectively. Either fungicides or resistant varieties would be better solutions until we know more about biological control of rust.

D. Smith:
With respect to biological control of foliar pathogens, one of the things I have observed with hyperparasites or mycoparasites is that when they occur naturally, the disease epidemic is well under way. We have at Texas a mycoparasite of late leaf spot called *Dicyma pulvinata.* I tested this for two years under field conditions, applied as a foliar spray and compared with Daconil®. I was never able to get one leaf colonized by the hyperparasite. So 1 think we will be in a better position to search for disease resistance than depend on hyperparasites.

D. Alhassane:
The climatology of many diseases and pests of groundnuts is known and resistant lines have been developed. I would like to know if early warning systems for groundnut pest control and diseases have been developed. These systems would reduce the number of pesticide and fungicide treatments required which are expensive and polluting.

R. W. Gibbons:
Most of the early warning systems for groundnut pest control have been developed in USA. Dr. D. Smith will be speaking on a leaf spot system later on in this symposium. Such systems are needed in the SAT for rust and leaf spot and insect control.

A. Ba:
a. You have talked about a possible interaction between rust and leaf spot. In western Senegal and Casamance, a combination of these two diseases has been observed and a breeding program has been set up to identify varieties resistant to rust. Considering the possible interaction between rust and leaf spot, don't you think that identification of rust-resistant varieties would favor leaf spot development which we know reduces yield up to 50%?
b. It has also been observed in Senegal that rust presence is limited to uredospores and subsequent stages have never been detected. Uredospores are generally found around 15 days before harvest. How do you explain this sudden interruption or lack of continuity in the fungus development?
c. You have discussed tests to evaluate the resistance of different varieties to fungus invasion by *A. flavus.* I would like to have more information on these tests. If resistant varieties have been identified, could you tell us more about the possibilities of transferring this resistance to the progenies by breeding?
d. You have mentioned a disintoxification work on aflatoxin- contaminated cakes in Senegal. Don't you think that there may be surviving spores after the treatments and a reinfestation of the cakes during conservation?

R. W. Gibbons:
a. There are probably interactions between rust and leafspots. The first pathogen probably destroys tissues and reduces photosynthesis—this could make the leaf a less suitable substrate for a second pathogen. There are indications that if you use selective fungicides to control leafspots then more rust than usual develops.
b. In S. America and the USA uredospores are commonly found, and teliospores are occasionally found. I do not think teliospores have been found elsewhere. In the SAT and SE Asia only uredospores have been found. No other stages of *Puccinia arachidis* have been found todate.

As uredospores only remain viable for upto 40 days it is suspected that the disease maintains itself on volunteer groundnuts or by long distance transport of uredospores from other regions where groundnuts are being grown in different seasons.
c. The inoculation test for 'dry seed resistance' to A *flavus* has been worked out and published. I will send you a copy of the ICRISAT technique. The resistant factor to invasion is contained in the testa and has been correlated to various characters such as wax deposits, amino acid contents etc. As soon as the testa is broken, infection of the cotyledons takes place.

d. There is no doubt that detoxification of the cake helps in reducing aflatoxin, but after detoxification if conditions are favourable then *A. flavus* could probably reinfect the cake and produce more aflatoxin.

D.Smith:
One possibility of dispersing uredospores is the fabric of the travelling scientist. It has been shown that rust uredospores can survive on fabric.

R.E. Lynch:
Research has also been done on the movement of insects by meteorological factors, especially the jet stream. Insects can move disease organisms, specially rust uredospores.

P. Sankara:
In general and as far as resistant varieties are concerned there has always been a pustule that appears on the leaf but does not evolve. This is because it is the more important secondary inoculum that destroys the leaf. Is'nt there a parasite accumulation which leads to the establishment of resistance mechanisms for the inoculum not to develop?

R. W. Gibbons:
We know quite a lot about resistance mechanisms for rust. In resistant germplasm rust development takes longer, pustule size is reduced, the number of spores produced are less, and the spores germinate less than in susceptible plants. It is a 'slow-rusting' response, very similar to the slow-rusting response in some cereals. In some wild species we get an immense response to infection by rust: in other wild species one can get a hypersensitive reaction.

A. P. Ouedrago:
In the Peanut CRSP project on insect densities south of Burkina Faso in 1984, we observed more thrips in the intermediate-rainfall zone. Is there an interaction between development of thrips and quantity of water?

R. W. Gibbons:
There are certainly interactions between insects and quantity of water in the soil, air, and in the plant. I am not aware of specific conditions regarding thrips but they certainly migrate from plant to plant and from crop to crop as plants age or dry. In India they migrate from weeds to groundnuts soon after the crop emerges. In the intermediate-rainfall zone of Burkina Faso you may be getting migrations from other crops or from other rainfall areas because of desiccation in other areas.

Session II

Water Relations of Groundnut

Chairman: D.G. Cummins
Co-chairman: M. Konate

Rapporteur: R. Chase

Alimentation en eau de l'arachide en zone tropicale semi-aride

C. Dancette[1] et F. Forest[2]

Résumé

Les besoins en eau de l'arachide (Evapotranspiration réelle maximum ETRM ou ETM) ont été mesurés au champ, en Afrique de l'Ouest, entre 1970 et 1980 surtout sur des variétés dont la durée de cycle allait de 90 à 120 jours. L'évapotranspiration réelle (ETR), en conditions pluviales strictes (sans irrigation de complément) a elle aussi été chiffrée maintes fois. Les chercheurs ont essayé de mieux comprendre l'élaboration du rendement final, à partir du taux de satisfaction des besoins en eau (ETR/ETM %).

La simulation du bilan hydrique (méthode Forest) a permis par ailleurs de faire la synthèse des connaissances portant sur la demande évaporative, sur les besoins en eau des cultures, sur leurs consommations réelles, sur les propriétés hydriques des sols, sur le passé pluviométrique des stations, etc. Ce bilan hydrique simulé, bien calé sur les réalités de terrain, tout au moins en Afrique de l'Ouest, permet d'analyser à posteriori de longues séries pluviométriques et les données de rendement correspondantes, en vue d'une adaptation plus rationnelle de la culture d'arachide et d'une meilleure compréhension des rendements obtenus. Certes, le bilan hydrique simulé, même s'il est opérationnel et répond de façon suffisante à la plupart des besoins agronomiques immédiats, peut être sensiblement améliorés. Dans le cas de l'arachide, les améliorations iront dans le sens d'une meilleure prise en compte de l'enracinement, de l'incidence des niveaux de fertilité (engrais et travaux du sol notamment), de l'influence des stress hydriques eux-mêmes sur une reprise plus ou moins rapide et efficace de la croissance, etc.

Il faut être conscient que les facteurs hydriques, surtout en conditions excédentaires, ne suffisent pas à expliquer dans tous les cas, l'élaboration du rendement final. Ils y contribuent en partie, et cette part est plus ou moins importante selon les situations agro-pédoclimatiques. Pour l'arachide, tout progrès en vue de mieux comprendre cette culture déroutante, devra s'appuyer sur des observations et tests physiologiques plus fins. Pour la recherche, cette compréhension répond à un souci concret de meilleure adaptation de l'arachide, à un milieu qu'il convient lui aussi d'améliorer, dans un sens favorable aux objectifs agroéconomiques des Etats concernés, sans que le coût des intrants ne soit prohibitif.

Abstract

Water Requirements of Groundnuts in the Semi-Arid Tropics: *Water requirements of groundnuts (Maximum evapotranspiration- MET) were measured in the field in West Africa between 1970 and 1980 for varieties of 90- to 120-day duration mainly. Actual evapotranspiration (AET) under rain fed conditions (without supplemental irrigation) was also calculated several times. The level at which water requirements are met (AET/MET %) was used by scientists to understand the factors determining final yield.*

The water-balance model (Forest's method) helps in summarizing the influence of the evaporative demand in the crop growth, crop-water requirements, water use, soil-water characteristics, and rainfall at certain stations. This simulated water balance adjusted to ground truth permits (at

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least in West Africa) a posteriori analysis of long series of rainfall and crop yield data for obtaining a closer adaptation of the groundnut crop to climate resources and for a better understanding of the yield levels obtained. The water balance simulation, which is operational and responds satisfactorily to most of the immediate agronomic needs, can still be improved. For groundnuts, these improvements will be towards a better grasp of rooting habits, effect of fertilizer levels, soil preparation, and stress on a more or less fast and effective recovery of the crop.

Final yield is not always sufficiently explained by hydrological factors, although these contribute to a degree determined by agropedoclimatic factors. Better understanding of groundnut crop growth requires further physiological tests and observations. For research this understanding will lead to a better adaptation of the crop to an environment, which itself needs to be improved and to the attainment of the agroeconomic objectives of the countries concerned, without prohibitive costs of inputs.

Introduction

Une bonne connaissance des exigences en eau de l'arachide est nécessaire, en vue d'orienter rationnellement les recherches conduites (sélection notamment), de faciliter les choix du développement (importance à attribuer localement à cette culture, variétés à retenir) et de mieux maîtriser cette délicate spéculation agricole (explication du rendement et par là, interventions plus efficaces sur les facteurs de production voulus).

Connaître les exigences hydriques de l'arachide suppose que l'on sache estimer, partout et n'importe quand, ses besoins en eau maximum (idéal agronomique) comment la plante se situe par rapport à cet idéal et surtout comment elle réagit à des taux de satisfaction des besoins en eau, plus ou moins bons. La mesure des besoins, et le contrôle du niveau d'alimentation hydrique nécessitent des techniques relativement élaborées et coûteuses, le plus souvent très localisées dans le temps et dans l'espace. Notre souci constant sera donc, au-delà de la phase de recherche expérimentale conduite en station, de déboucher sur des méthodes de généralisation de nos connaissances. Nous serons ainsi amenés, surtout dans le cadre de la simulation du bilan hydrique, à proposer certaines hypothèses simplificatrices, certainement discutables et que nous discuterons avec plaisir, au cours de ce symposium.

Besoins en eau de l'arachide (évapotranspiration réelle maximale : ETM ou ETRM)

Ils ont été mesurés à la station de Bambey, au Sénégal entre 1973 et 1977. Les conditions d'expérimentation peuvent être ainsi resumées.

- Pluviométrie moyenne sur 60 ans = 630 mm (±180) (CV 29%); moyenne entre 1968 et 1984 = 471 mm (±106) (CV 23%);
  médiane entre 1968 et 1984 = 459 mm;
  seuil de dépassement à 80%, 1968 à 1984 = 376 mm.
- Sol sableux, profond, de réserve en eau utile voisine de 100 mm m^{-1}.
- 4 répétitions, parcelles carrées de 196 m^2, sur terrain assez plat et après culture d'homogénéisation de mil-engrais vert, en 1972.
- Fumure NPK : 150 kg ha^{-1} de 6-20-10, sol labouré (Chopart et Nicou 1973).
- Ecartement sur les variétés hâtives = 45 cm d'interligne, 15 cm sur la ligne.
- Ecartement sur les variétés tardives et semi-hâtives = 60 cm d'interligne et 15 cm sur la ligne. Irrigation en complément des pluies, par asperseurs d'angle à secteur réglable. Les apports sont contrôlés avec des pluviomètres et sont de l'ordre de 25 mm, apportés en gros chaque fois que la réserve en eau utile a diminué de 50% dans les 50 premiers centimètres.

Mesure des besoins en eau

Par bilans hydriques effectués avec des humidimètres à neutrons, sur des tubes d'accès de 4 m de profondeur, installés au centre de chaque parcelle. On se préserve du ruissellement par des lames verticales enfoncées autour de chaque tube et par

Tableau 1. Besoins en eau de la variété d'arachide 55-437 de 90 jours, mesurés en 1974 (semis le 14 juillet).

Intervalle de temps	Besoins en eau ou ETRM (mm jour^{-1})	Evaporation bac cl.A (mm jour^{-1})	K'coeff. cult. ETRM/Ev (après lissage)	K'coeff. cult. ETRM/ETP (après lissage)
14-20 Juil.	3,3	8,0	0,41	0,51
21-31 Juil.	3,9	6,9	0,57	0,65
1-10 Août.	5,0	7,5	0,72	0,80
11-20 Août	5,3	5,9	0,90	0,96
21-31 Août	4,2	5,1	0,85	0,90
1-10 Sept.	4,8	6,2	0,78	0,84
11-20 Sept.	4,2	5,5	0,72	0,78
21-30 Sept.	4,0	6,1	0,67	0,70
1-11 Oct.	3,7	5,7	0,63	0,67

des levées de terre isolant chaque parcelle. Des tensiomètres ont permis de contrôler la direction des flux (Vachaud et al. 1973; Dancette et al. 1979). Les bilans hydriques ont été facilités par des humectations du sol ne dépassant guère 150 cm de profondeur, au cours de saisons des pluies très déficitaires par rapport à la normale.

Par évapotranspiromètres, ou cuves de végétation, métalliques, de 4 m^2 de surface et 1 m de profondeur, à drainage gravitaire, reliées par des tuyaux à des puits de drainage. Cette méthode des évapotranspiromètres était prévue pour remplacer celle du bilan par humidimétrie neutronique, en cas de percolations trop profondes. Les résultats obtenus par les deux méthodes étant très voisins, nous avons préféré retenir ceux du bilan neutronique, méthode plus élaborée, moins perturbatrice du milieu. Les problèmes de mesure des besoins en eau sont discutés dans une synthèse récente (Dancette 1983a). Les principaux résultats portent sur les variétés érigées 55-437 de 90 jours, non dormantes et de bonne résistance à la sécheresse; 57-422 de 105 à 110 jours dormantes et très vigoureuses; 28-206 de 120 jours (Tab. 1-3). Dans ces tableaux, on donne les valeurs d'ETRM et d'évaporation du bac normalisé classe A, ramenées aux décades "météorologiques". Les coefficients de culture ont été retenus par lissage des courbes de variation dans le temps : K'=ETRM/Ev bac et K = ETRM/ETP Penman. L'ETP Penman a été estimée à partir des calculs mensuels effectués par mois à Bambey (Vasic, CNRA, Sénégal, documents manuscrits 1977) et d'une bonne corrélation avec le bac, établie pendant les quatre mois de saison de pluies et pendant huit ans.

Tableau 2. Besoins en eau de la variété d'arachide 57-422 de 105 à 110 jours, mesurés en 1973 (semis le 5 juillet).

Intervalle de temps	Besoins en eau ETRM (mm jour^{-1})	Evaporation bac cl. A (mm jour^{-1})	K'coeff. cult. ETRM/Ev (après lissage)	K'coeff. cult. ETRM/ETP (après lissage)
5-10 Juil.	1,9	8,4	0,23	0,29
11-20 Juil.	3,4	8,3	0,41	0,52
21-31 Juil.	4,6	7,1	0,65	0,75
1-10 Août	4,7	5,1	0,93	0,95
11-20 Août	6,1	5,8	1,06	1,07
21-31 Août	5,8	5,6	1,04	1,06
1-10 Sept.	5,2	5,6	0,93	0,97
11-20 Sept.	5,5	5,9	0,93	1,00
21-30 Sept.	6,5	7,1	0,92	1,06
1-10 Oct.	7,3	8,1	0,90	1,09
11-17 Oct.	6,8	7,6	0,90	1,08

Tableau 3. Besoins en eau de la variété d'arachide 28-206 de 120 jours, mesurés en 1977 (semis le 7 juillet).

Intervalle de temps	Besoins en eau ETRM (mm jour^{-1})	Evaporation bac cl. A (mm jour^{-1})	K'coeff. cult. ETRM/Ev (après lissage)	K'coeff. cult. ETRM/ETP (après lissage)
7-20 Juil.	1,9	7,4	0,26	0,34
21-31 Juil.	3,5	7,1	0,38	0,50
1-10 Août	4,1	8,7	0,52	0,65
11-20 Août	4,7	6,9	0,68	0,82
21-31 Août	5,9	6,8	0,83	0,93
1-10 Sept.	4,9	5,0	1,00	0,96
11-20 Sept.	4,4	3,8	1,10	0,98
21-30 Sept.	5,1	5,2	1,00	0,96
1-10 Oct.	9	6,5	0,83	0,93
11-20 Oct.	6,0	7,5	0,74	0,88
21 Oct 3 Nov.	5,8	8,4	0,68	0,81

En 1974, la pluviométrie reçue sur cet essai avait été de 492 mm; l'irrigation de complément s'était élevée à 72 mm (surtout pour corriger une mauvaise répartition des pluies). Les consommations brutes globales relevées avaient été de 405 mm (±32) (CV de 8%). Les rendements en gousse étaient de 2945 kg ha^{-1} (±256) (CV de 9%) et en fanes de l'ordre de 3300 kg ha^{-1}.

En 1973, la pluviométrie avait été de 400 mm et l'irrigation de complément totalisait 182 mm. Les consommations globales, avaient atteint 548 mm (±30) (CV de 5%) pour des rendements en gousse de 3660 kg ha^{-1} (±30 (CV de 1%) et en fanes de 4990 kg ha^{-1}. Cette variété s'est montrée d'une très grande vigueur et surtout n'a manifesté aucun symptôme de vieillissement en fin de cycle, tant que l'on a continué de l'arroser; ses besoins en eau, pendant le dernier mois ont suivi d'une façon remarquable la forte augmentation de la demande évaporative d'où des coefficients de culture qui se maintiennent à un niveau très (et peut-être trop) élevé. Pour se rapprocher de conditions de culture sous pluie plus courantes, il aurait mieux valu réduire un peu les apports hydriques, et donc les consommations et les coefficients de culture du dernier mois. On n'aurait rien perdu sur les rendements en gousse, mais certainement perdu sur la quantité et la qualité des fanes (produit de mieux en mieux valorisé par les cultivateurs).

La pluviométrie avait été de 374 mm et la dose totale d'irrigation complémentaire, de 259 mm. La moyenne des ETRM globales des quatre parcelles était de 557 mm (±51) (CV de 9%), pour des rendements en gousses de 3700 kg ha^{-1} (±290) (CV de 8%) et en fanes de 3900 kg ha^{-1}.

Les coefficients de culture donnés par rapport au bac normalisé classe A ou par rapport à l'ETP calculée (Penman) sont regroupés pour les trois variétés étudiées, dans les Figures 1 et 2 et attirent les commentaires suivants : le coefficient de la variété de cycle court "démarre plus fort" que les deux autres; en revanche il atteint un maximum moins élevé, décroît assez vite et vers des valeurs plus basses. Cette variété de cycle court couvre rapidement le sol (de plus, elle est semée à 45 cm d'interligne et non à 60 cm comme pour les deux autres); elle est réputée résistante à la sécheresse et nous montrons qu'elle est économe en eau. Il y a tout intérêt à ne pas la semer trop tôt — on évite ainsi les fortes demandes évaporatives (ETP élevée) et les risques de sécheresse du début de la saison des pluies. De plus, comme elle n'est pas dor-

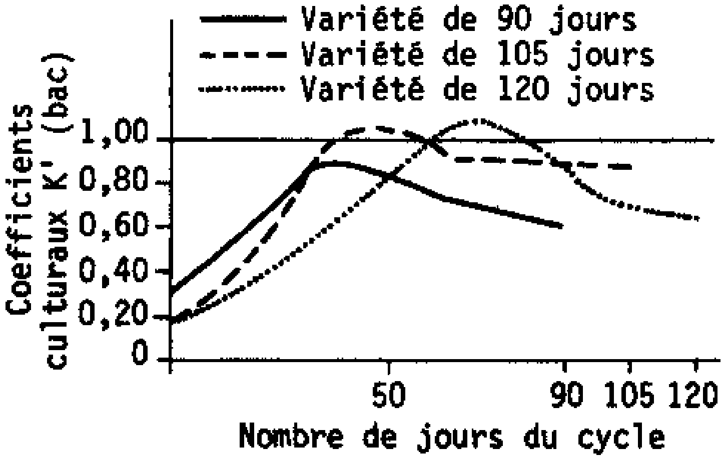

Figure 1. Variation des coefficients de culture d'arachide par rapport au bac normalisé classe A.

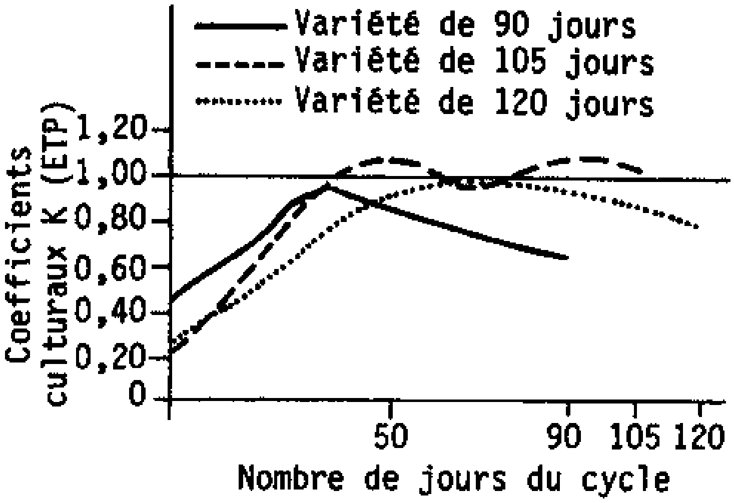

Figure 2. Variation des coefficients de culture d'arachide par rapport à l'ETP calculée (Penman).

mante, il faut veiller à ce qu'elle ne reçoive pas trop de pluies pendant et après la récolte. La variété semi-hâtive de 105 jours a bien, en début de cycle, des coefficients intermédiaires entre ceux des deux autres variétés, ce qui est logique; ces coefficients atteignent un maximum élevé, après la variété de 90 jours et avant celle de 120 jours, ce qui est encore logique. Ce qui diffère des deux autres variétés, c'est que les coefficients ne chutent pas en fin de cycle, du fait de sa grande vigueur et de son absence de vieillissement en présence d'eau abondante. De plus, en fin de saison 1973, la demande évaporative avait été très élevée, avec des valeurs très fortes pour l'évaporation du bac et proportionnellement plus faibles pour l'ETP calculée, ce qui se répercute sur l'allure des courbes de variation des coefficients. On pourrait rapprocher ces résultats de ceux obtenus sur trois variétés de mil de durée de cycle différente (75, 90 et 120 jours) (Dancette 1983b) car ils montrent des tendances assez voisines.

Généralisation des besoins en eau

Les besoins en eau de l'arachide varient donc selon les variétés, mais aussi selon la demande évaporative. Or cette dernière varie au cours d'une même saison, d'une année à l'autre et d'un lieu à un autre (Dancette 1979 et 1983a). Notre méthode de généralisation sera donc basée, pour un territoire donné, sur la détermination des gradients de demande évaporative (le plus souvent reliés à la pluviométrie).

Dans le Tableau 4, l'évaporation en bac normalisé classe A est donnée pour le site de Bambey au Sénégal, décade par décade à partir du 1er juin, accompagnée de son écart type et de son coefficient de variation interannuelle (calculé sur 12 ans), de l'ETP calculée (Vasic, CNRA, Sénégal, documents manuscrits 1977) de 1967 à 1976, mensuellement, de juin à octobre (les

Tableau 4. Variations portant sur la demande évaporative.

		Ev bac décadaire (mm jour^{-1})			Ev bac N cl. A (mm jour^{-1})	ETP Penman (mm jour^{-1})
Mois		d1	d2	d3	Mensuelle	Mensuelle
Juin	Moy.	9,4	9,0	9,0	9,1	7,2
	Ecart type ±	1,4	0,9	0,9	0,92	0,32
	CV(%)	15	10	10	10	4
Juil.	Moy.	8,5	7,6	7,2	7,7	6,5
	Ecart type ±	0,8	0,8	1,0	0,55	0,44
	CV(%)	13	11	14	7	7
Août	Moy.	6,6	6,2	5,9	6,2	5,8
	Ecart type ±	1,0	0,6	0,6	0,61	0,41
	CV(%)	15	10	10	10	7
Sept.	Moy.	5,8	5,4	5,8	5,7	5,5
	Ecart type ±	0,5	0,7	0,9	0,49	0,24
	CV(%)	9	13	16	9	4
Oct.	Moy.	6,6	6,7	7,2	6,8	5,7
	Ecart type ±	0,8	0,9	0,8	0,61	0,27
	CV(%)	12	13	11	9	5

Tableau 5. Besoins en eau de l'arachide à Bambey en fonction du niveau de demande évaporative.

Pluviométrie, évaporation et besoins en eau	Saison à faible demande évaporative (1975)	Saison à moyenne demande évaporative (moy. 1972-1983)	Saison à forte demande évaporative (1983)
Pluviométrie utile reçue pendant la culture (mm)	494	422	240
Evaporation bac moyenne pendant la culture (mm jour^{-1})	6,0	6,6	7,2
Besoins en eau variété 90 jours (mm)	368	405	454
Besoins en eau variété 105 jours (mm)	492	530	586

écarts types sont toutefois plus faibles que pour les décades).

Ainsi à Bambey, à supposer que l'on sème les deux variétés le 1er juillet, les besoins en eau moyens seraient sur 12 ans de l'ordre de 405 mm pour la variété de 90 jours et de 530 mm pour celle de 105 jours; ce sont les deux variétés sur lesquelles on pouvait hésiter dans cette zone, celle de 120 jours ayant une durée de cycle trop longue. Pour l'année la plus humide sur les 12 ans (1975) on obtient des besoins en eau de 368 mm pour la variété hâtive et de 492 pour la semi-hâtive; pour l'année la plus sèche sur les 12 ans (1983) ces besoins en eau deviennent de 454 mm pour la variété hâtive et de 586 pour la variété semi-hâtive.

Pour résumer, dans un site donné, les besoins en eau devraient toujours être exprimés en fonction des années à faible, moyenne et forte demande évaporative, ce qui permet de nuancer les résultats. Dans le cas de Bambey et des deux variétés retenues, ceci nous conduit au Tableau 5.

Quand on assure le suivi hydrique d'une culture, il est nécessaire d'avoir une idée du degré d'imprécision auquel on s'expose, en se basant sur une demande évaporative moyenne pour plusieurs années, et non sur celle de l'année en cours : ±10% en gros.

Sans vouloir développer trop longuement le problème des variations géographiques des besoins en eau, liées à celles de la demande évaporative, il faut toutefois insister sur l'importance de disposer de bonnes cartes d'ETP (Cochemé et Franquin 1967; Virmani et al. 1980; FAO 1984) ou d'évaporation bac (Dancette 1979 et 1983a). A partir de ces cartes, on pourra estimer pour diverses situations géographiques les besoins en eau des cultures, comparativement à un site de mesure effective. Par exemple, si les besoins en eau moyens de l'arachide de 90 jours, sont de 405 mm à Bambey, au Centre du Sénégal, ils seront de l'ordre de 405 × 1,16 = 470 mm à Louga, vers le Nord du pays où la demande évaporative est 1,16 fois plus élevée qu'à Bambey, et de 405 × 0,85 = 345 mm, à Nioro du Rip, plus au Sud, où la demande évaporative est de 0,85 fois celle de Bambey. La validation géographique de la méthode d'estimation des besoins en eau, à partir des données relatives à la demande évaporative et des coefficients de culture mesurés ponctuellement dans le temps et dans l'espace (et que l'on suppose avoir une valeur universelle...) reste à faire. C'est pourquoi nous avons toujours préconisé que la mesure des besoins en eau puisse être faite dans plusieurs régions ou pays, au niveau de la vaste zone soudano-sahélienne. Une fois créé, ce réseau (par exemple d'Ouest en Est : Sénégal, Mali, Burkina Faso, Niger...) on pourrait s'accorder pour mesurer, la même année, les besoins en eau d'une arachide de 90 jours (la variété 55-437 est très répandue) ou d'un mil de durée de cycle donnée. On pourra comparer les coefficients obtenus par rapport à l'ETP calculée (Penman) ou par rapport à l'évaporation (bac normalisé classe A) ou a tout autre standard de référence relatif à la demande évaporative locale.

Ce qui serait fait d'Ouest en Est, à une latitude voisine, devrait être fait aussi du Nord au Sud, à des latitudes différentes. Le Sénégal, pour cela, avec les stations de Louga au Nord (pluviométrie moyenne 1968-1982 = 290 mm), de Bambey au Centre (pluviométrie moyenne 1968-1982 = 490 mm) et de Nioro du Rip plus au Sud (pluviométrie moyenne 1968-1982 = 680 mm) serait assez bien équipé pour faire ce travail, moyennant quelques légers moyens supplémentaires.

Tant que cette vérification relativement simple et d'un coût limité, n'aura pas été réalisée, on pourra continuer à discuter ou à contester à n'en plus finir, toutes les méthodes classiques de suivi hydrique actuellement proposées.

Rendements et satisfaction des besoins en eau de l'arachide

Nous avons vu plus haut qu'avec des besoins en eau bien satisfaits, et d'excellentes conditions de travail du sol et de fertilisation chimique, l'arachide pouvait atteindre d'excellents rendements.

Dans le cas de la variété de 90 jours (55-437) on a pu récolter 2945 kg ha^{-1} (±256) de gousses et 3300 kg ha^{-1} de fanes pour des besoins en eau de 405 mm (±32) (1974). A noter que sur un traitement voisin, qui avait reçu 492 mm de pluie et aucune irrigation, on trouve des consommations en eau du même ordre, soit 403 mm (±20), pour des rendements en gousse de 2705 kg ha^{-1} (±292) et en fane de 2770.

Avec la même variété, dans les conditions très marginales de Louga, nous avions pu vérifier que les rendements gousses étaient bien corrélés avec le niveau d'alimentation hydrique (Forest et Dancette 1982). En revanche, lorsque cette variété est bien adaptée à sa zone géographique, les problèmes d'ordre hydrique sont limités. Ainsi à Bambey, ou dans 80% des années, la pluviométrie peut atteindre ou dépasser 380 mm, d'après l'analyse de la période de sécheresse 1968-1984, les variétés de 90 jours se comportent honorablement : 2140 kg ha^{-1} en moyenne, entre 1972 et 1980, sur des essais agronomiques (Dancette 1984). Par ailleurs, les variations de rendement ne pourront pas être reliées au seul facteur de consommation hydrique car ce n'est plus le facteur limitant principal. Ce qui jouera alors ce sera : éventuellement l'excès hydrique, le niveau de fertilité, l'état phytosanitaire, la qualité des semences, certains mécanismes physiologiques mal connus, etc.

En ce qui concerne la variété de 105 jours, 57-422, des rendements gousse de 3660 kg ha^{-1} (±30) et fane de 4990 kg ha^{-1} avaient été obtenus en 1973 pour des besoins en eau de l'ordre de 550 mm (±30). A noter que cette fois, sur le traitement voisin la consommation hydrique avait été de 397 mm (±17) et les rendements atteignaient 2970 kg ha^{-1} (±440) pour les gousses et 5650 kg ha^{-1} pour les fanes. A la suite d'irrigations intempestives, et de maladies, la densité à la récolte du traitement irrigué était inférieure de 19% à celle du traitement non irrigué. Pour une satisfaction des besoins en eau de 72%, ou si l'on préfère un déficit hydrique de l'ordre de 28%, la chute du rendement en gousse avait été de 19%. A Bambey, où la durée d'hivernage utile sur la période 1931-1975, peut atteindre ou dépasser 93 jours dans 80% des années, on préfère une variété de 90 jours. Même si les rendements en station des variétés de 90 jours et de 105 jours, sont peu différents, il semble raisonnable de choisir la variété de 90 jours :

- Pour des raisons d'économie d'eau et de bilan hydrique général (alimentation des couches profondes du sol et des nappes, maintien de la population arborée etc.)

- Pour des raisons de calendrier agricole plus souple.

Enfin, en 1977, la variété 28-206 de 120 jours, avait donné 3700 kg ha^{-1} (±290) de gousse et 3900 kg ha^{-1} de fanes, pour des besoins en eau de 560 mm (±50). Sur le traitement voisin avec 374 mm de pluviométrie et sans irrigation de complément, la consommation réelle avait été de 387 mm (±4) (léger prélèvement sur des réserves hydriques du sol, antérieures à la saison des pluies); cette fois-ci, le rendement en gousse n'avait atteint que 1310 kg ha^{-1} (±300), pour un rendement en fane de 3670 kg ha^{-1}. Donc pour un taux de satisfaction des besoins en eau de 69% (déficit de 31%) le rendement en gousse avait chuté de 64%. Comme le stress hydrique n'était pas intervenu pendant la phase végétative, mais en fin de floraison et pendant la maturation, les rendements en fane étaient restés voisins.

Pour diverses raisons liées surtout à la baisse de la pluviométrie et au raccourcissement (causé par des fins de saison prématurées) de la durée de l'hivernage utile, l'aire des variétés de 120 jours s'est trouvée décalée au Sénégal, de près de 200 km plus au Sud. Simultanément, les variétés de 90 jours, et dans une moindre mesure celles de 105 jours, ont remplacé les variétés tardives.

A partir de nos résultats portant sur les besoins en eau et sur les consommations réelles mesurées en pleine culture, sur les caractéristiques hydrodynamiques des principaux sols, sur la détermination des données relatives à la demande évaporative et ses variations, des tentatives de simulation du bilan hydrique des principales cultures (dont l'arachide) ont été faites (Forest 1974, Franquin et Forest 1977, Forest et Dancette 1982, etc.). Bien calé sur les réalités de terrain, le bilan hydrique simulé permet, *à posteriori*, d'analyser de longues séries d'années pluviométriques et de rendements, pour les principales variétés et les principaux types de sol rencontrés. D'importantes applications en découlent sur le zonage variétal, l'adaptabilité des diverses variétés et son évolution dans le temps, l'explication du rendement d'un point de vue hydrique, le recours à l'irrigation etc. (Tab. 6, Fig. 3). Ces aspects pourront être illustrés

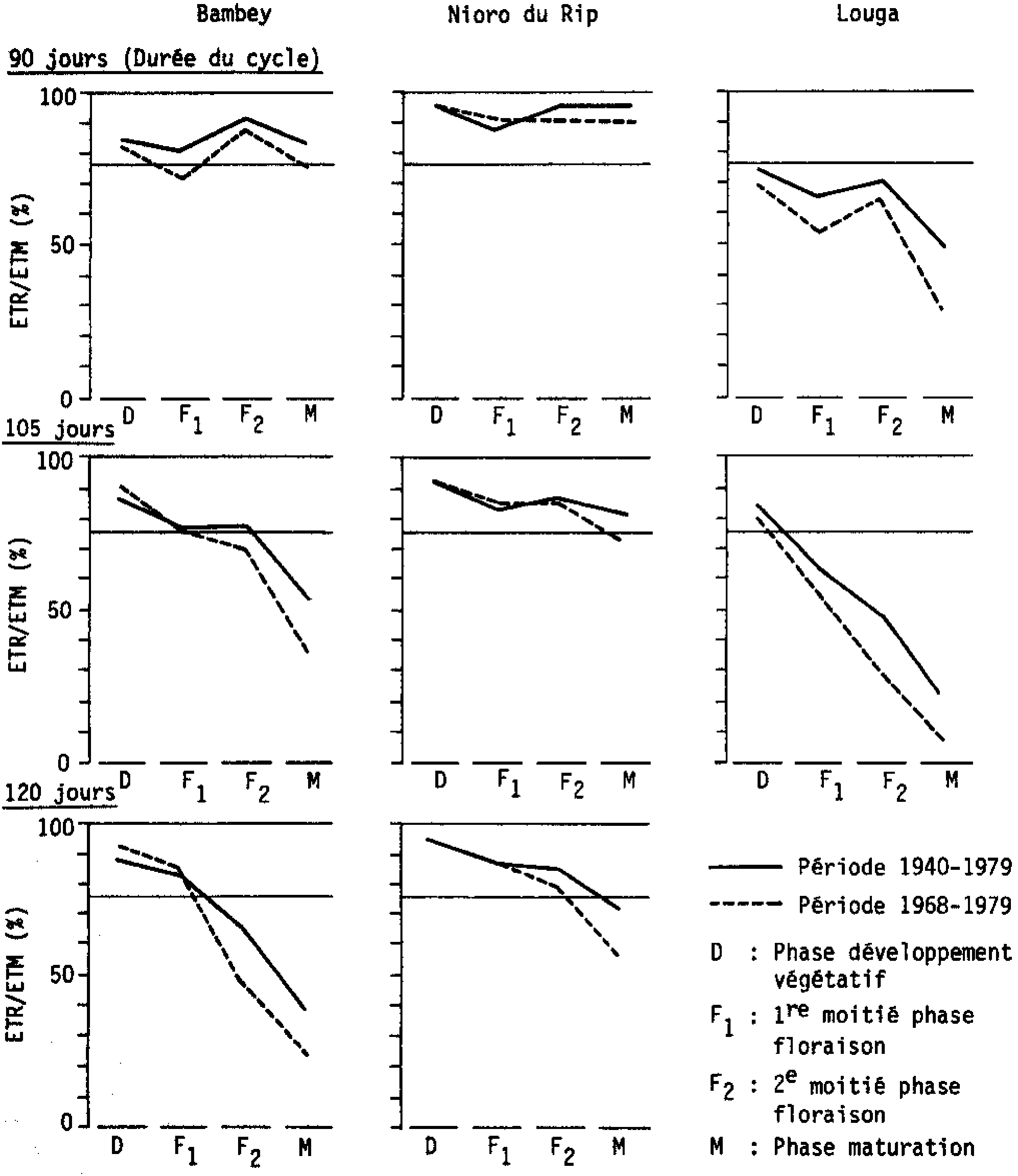

Figure 3. Influence des conditions pluviométriques sur la satisfaction des besoins en eau de la culture de l'arachide.

Tableau 6. Taux moyens de satisfaction des besoins en eau ETR/ETM (%) à Bambey, Sénégal.

Variété	Réserve utile (mm)	D	F_1	F_2	M	Total cycle
120 jours	80	89[1] (94)[2]	84 (84)	66 (48)	39 (25)	71 (65)
105 jours	80	87 (91)	77 (76)	78 (70)	54 (36)	74 (68)
90 jours (semée après 1er Juin)	80	77 (82)	74 (74)	88 (88)	85 (75)	81 (80)
90 Jours (semée après 1er Juillet)	80	84 (82)	81 (72)	91 (90)	83 (78)	84 (80)
90 Jours (semée après 1er Juin)	50	75 (80)	70 (69)	85 (84)	77 (64)	77 (73)

1. Moyenne (%) sur 40 ans 1940-1979.
2. Moyenne (%) période sécheresse 1969-1979.

D = Phase de développement végétatif.
F_1 = 1re moitié phase floraison.
F_2 = 2e moitié phase floraison.
M = Phase de maturation.

d'un point de vue essentiellement opérationnel : recherche et développement, en vue d'une meilleure valorisation de l'eau.

Simulation du bilan hydrique de l'arachide

Le modèle du bilan hydrique simulé de l'IRAT a été présenté par ailleurs, dans un document CIEH-IRAT (1984, pages 104-112). L'application du modèle Bilan hydrique des cultures irriguée et pluviale (BIP) de l'IRAT a fait l'objet de plusieurs publications (Forest) au cours des dernières années.

En ce qui concerne l'arachide, nous avons utilisé le bilan hydrique simulé pour :

- Trois stations sénégalaises: Louga au Nord du pays, Bambey au centre et Nioro du Rip au Centre-Sud;
- Deux à trois types du sol différents par leur granulométrie et leur réserve en eau utile (de 50 à 150 mm);
- Trois variétés d'arachides de 90, 105 et 120 jours de durée de cycle (le semis peut être simulé comme pour Bambey, soit après le 1er juin soit après le 1er juillet);
- 40 années (données pluviométriques quotidiennes) : 1940-1979, en distinguant toute la période d'une part, et la période de sécheresse d'autre part : 1966-1979.

Les principaux résultats sont présentés dans un document sur la simulation du bilan hydrique de l'arachide (Forest et Dancette 1982). Cette étude a fourni des éléments de choix précieux concernant une nouvelle esquisse de la carte d'adaptation variétale de l'arachide au Sénégal (Tab. 7 et Fig. 3).

Le bilan hydrique simulé permet d'expliquer les séries de rendement obtenues à Louga, à partir du taux de satisfaction des besoins en eau ETR/ETRM.

L'explication des rendements est beaucoup plus délicate à Bambey où les variétés d'arachide de 90 et 105 jours restent encore relativement bien adaptées aux pluviométries reçues. En gros, les rendements inférieurs à 1000 kg ha^{-1} peuvent le plus souvent être expliqués par des stress hydriques, mais les choses sont beaucoup moins nettes pour une gamme de rendements pouvant aller de 1000 à 2500 kg ha^{-1} et pour des pluviométries variant entre 400 et 600 mm. Il faut bien reconnaître que, lorsque des rendements de 2500 kg ha^{-1} sont atteints les conditions hydriques ont été effectivement très bonnes, mais avec les mêmes conditions hydriques, on peut obtenir des rendements parfois très médiocres et décevants; ces rendements ne s'expliquent pas par des facteurs d'ordre hydrique mais par de nombreux autres facteurs souvent mal élucidés : maladies, mauvaise qualité des semences, raisons physiologiques plus ou moins obscures, fertilité du sol, état de la surface du sol, etc.

Enfin à Nioro du Rip, 75% des rendements pouvaient en gros être expliqués à partir des taux de satisfaction des besoins en eau et des périodes d'apports excédentaires décelées par les estimations d'eau drainée ou ruisselée.

Actuellement, la simulation du bilan hydrique s'oriente vers des améliorations portant sur une meilleure prise en compte des lois de la dynamique d'enracinement des cultures (Chopart et Nicou 1973) et sur une meilleure définition des conditions d'évaporation à la surface du sol en début de culture (15 à 20 premiers jours au maximum). Ce travail préparé par des fiches de bilan que l'on peut établir à la main ne demande plus qu'à être informatisé. En fait, le bilan hydrique simulé est en constante amélioration, compte tenu des connaissances en cours d'acquisition,

Tableau 7. Taux moyen de satisfaction des besoins en eau (ETR/ETM %) pendant les principales phases du cycle de l'arachide (sur 40 années).

Station	Variété	Réserve utile (mm)	D	F_1	F_2	M	Total cycle
Louga	Arachide de 105 jours	80	84 (80)[1]	63 (55)	48 (30)	21 (7)	55 (45)
	Arachide de 90jours	80	73 (70)	65 (54)	70 (64)	49 (28)	65 (52)
		50	71 (68)	59 (48)	66 (60)	42 (21)	59 (48)
Bambey	Arachide de 120 jours	80	89 (94)	84 (84)	66 (48)	39 (25)	71 (65)
	Arachide de 105 jours	80	87 (91)	77 (76)	78 (70)	54 (36)	74 (68)
	Arachide de 90 jours semée après le 1er juin	80	77 (82)	74 (74)	88 (88)	85 (75)	81 (80)
	semée après le 1er juillet	80	84 (82)	81 (72)	91 (90)	83 (78)	84 (80)
	semée après le 1er juin	50	75 (80)	70 (69)	85 (84)	77 (64)	77 (73)
Nioro du Rip	Arachide de 120 jours	80	95 (93)	89 (90)	86 (81)	73 (57)	86 (81)
		150 (94)	95 (93)	92 (88)	92 (76)	84 (88)	91
	Arachide de 90 jours	80	96 (97)	89 (92)	95 (91)	96 (90)	95 (93)
	semée après le 25 juin	150	96 (97)	91 (94)	97 (96)	98 (96)	96 (96)

D, F1, F2, M : Voir note en bas du Tableau 6.

[1] Péjoration des conditions pluviométriques au cours des 12 dernières années (1968-1979).

relatives soit à la demande évaporative, soit aux facteurs climatiques eux-mêmes (pluviométrie essentiellement), soit aux exigeances hydriques de la plante (besoins en eau, réactions physiologiques, courbe de réponse à l'eau, etc.), soit enfin aux caractéristiques hydrodynamiques du sol. Le bilan hydrique simulé constitue en quelque sorte une synthèse, que l'on veut opérationnelle de toutes nos connaissances portant sur les principaux facteurs de ce bilan qui font parallèlement et simultanément l'objet d'études de plus en plus approfondies.

Sous sa forme actuelle (présentant quelques légères variantes en fonction des besoins exprimés) le bilan simulé (modèle BIP par exemple) traduit relativement bien la réalité, dans les conditions inter-tropicales d'Afrique de l'Ouest. Ainsi, si on compare l'ETR mesurée au champ avec un certain nombre de répétitions, et l'ETR obtenue par le bilan hydrique simulé, on arrive pour l'arachide aux résultats suivants :

- Arachide de 90 jours
- Essai AIEA en 1979 au Centre national de

recherches agronomiques (CNRA) de Bambey (sur 6 répétitions)
ETR totale mesurée = 333 mm (±23)
ETR simulée (modèle Forest) = 316 mm

- Essai AIEA en 1983 à Thilmakha (sur 4 répétitions)
  ETR totale mesurée = 173 mm (±8)
  ETR simulée = 168 mm

- Essai "némagon" à Bambey 1983 (4 répétitions)
  ETR totale mesurée = 223 mm (±3)
  ETR simulée = 247 mm

- Arachide 105 jours :
- Essai au CNRA Bambey en 1973 (4 répétitions)
  ETR totale mesurée = 397 mm (±17)
  ETR simulée = 380 mm

- Arachide de 120 jours :
- Essai au CNRA de Bambey en 1977 (4 répétitions)
  ETR totale mesurée = 387 mm (±4)
  ETR simulée = 359 mm

Un essai arachide réalisé en 1984 par D. Annerose du Centre de coopération internationale en recherche agronomique pour le développment (CIRAD) au CNRA de Bambey a été interprété (Forest 1985). Le modèle de bilan hydrique simulé, dérivé du modèle BIP avait été adapté sur un mini ordinateur Commodore. Trois dates de semis différentes, d'une variété de 90 jours, ont été analysées. Le rendement est estimé à partir de la relation :

Rdr espéré = Indice de productivité de l'arachide en conditions d'ETRM × ETR du cycle × ETR/ETRM pendant la phase la plus critique de la culture.

Les rendements ainsi calculés correspondent assez bien aux rendements réellement obtenus sur l'essai. A ce stade encore peu avancé des études, il est estimé qu'en distinguant la part qui revient au type d'année, au choix de la date de semis et à la variété, le modèle utilisé constitue bien un outil d'aide au diagnostic (Forest 1985).

Tableau 8. Cycle de la culture d'arachide (90 jours) découpé en quatre phases distinctes.

Phase	Durée	Sensibilité
Semis-croissance	30 jours	faible
Initiation fleurs	15 jours	forte
Pleine floraison	15 jours	très forte
Remplissage gousse	30 jours	faible

Analyse des taux de satisfaction ETR/ETM pour trois dates de semis d'arachide de 90 jours : Essai variétal 1985

A titre d'application, un essai date de semis effectué par M. Annerose, chercheur CIRAD, travaillant au CNRA de Bambey, a été analysé à l'aide du bilan hydrique.

Bien que les parcelles soient de petites dimensions, cette étude de la relation rendement × régime d'alimentation hydrique permet de mettre en évidence des seuils de résistance de la plante à la sécheresse, variables selon le stade phénologique.

L'interprétation des résultats est encore sommaire, elle démontre toutefois l'intérêt de l'utilisation du modèle de bilan hydrique BIP4 pour les sélectionneurs. En distinguant la part qui revient au type d'année, au choix de la date de semis et à la variété, ce modèle constitue bien un outil d'aide au diagnostic.

Description sommaire des matériels et méthodes

Le sol concerné est de type Dior avec une réserve racinaire de l'ordre de 100 mm pour 120 cm d'enracinement.

La durée de cycle de la culture d'arachide analysée est de 90 jours. Un découpage du cycle en quatre phases distinctes est proposé (Tab. 8) :

Le bilan hydrique est calculé par périodes de cinq jours pour chaque traitement date de semis (Tab. 9).

La formule proposée par Forest et Reynier est utilisée pour analyser la relation rendement × satisfaction des besoins en eau:

Rendement espéré = Ivar × ETR cycle x ETR/ETM (période critique)
Avec: Ivar = productivité de la plante dans les conditions de l'ETM
Par exemple pour 4500 kg ha^{-1} de gousse par hectare et pour ETM = 500 mm, Ivar = 9

La période critique correspond à la phase du cycle

Tableau 9. Bilan hydrique d'arachide de 90 jours sur le sol de type Dior.

Période	Evaporation bac.cl. A mm j^{-1}	Pluviometrie totale (mm)	Date de semis		
			20 junin	27 juillet	1er août
			ETR/ETM (%)		
Juin					
20-25	6,9	0	100%	-	-
26-30	6,8	29	100	-	-
Juillet					
1-5	7,3	0	93	-	-
6-10	7,6	12	60	-	-
11-15	6,5	7	35	-	-
16-20	6,6	0	16	-	-
21-25	7,2	35	fl$_1$[1] 57	-	-
26-31	6,5	26	76	100	-
Août					
1-5	5,5	63	97	100	100
6-10	6,8	0	fl$_2$[2] 98	100	100
11-15	7,1	0	60	81	84
16-20	6,5	31	94	100	100
21-25	6,5	8	matu[3] 78	76	86
26-31	6,8	0	34	fl$_1$ 19	27
Septembre					
1-5	7,6	0	41	17	fl$_1$ 18
6-10	5,7	38	87	66	66
11-15	7,0	50	100	fl$_2$ 100	100
16-20	4,6	0	99	100	fl$_2$ 100
21-25	6,0	19	-	100	100
26-30	4,8	0	-	matu 88	85
Octobre					
1-5	4,9	12	-	90	matu 86
6-10	6,6	0	-	66	61
11-15	6,6	0	-	36	34
16-20	7,1	0	-	9	5
21-25	7,1	0	-	1	1
26-31	7,6	0	-	-	1
Novembre					
1-5	7,6	0	-	-	-
Som ETM cycle			475	465	481 mm
Som ETR cycle			343	293	268 mm
ETR/ETM cycle			0,72	0,63	0,56 mm
Som drainage			0	0,2	23 mm

1. fl$_1$: initiation des fleurs.
2. fl$_2$: pleine floraison.
3. matu: phase de maturation.

sensible pour laquelle le taux ETR/ETM moyen est minimum.

Interprétation

Observations sur les bilans globaux

La meilleure valorisation de l'offre en eau pluviométrique est obtenue pour le semis le plus précoce. L'écart ETR est de 75 mm pour un décalage de 36 jours. La perte par drainage est significative (23 mm) pour le semis du mois d'août. Ces pertes ont eu lieu dès le début de la culture en raison d'une faible activité racinaire.

Analyse des taux de satisfaction ETR/ETM par période phénologique

En utilisant le découpage proposé, il est possible d'avoir une indication sur l'importance et la place des stress hydriques au cours des cycles de culture et leur effet sur la production (Tab. 10).

L'analyse des résultats montre que l'estimation du rendement par la formule est acceptable. Le stress hydrique pour la date de semis du 27juillet semble toutefois surestimé. En termes physiologiques, on notera que des taux de satisfaction supérieure à 75% au cours des phases de floraison sont nécessaires pour l'extension de rendements supérieurs à la moitié du potentiel. Des valeurs de l'ordre de 60% semblent être la limite pour dépasser la tonne à l'hectare.

L'intérêt d'une irrigation de complément permettant d'améliorer les valeurs de ETR/ETM au cours des phases sensibles apparaît bien justifié.

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Tableau 10. Analyse des taux de satisfaction ETR/ETM (%).

	ETR/ETM par phase								
Semis	idv[1]	fl_1[2]	fl_2[3]	matu[4]	ETR cycle (mm)	ETR/ ETM (%)	Ivar	Rendement gousse espéré (kg ha^{-1})	Rendement (kg ha^{-1})
20 Juin	67	76	84	73	343	76	9	2346	2400
27 Juil.	93	34	100	48	293	34	9	896	1400
1er Août	82	61	95	31	268	61	9	1417	1600

1. idv : levée croissance.
2. fl_1 : initiation des fleurs.
3. fl_2 : pleine floraison.
4. matu : phase de maturation.

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Studies on Water Relations of Groundnut

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Abstract

Approximately 70% of the world groundnut production comes from the developing countries, many of which lie in the semi-arid tropics (SAT). Yields in the SAT are low and variable due to erratic rainfall. Water deficits that are a consequence of the imbalance between water supply and plant-water needs affect groundnut growth depending on the stage of crop growth and the degree or intensity of the drought stress. In order to develop management strategies to increase and stabilize groundnut yields in the SAT it is necessary to study the effect of drought stress at different phenological phases on growth, water relations, and yield.

Total water use by groundnut is controlled by climatic, agronomic, and varietal factors. The role of some of these factors has been summarized with suitable examples. Drought stress effects at different phenological phases on the growth, water relations, and yield have been highlighted using the data collected in a series of experiments conducted over three postrainy seasons of 1980, 1981, and 1982 on a medium deep Alfisol at ICRISAT center in India employing the line-source sprinkler irrigation technique. The implications of research on water relations in developing strategies for improved groundnut production are discussed.

Résumé

Etudes sur les relations hydriques de l'arachide : *Environ 70% de la production mondiale d'arachide provient des pays en voie de développement, dont plusieurs se trouvent dans les zones tropicales semi-arides. Dans ces zones, les rendements sont faibles et variables en raison de l'irrégularité des pluies. L'effet des déficits hydriques (résultante du déséquilibre entre l'apport d'eau et les besoins hydriques des plantes) sur la croissance de l'arachide varie selon les stades de croissance de la culture et la gravité du stress hydrique. Pour développer des stratégies visant à accroître et régulariser la production d'arachide dans les zones semi-arides, il faut étudier les effets de la contrainte hydrique à différents stades phénologiques, les relations hydriques et les rendements de l'arachide.*

La consommation totale d'eau par l'arachide est fonction de facteurs climatiques, agronomiques et variétaux. Le rôle de certains de ces facteurs est illustré par quelques exemples. Les effets de la contrainte hydrique sur la croissance, les relations hydriques et les rendements sont résumés pour différents stades phénologiques. Pour ce faire, nous avons utilisé les données collectées lors d'une série d'essais conduits en 1980, 1981 et 1982, après la saison des pluies, sur des Alfisols de profondeur moyenne, au Centre ICRISAT en Inde. La technique d'irrigation par aspersion en ligne a été utilisée. Les implications de ces résultats sur le développement de stratégies de production d'arachide sont discutées.

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Introduction

At the end of an excellent compendium in Peanut Science and Technology reviewing the future needs of the groundnut industry, Pattee and Young (1982) suggested that future research on water-management technology should include basic studies of soil-plant- water relations of groundnut. This is important because groundnut has specific moisture needs due to the unique feature of developing the pods underground. The flower is borne above ground and after it withers, the stalk elongates, bends down, and forces the ovary underground. The seed matures below the surface. Hence both the quantity and the quality of groundnut seed is intimately related to conditions that favor the growth processes preceeding and during the development of the seed. Proper functioning of these growth processes requires a favorable balance controlled by the relative rates of soil-moisture uptake by the roots and the water loss by transpiration. Water deficits that are a consequence of the imbalance between water uptake and transpiration, affect groundnut growth depending on the stage of crop growth and the degree or intensity of the drought stress. It is hence imperative that studies on water relations of groundnut should include considerations of soil-water availability, and the influence of the adequacy or lack of soil water at different growth phases on plant-water status, plant growth, and yield.

Soil-Water Availability and Water Use

Groundnut yields are reported to be variable from year to year because of the large interannual variation in rainfall (Sindagi and Reddy 1972). Bhargava et al. (1974) reported that 89% of the yield variation over four regions in India could be attributed to rainfall variability in the Aug-Dec growing period. It is therefore not surprising that a large majority of the agronomic investigations conducted on groundnut, especially in the semi-arid regions, are concerned with irrigation aimed at stabilizing yields.

Depth of Water Extraction

One of the important considerations in the availability of soil water to groundnut plants is the rooting depth under normal conditions to fully exploit the profile water. Although the rooting depth of the groundnut plant is reported to extend up to 150 cm (Metelerkamp 1975) and even up to 200 cm (Hammond et al. 1978, Robertson et al. 1980), a majority of the roots are in the surface-soil layers. Robertson et al. (1980) reported 39% of the total rooting length in the top 15 cm of soil and 55% in the top 30 cm. Hammond et al. (1978) measured root densities of 1.5 cm cm^{-3} in the 0-30 cm soil layer while at greater depths the root densities were only 0.1-0.4 cm cm^{-3}. When the water supply is adequate, as under irrigated conditions, groundnut extracts up to 48% of the water required from the upper 30 cm (Mantell and Goldin 1964). Shalhevet et al. (1976) from the International Irrigation Centre using the data from two locations in Israel showed an average removal of 36% in the 0-30 cm depth, but only 7% in the 120-150 cm region. Under a limited-water situation, more water extraction occurred from the 90-150 cm soil layer. Avasarmal et al. (1982) and Hammond and Boote (1981) also concluded that maximum water extraction occurs in the 30-45 cm soil layer. Stansell et al. (1976) observed water extraction below 60-cm depth only 75 days after sowing.

Total Water Use

The total water use by a groundnut crop is controlled by climatic, agronomic, and varietal factors. A summary of the reported water use of groundnut is given in Table 1. The range of water-use values given reflects the variable soil-climatic conditions under which the crop is grown and the varieties used.

The total water use of groundnut could also be altered by agronomic practices irrespective of the rainfall or number of irrigations. Fertilizer application has been reported to increase the water use (Bhan 1973) and interactive effects of fertilizer and irrigation have also been shown (Babu et al. 1984, Narasimham et al. 1977). Row spacing was reported to affect water use although there was no unanimity on which spacing helps to increase water use. While Bhan and Misra(1970) and Bhan (1973) showed that groundnut grown in narrow rows of 30 cm used more water, Choy et al. (1977) reported less water use by the crop in 30-cm rows. Results of McCauley et al. (1978) also agreed with those of Choy et al. (1977). On the other hand, investigations of Reddy et al. (1978) showed highest consumptive water use with 45-cm row spacing in comparison to 30- or 60-cm rows. Row orientation (Choy et al. 1977, Davidson et al. 1983, McCauley et al. 1978) in these

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-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 7-10 day interval during winter months

spacing studies was reported to influence the water use.

The crop water-use requirements reach the maximum about midway through the growth of the crop when the canopy cover is complete (Davidson et al. 1973). Peak water-use values range from 5-7 mm^{-1} (Mantell and Goldin 1964, Stansell et al. 1976, Kenning et al. 1982). Soil-water availability exerts a controlling influence on the peak water use as reported by Vivekanandan and Gunasena (1976) who measured peak values of 6.1, 4.8, and 3.8 mm^{-1} under high, intermediate, and low water potentials respectively.

Soil-Water Availability and Total Water Use as Influenced by the Stage at which Drought Stress Occurs

Rainfall in the semi-arid regions is erratic in duration and distribution, which could lead to droughts of varying intensities and durations during the crop season. Hence, the total water use could vary with the stage of crop growth during which these droughts occur, and the water-use requirements of the crop at these stages. Using the line-source sprinkler irrigation technique (Hanks et al. 1976), we examined the effects of withholding irrigations at different growth stages on the growth, development, water relations, and yield responses of groundnut cultivar Robut 33-1 grown during the postrainy season.

The crop growth phases studied were:

A. emergence to start of flowering,

B. emergence to start of pegging,

C. start of flowering to start of seed growth,

D. start of seed growth to maturity, and

E. continuous stress from emergence to maturity.

Growth phases investigated during 1980/81 and 1981/82 included B to E, while in 1982/83 in place of growth phase D, growth phase A was included to gather additional data on the effects of withholding irrigations during the early growth phases. Although data were collected at three different distances from the line source, for the sake of simplicity in this paper we present data collected at the 12-18 m distance range from the line source, which only represents the fully stressed situation during the periods when line-source irrigations were given.

Seasonal changes in the available soil water at different soil depths in the 0-120 cm soil profile in different treatments during the 1982/83 growing season are presented in Figure 1. The data show that in growth phase A the soil-water extraction was more or less confined to the top 60 cm of soil. In growth phase B, since the drought stress was imposed till the start of pegging, i.e., up to 55 days after emergence (DAE), soil-water extraction in the 0-30 cm soil layer was higher than in growth phase A, and the extraction occurred even in the lower layers. In growth phase C (no irrigations from 30-90 DAE), soil-water extraction occurred at all depths, and at soil depths 60-120 cm the extraction was significanity higher than in the earlier two growth phases. When the drought stress was imposed throughout the growing season, water extraction in the 60-120 cm soil depths was the highest of all the treatments.

The effect of drought stress imposed at different growth phases on the total water use by groundnut during the three years is shown in Table 2. Total water use during the three seasons was different for any given growth phase because of the differences in the rainfall during the preceding rainy season (and hence the initial-profile water content) during the three years and because of the differences in the amount of water applied. However, when water use in any given growth phase is considered as a proportion of the water use in the fully irrigated control, the differences between the three years are less significant.

Peg Penetration into Soil in Relation to Soil-Water Availability

Soil-surface moisture content is considered critical to peg entrance into the soil. Taylor and Ratliff (1969) showed that as the soil dried, its mechanical resistance increased. For fruiting to occur the gynophores must enter the soil. Hence the soil physical condition is of importance since the gynophores are

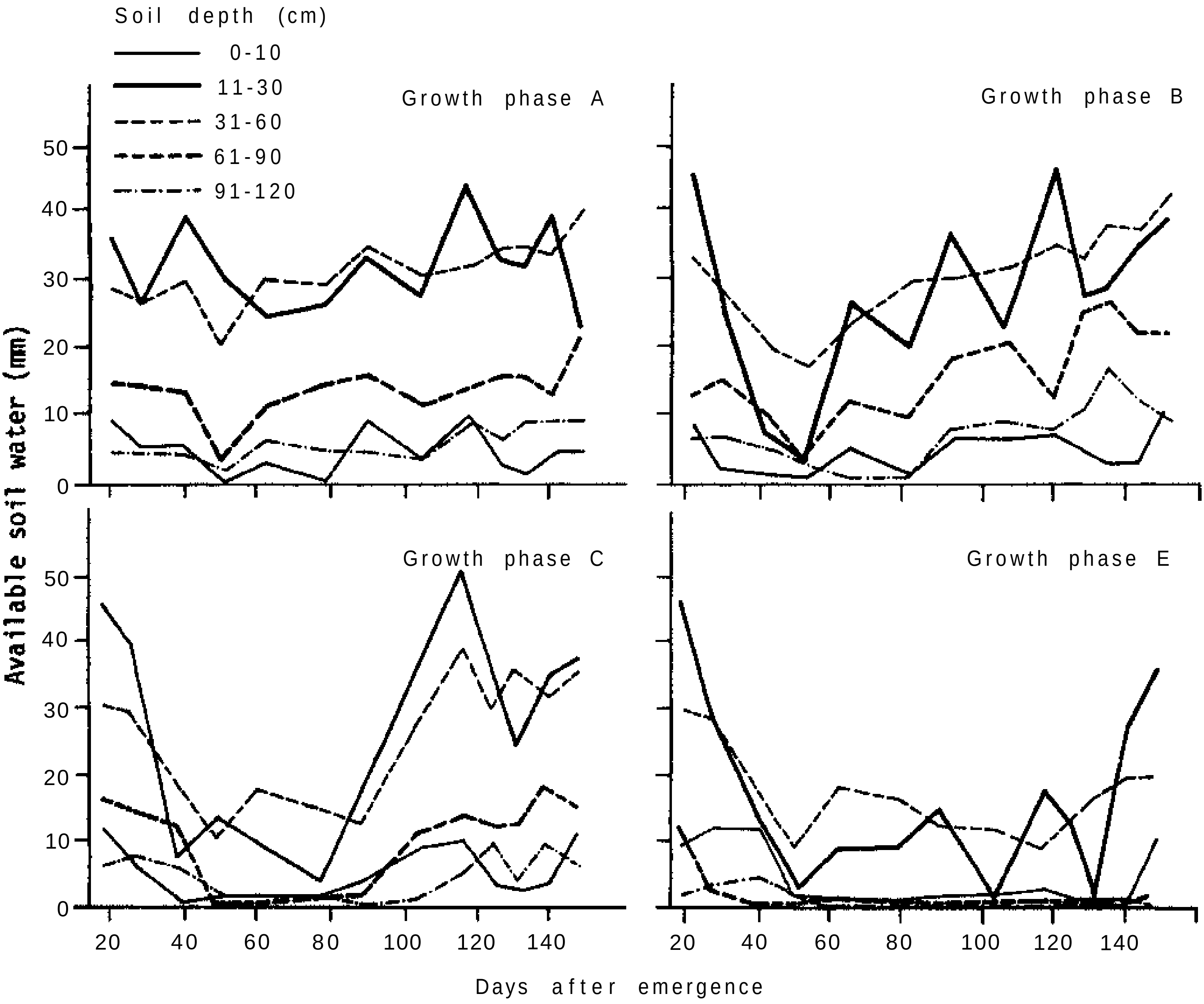

Figure 1. Seasonal changes in available soil water *(mm)* at different depths (cm) for groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83. (Growth phase A: emergence to start of flowering. B: emergence to start of pegging. C: start of flowering to start of seed growth. E: emergence to maturity.)

Table 2. Total water use (mm) of groundnut cv Robut 33-1 when drought stress was imposed at different growth phases during three growing seasons, ICRISAT Center, 1980-83.

Growth phase	Total water use (mm)		
	1980/81[1]	1981/82	1982/83
A. Emergence to start of flowering	—		611
B. Emergence to start of pegging	614	753	494
C. Start of flowering to start of seed growth	483	516	401
D. Start of seed growth to maturity	529	441	
E. Emergence to maturity	176	231	169
Control	807	831	687

1. 77 mm of rain received during the growing season.

able to exert a pressure equivalent to only 3-4 g cm^{-2} on the soil (Underwood et al. 1971).

We measured the soil-penetration resistance (SPR) in the surface 5-6 cm of soil during the 1982/83 growing season from the beginning of pegging to the pod development period.

Seasonal variation in the SPR for the different treatments (Fig. 2) shows that in growth phase C, the SPR was higher than in growth phases A and B with the highest SPR value of 9.9 kg cm"^{2} recorded at 86 DAE. In the continuous stress treatment these values ranged from 8.2-10.3 kg cm^{2}.

The implications of increased SPR for groundnut are reduced peg penetration into the soil (Cox 1962, Underwood et al. 1971, Boote et al. 1976) and reduced peg development into pods (Ono et al. 1974).

Influence of Soil-Water Availability on Crop Growth

Soil-water deficiency is known to inhibit leaf expansion and stem elongation through lowered relative turgidity (Slatyer 1955, Allen et al. 1976, Vivekanandan and Gunasena 1976). Leaf area index (LAI) of groundnut in different stress treatments during the 1982/83 growing season is shown in Figure 3. The recovery in leaf-area production when stress was relieved at the start of pegging was remarkable. However, this recovery was much less rapid in the case where stress was imposed during flowering to start of seed growth. The maintenance of leaf area up to the time of maturity was also remarkable for stress imposed in growth phase B as compared to the fully irrigated control. Maximum LAI in the control treatment was 4.4 while in the continuous-stress treatment it was only 1.7. Vivekanandan and Gunasena (1976) also reported reduced LAI with reduced soil-water potential, with maximum LAI of 6.25 at a soil-water potential of -0.033 MPa. A study of the anatomy of groundnut leaves under stress (Ilyina 1959) revealed that leaves formed under stress had smaller cells than others.

Several studies reported reduction in the dry-matter production due to drought stress (Fourrier

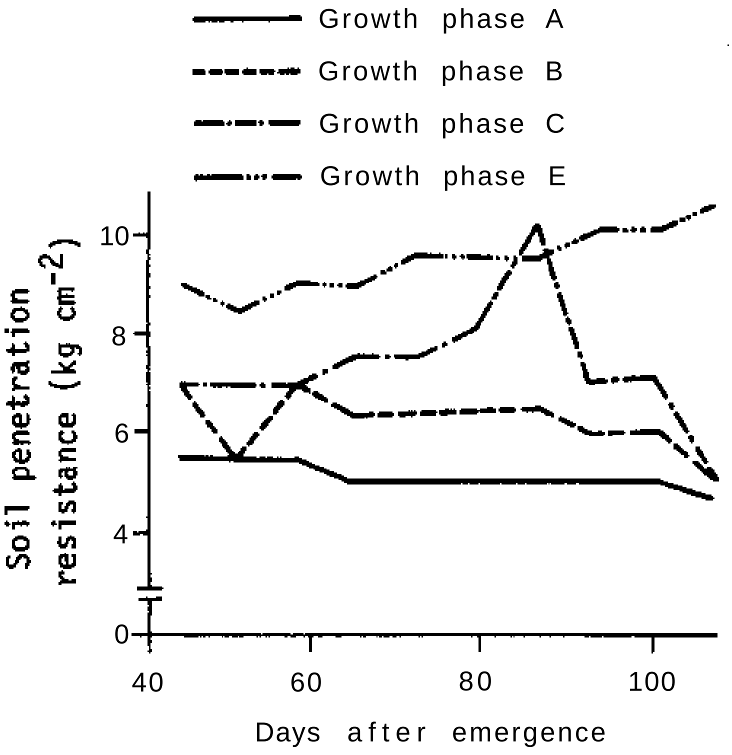

Figure 2. Seasonal changes in mean daily soil-penetration resistance (kg cm^{-2}) in drought-stress treatments imposed at different growth phases, ICRISAT Center, 1982/83.

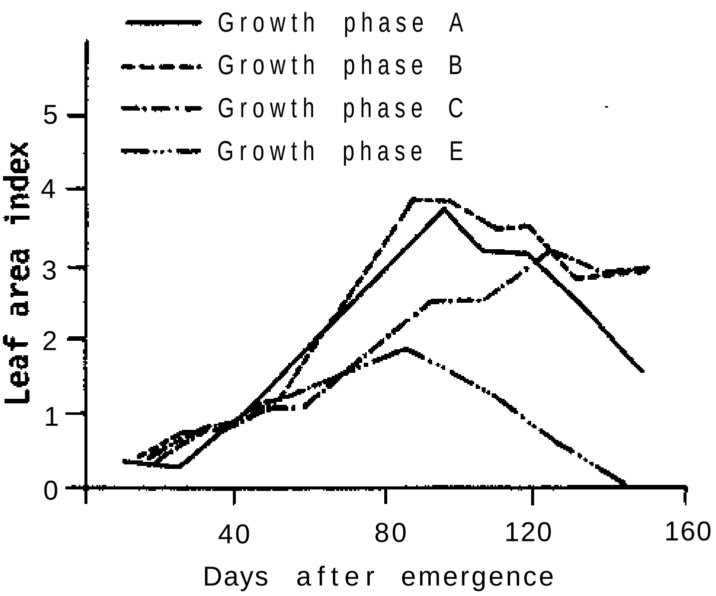

Figure 3. Seasonal changes in the leaf area index of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

and Prevot 1958, Ochs and Wormer 1959, Su et al. 1964, Lenka and Misra 1973, Stansell et al. 1976, Vivekanandan and Gunasena 1976, Pallas et al. 1979). Seasonal variation in the total dry-matter production of groundnut in different stress treatments during the 1982/83 growing season is shown in Figure 4. Although drought stress in growth phase B caused a decrease in dry-matter accumulation compared to growth phase A, there was little difference in the total dry matter at the time of final sampling between the two treatments, thereby emphasizing the rate of recovery from early drought stress in growth phase B. In the treatment covering growth phase C, the crop was irrigated from 90 DAE and the recovery in the accumulation of dry matter did not start until 20 days later. As expected, continuous-stress treatment did not increase dry matter beyond 60 DAE.

Dry-matter partitioning at the time of maturity expressed as a percentage among various plant parts for stress treatments imposed at different growth phases during the 1982/83 growing season is shown in Table 3. The recovery in dry-matter production for the treatment which was under stress from emergence to pegging (up to 50 DAE) could be gauged from the close correspondence of the different partitioning values between this treatment and the fully-irrigated control treatment. The proportion of dry matter partitioned into pods is the highest for the emergence-to-pegging phase treatment. This could also be judged from the plot of the changes in the pod growth (Fig. 5) which showed a linear growth rate for this treatment. Boote et al. (1982) suggest that an increased ratio of pods to vegetative growth under small periodic water deficits may be a natural and important mechanism of groundnut adaptation to droughty conditions. The extended drought in growth phase C, however, reduced the proportion of dry matter partitioned to the kernel in comparison to the other treatments. Ong (1984) also showed that mild drought stress promoted peg and pod production. Drought stress during pod formation (growth phase C) resulted in a slower rate of pod growth even after the stress was released as Billaz and Ochs (1961) also observed.

Influence of Soil-Water Availability on Plant-Water Status

An understanding of the response of crop foliage to changes in the amount and status of soil water in the root zone is far from complete. Kramer (1963) concluded that too much emphasis was placed on soil-water status and too little on plant-water status. The status of water in the plants represents an integration

Table 3. Dry-matter partitioning (%) at maturity among the various plant parts when drought stress was imposed at different growth phases, ICRISAT Center, 1982/83.

	Dry-matter distribution (%) for growth phases				
Plant component	A	B	C	E	Control
Leaves	23.5	24.9	20.2	29.8	22.0
Stems	26.6	21.9	18.8	59.0	24.7
Flowers	0.1	0.1	0.1	0.8	0.1
Pegs	5.2	3.4	12.6	0.9	1.5
Pods	27.3	32.1	37.4	6.8	29.8
Kernels	17.3	17.6	15.8	2.7	22.0

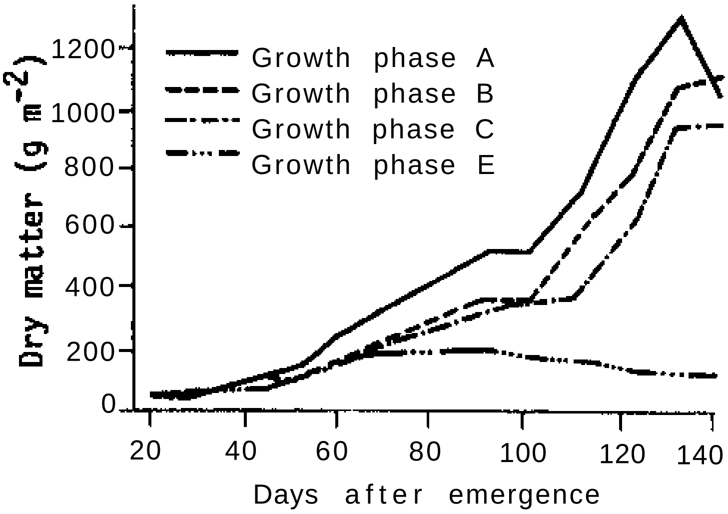

Figure 4. Seasonal changes in dry-matter production (g m^{-2}) for groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

of atmospheric demand, soil-water potential, rooting density, and distribution, as well as other plant characteristics (Kramer 1969). Therefore to obtain a true measure of plant-water deficit, the measurements should be made on the plant. Several plant measurements could be used as indicators of drought stress for groundnut. The most promising ones reported to be useful under field conditions include stomatal resistance (Pallas and Samish 1974, Pallas et al. 1974, Bhagsari et al. 1976), leaf-water potential (Bhagsari et al. 1976, Pallas et al. 1977, Pallas et al. 1979), and canopy temperature (Sanders et al. 1982). Recent advances made in porometry instrumentation now enable measurements of transpiration, which is related to stomatal opening and closing mechanisms under drought stress.

Stomatal Conductance

Under drought stress significant changes in stomatal resistance of groundnut plants have been shown. Bhagsari et al. (1976) showed that when relative water content decreased below 80%, a groundnut crop showed adaptation to drought stress by reducing the stomatal conductance. Diffusive resistance in the stressed plants was 30-35 s cm while in the watered plants it varied from 0.5-2.5 s cm^{-1}. Reduced photosynthesis due to drought stress in groundnut was attributed to stomatal closure (Bhagsari et al. 1976).

We made diurnal measurements of stomatal conductance and transpiration using a steady state porometer at weekly intervals from 0900 to 1700 at 2-hour intervals each day throughout the crop-growth period during the 1982/83 growing season. Diurnal variation in the stomatal conductance of groundnut that was subjected to drought stress at different growth phases is shown in Figure 6. These measurements were made at 75 DAE when stress was relieved in growth phases A and B and growth phase C was undergoing stress. Both time of the day and drought stress influenced the observed stomatal conductance values. The recovery from drought stress imposed during growth phase B was reflected well by the typical diurnal response exhibited by the

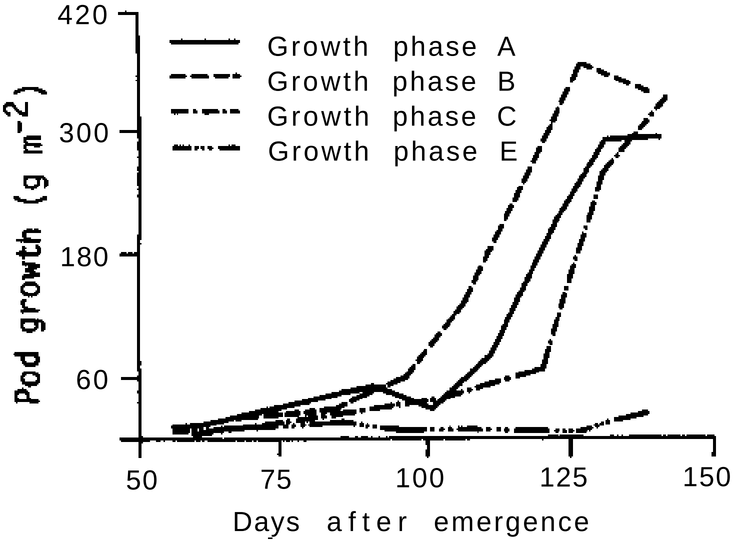

Figure 5. Changes in pod growth (g m^{-2}) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

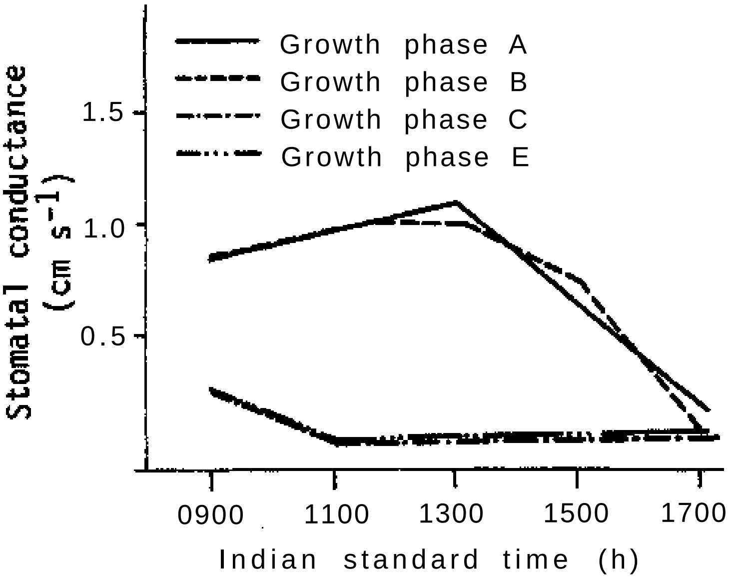

Figure 6. Diurnal variation in stomatal conductance (cm s^{-1}) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

groundnut plants to increasing irradiance levels during the day and reduced stomatal conductance in the late afternoon with reduced irradiance levels. Allen et al. (1976) have also shown that even when the stomatal conductance reached 0.1 cm s^{-1}, a cloud cover extending over a 1-hour period could improve it to 0.5 cm s^{-1}. Plants undergoing drought stress in growth phase C and in the continuous drought stress treatment closed their stomata by 1100 in response to reduced soil-water availability.

To show the drought-stress modulated responses of stomatal conductance to photosynthetic photon flux density (PPFD) we used the data collected in the fully-irrigated control treatment and the continuous-stress treatment. In the fully-irrigated control treatment, stomatal conductance increased with increasing PPFD (Fig. 7), a response typical of a crop under adequate water availability. In the continuous drought stress treatment, changing radiation levels had little influence on the stomatal conductance, thereby indicating the dependance of stomatal activity on the soil-water availability.

Seasonal variation in the stomatal conductance of groundnut with drought stress imposed at different growth phases is shown in Figure 8. In growth phase B, which was under drought stress up to about 51 DAE, the conductance was greatly reduced, but recovered steadily after water application, and reached the levels of the fully-irrigated control. In growth phase C the stomatal conductance reached a minimum mean value of 0.07 cm s^{-1} from 60-80 DAE. At 92 DAE when drought stress was relieved, the recovery extended over a longer period. In the continuous-stress treatment the lowest mean value of 0.02 cm s^{-1} was recorded. Measurements made by Allen et al. (1976) also showed that after 17 days of drought the stomatal conductance reached a minimum value of 0.1 cm s^{-1} compared with 0.5 cm s^{-1} in the irrigated plots.

Transpiration

Diurnal variation in groundnut transpiration is shown in Figure 9. The adaptation of groundnut to reduce transpiration under drought stress conditions through stomatal closure is reflected in the pattern of transpiration during the day in growth phase C and the continuous drought stress treatment.

Seasonal variation in transpiration (Fig. 10) also showed a six-fold reduction in daily mean transpiration during the period when groundnut underwent drought stress. While the fully-irrigated control treatment recorded a daily mean transpiration of 10 μg cm^{-2} s^{-1}, it was 1.8 μg cm^{-2} s^{-1} in groundnut undergoing drought stress in growth phase C.

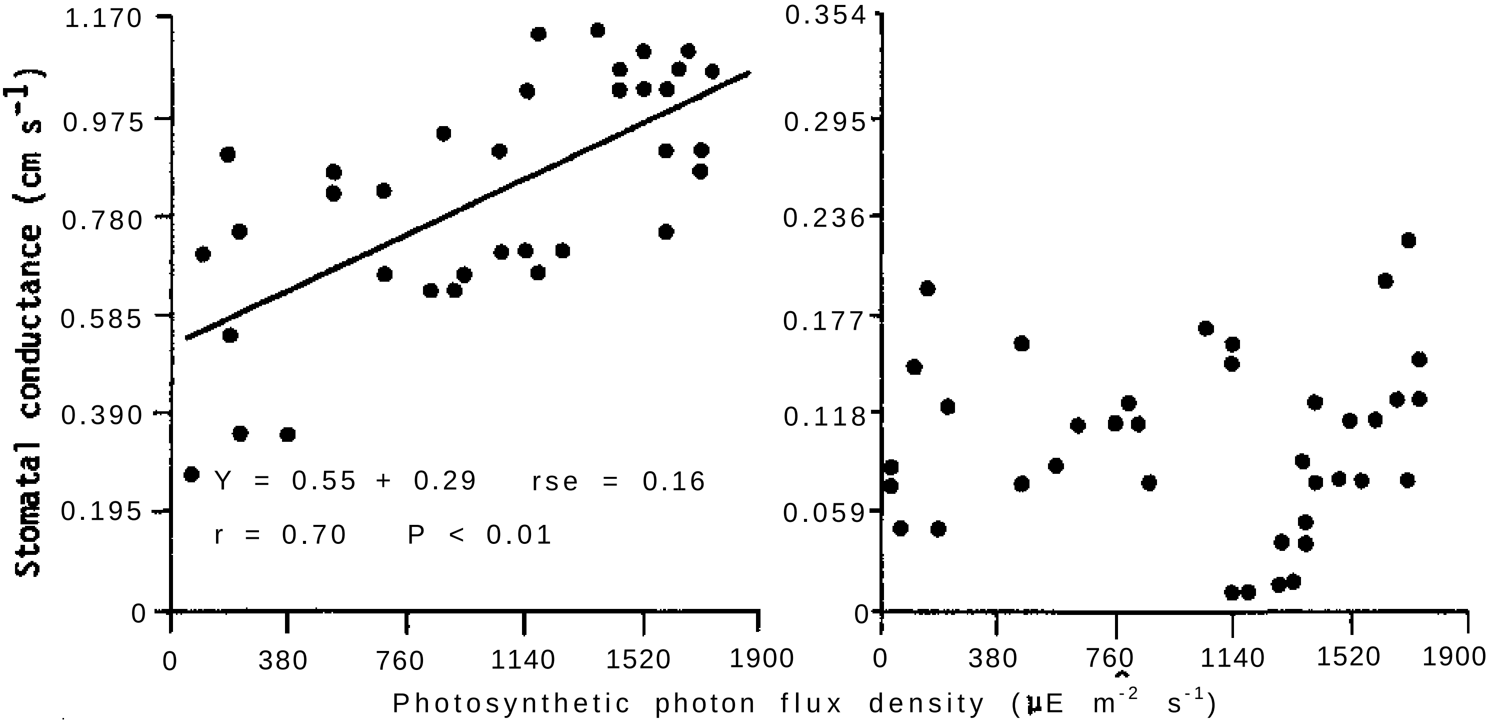

Figure 7. Stomatal conductance (cm s^{-1}) of groundnut as a function of photosynthetic photon flux density in fully-irrigated (left), and continuous-stress treatments, ICRISAT Center, 1982/83.

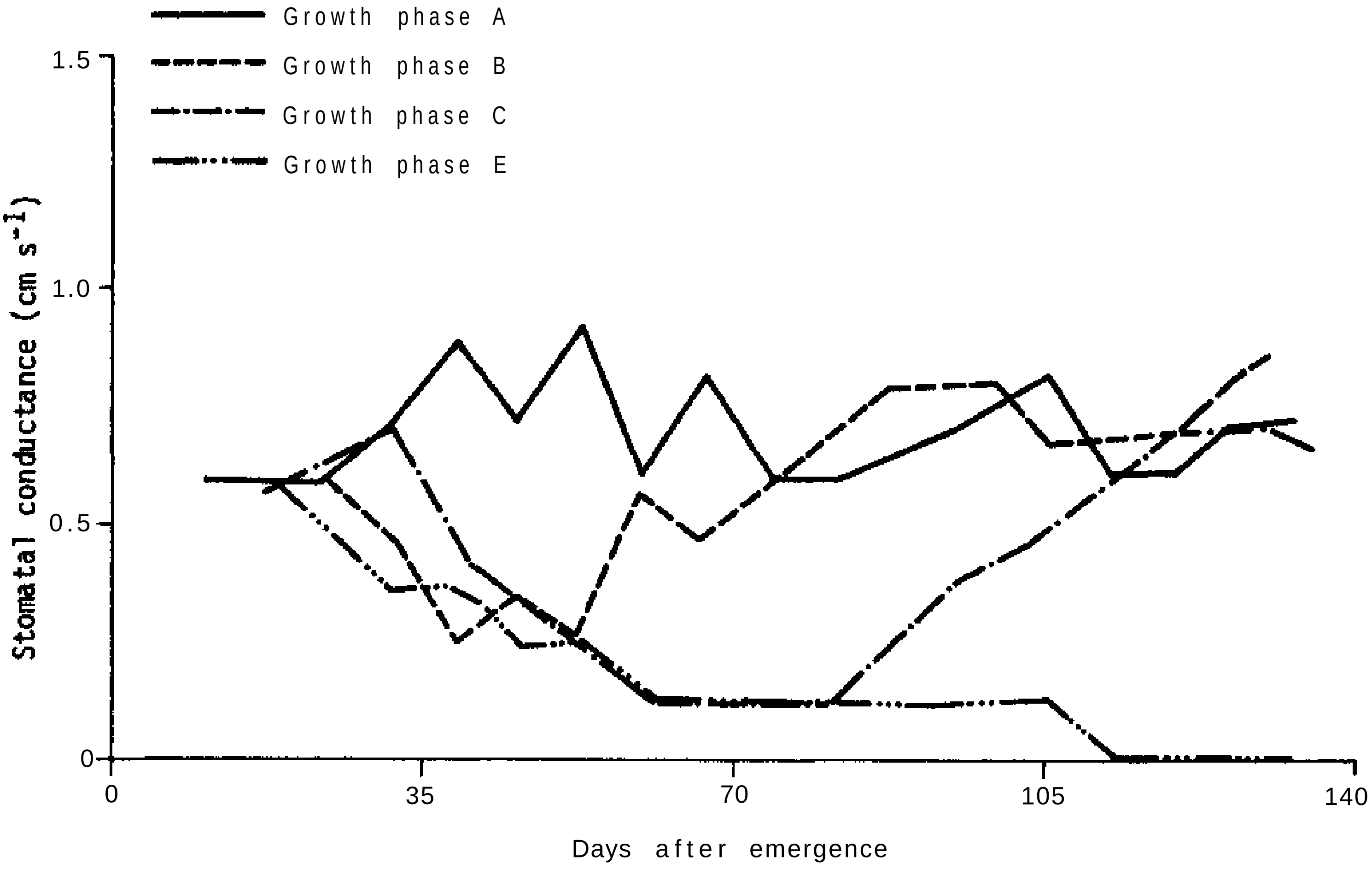

Figure 8. Seasonal changes in average daily stomatal conductance (cm s^{-1}) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

Canopy Temperature

Diurnal variation in canopy temperature of groundnut measured at 75 DAE in different drought stress treatments is shown in Figure 11. As with stomatal conductance and transpiration, canopy temperature was influenced by time of the day and the stage at which drought stress was imposed. Canopy temperature of groundnut undergoing stress in growth phase C peaked to 35°C at 1300, while in the continuous-stress treatment the canopy reached a maximum temperature of 33°C by 1100 and maintained the same until 1300. In growth phases A and B the canopy temperatures were low because the drought stress was relieved in these treatments long before 75 DAE. Sanders et al. (1982) also observed that canopy temperatures increased with drought. Afternoon canopy temperatures under irrigated conditions in their study were 28,5°C, while they were 35°C in the other treatments where three combinations of drought and soil temperatures were imposed.

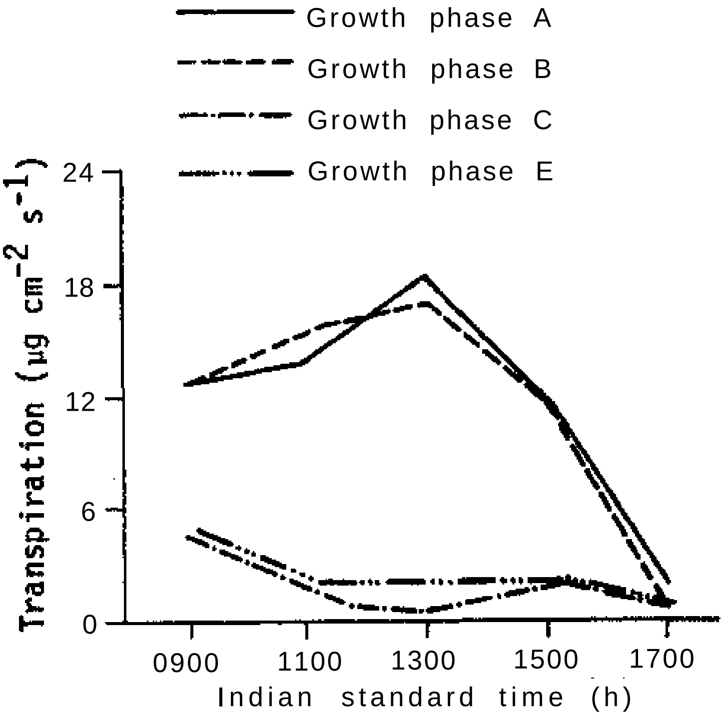

Figure 9. Diurnal variation in transpiration (µg cm^{-2} s^{-1}) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

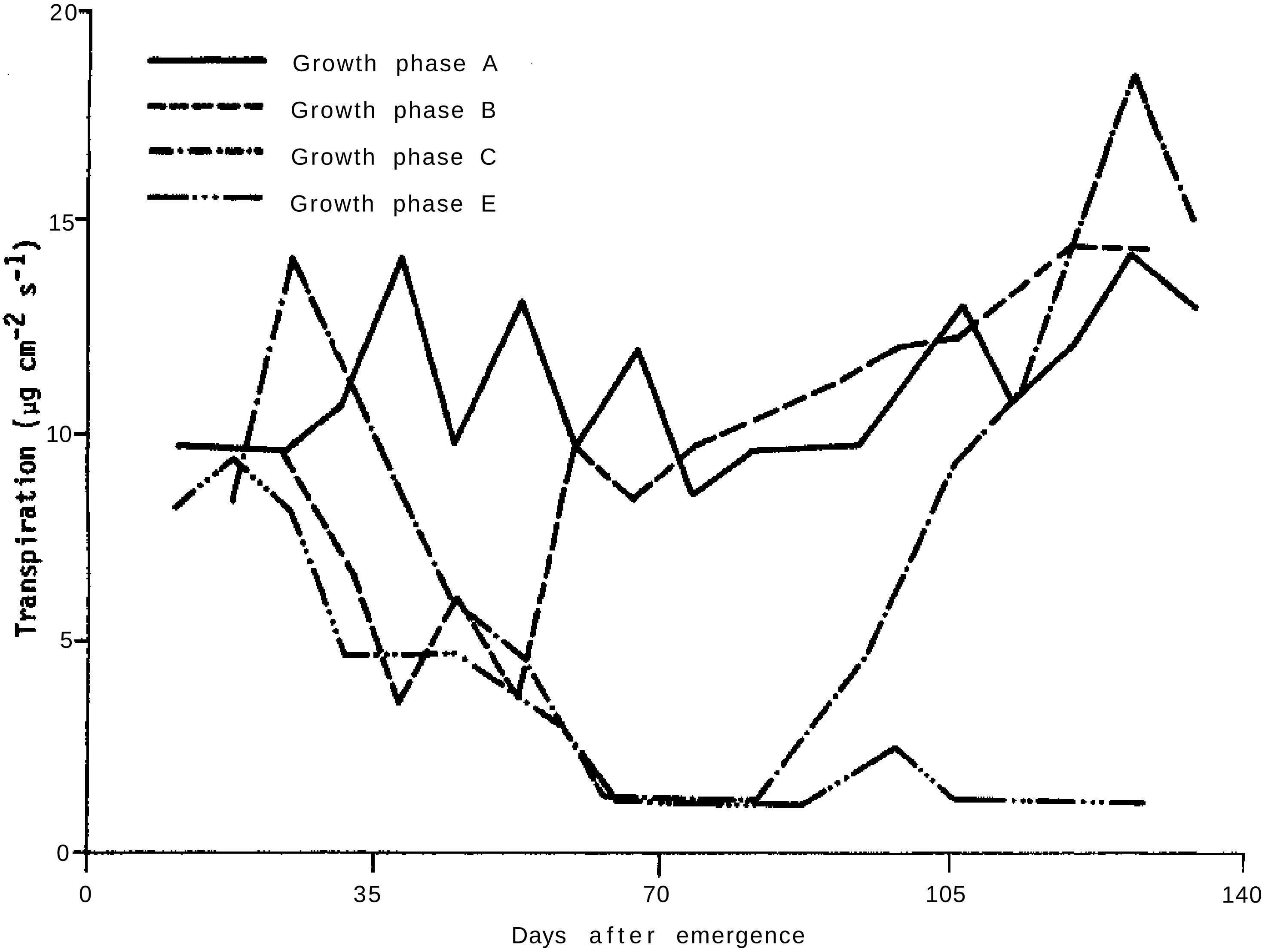

Figure 10. Seasonal changes in mean daily transpiration (µg cm^{-2} s^{-1}) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

Seasonal variation in the canopy-air temperature differential (CATD) are shown in Figure 12. In growth phase B the CATD reached a low value of -2.9°C to 1.9°C during the period of stress, but when stress was released the CATD values reflect the transpirational cooling achieved through adequate water availability. In growth phase C, the CATD values ranged from -3.7°C to 2.0°C during the period of drought stress from 30-90 DAE. The severity of drought stress in the continuous-stress treatment is evident from the more or less positive CATD for most of the growing season.

Leaf-Water Potential

The water potential of plant tissue has become a standard means of expressing plant-water status. Studies conducted so far on measurements of leaf-water potential of groundnuts indicate that reduced

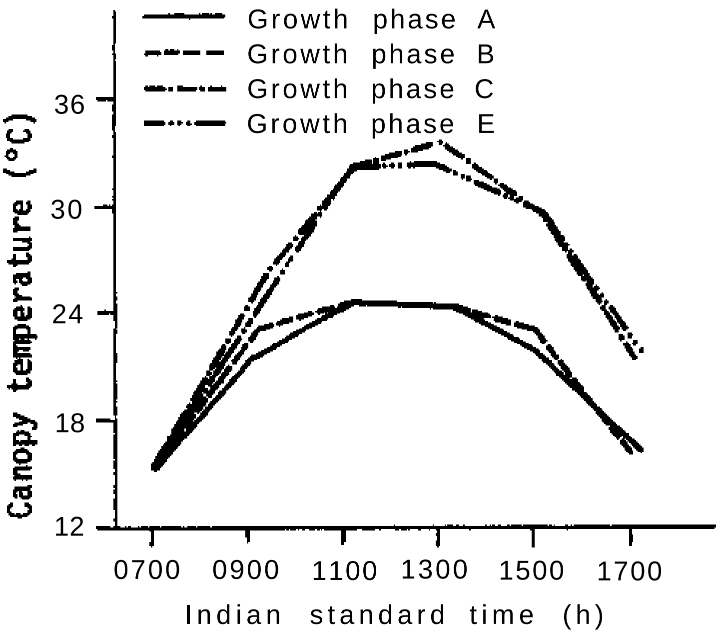

Figure 11. Diurnal variation in canopy temperature (°C) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

transpiration due to drought stress could lead to leaf- water potentials of -3.0 to -4.5 MPa (Bhagsari et al. 1976, Pallas et al. 1977, 1979), while in the frequently irrigated plants water potentials stayed at around -1.2 or -1.3 MPa (Allen et al. 1976, Pallas et al. 1977, 1979). Patel et al (1983) showed that leaf-water potentials decreased from -1.0 to -3.8 MPa with a decrease in soil-water potential from -0.05 to -2.0 MPa. Sarma (1984) recorded large differences in leaf-water potentials of groundnut grown under different ET levels. In the treatment that received no supplemental water from emergence to maturity where the seasonal evapotranspiration was only 47 mm, the leaf-water potential reached -6.3 MPa.

Gautreau (1977) used leaf-water potential measurements to evaluate the drought tolerance of 21 groundnut cultivars in Senegal. Early cultivars which avoid the end of wet-season drought by a short life cycle had intermediate leaf-water potential; those with the lowest potentials had the highest yield. Bennett et al. (1981) reported that in field tests, zero-turgor potential occurred at leaf-water potential of-1.6 MPa and concluded that water relations of groundnuts were similar to other crops with no unique drought-resistance mechanism. Stansell et al. (1976) however, noted that clouds can cause significant changes in plant-water status of groundnut in a short time. Therefore they cautioned that care should be taken to sample different treatments under comparable radiation.

Influence of Soil-Water Availability on Pod Yield

It is difficult to find uniform conclusions from studies conducted so far on the influence of soil-water availability on yield at different growth phases. Since groundnut is often grown under contrasting

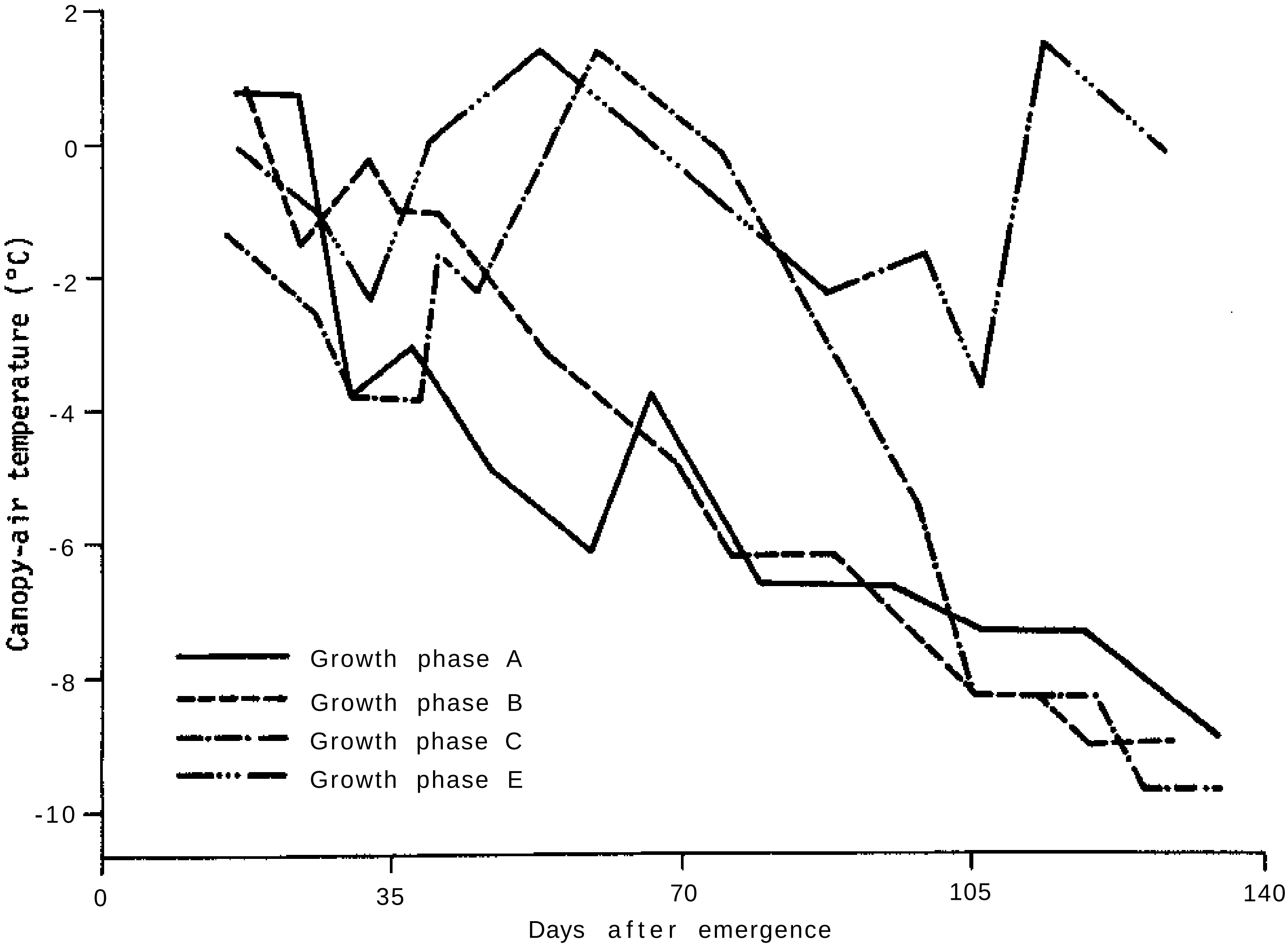

Figure 12. Seasonal changes in mean daily canopy-air temperature differential of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

moisture regimes in a range of environments, measured yield responses are different. While some earlier studies showed a marked trend for higher yields at high moisture levels (Goldberg et al. 1967, Matlock et al. 1961, Su and Lu 1963), the more recent investigations (Nageswara Rao et al. 1985) confirmed that irrigations can be withheld during much of the vegetative period without any apparent effect on pod yield. As shown earlier, drought stress imposed from emergence to start of peg initiation had not affected the total dry matter produced and the rate of pod growth. Various plant-water stress measurements also showed impressive recovery from the stress in this treatment.

Pod yields for different drought-stress treatments during the three growing seasons at ICRISAT Center (Table 4) show that in comparison to the fully irrigated control, stress from emergence to pegging gave 18, 12, and 34% increased yields. As Nageswara Rao et al. (1985) surmised, this effect provides a significant managerial option in that stress at this stage can be allowed to maximize use of irrigation resources. Water savings that accrue from withholding irrigations during this stage could be substantial and could contribute to increased water-use efficiency. It was proposed that in farming systems where irrigation could be used to initiate a crop of groundnut with a long-season cultivar in advance of rains, it may be possible to exploit the benefits of stress before the rains arrive.

When stress was imposed during growth phase C, the reduction in pod yields was 30% during the first season, 18% during the second, and 25% during the third season. Lower soil-moisture content in the top soil might have contributed to considerable mechanical resistance to peg penetration (Cox 1962, Underwood et al. 1971, Boote et al. 1976).

Reductions in pod yield due to stress were large in growth phase D. The indeterminate nature of the crop as well as the subterranean fruiting habit should be considered here. Since fruit initiation continues after the start of kernel growth, soil-water deficits during pod filling stage reduce both the initiation and development of pods (Matlock et al. 1961, Boote et al. 1976, Pallas et al. 1979, Underwood et al. 1971, Ono et al. 1974). High soil temperatures (Ono et al. 1974) might have affected the peg development into pods, and growth of pods in the soil might have been affected by inadequate moisture in the root zone (Allen et al. 1976, Boote et al. 1976).

Developing Strategies for Improved Groundnut Production: Implications of Research on Water Relations

Several speakers in this symposium have already emphasized the need to develop strategies that will make more efficient use of the limited water available for groundnut production in the SAT. Research on water relations that treats the soil, the plant, and the atmosphere as a continuum emphasizes that drought stresses affect crop growth and development because of low water availability (or in other words, low probability of receiving rainfall) during certain sensitive stages of the crop-growth cycle. Historical rainfall data should permit determination of probabilities of drought stress periods for groundnut from a mean sowing date, which could be calculated from the beginning of rains. As an extension of this approach, information on soil water-holding capacity and patterns of change in evapotranspiration with crop growth could be used in a simple

Table 4. Pod yields (kg ha^{-1}) of groundnut cv Robut 33-1 when drought stress was imposed at different growth phases during three growing seasons, ICRISAT Center, 1980-83.

	Pod yields (kg ha^{-1})		
Growth phase	1980/81[1]	1981/82	1982/83
A. Emergence to start of flowering			2701
B. Emergence to start of pegging	5480	5300	4396
C. Start of flowering to start of seed growth	3257	3870	2438
D. Start of seed growth to maturity	1450	3610	
E. Emergence to maturity	590	75	503
Control	4615	4720	3258

1. 77 mm of rain received during the growing season.

soil-moisture model with climatic data as input to compute soil-moisture budget on a daily basis, and to calculate frequencies of stress periods of various lengths.

Knowledge of probable stress periods at a given location could then be used to:

- Select appropriate varieties with a growing cycle that would match the probable stress periods with the dependable-rainfall periods.
- Adjust the sowing date to take advantage of the dependable-rainfall periods. The choice of sowing date adjustments in the SAT may be limited, especially in regions with low rainfall. In view of the capacity of groundnut to withstand stress during the early stages, maximum advantage should be taken of the first rains. This may necessitate the completion of primary tillage after the harvest of the previous crop in order to make use of the first rains for sowing.
- Maximize the water-use efficiency (WUE) under irrigated conditions by establishing the groundnut crop with irrigation ahead of the probable date of beginning of rains. This would take advantage of the lower water needs during the early growth phase, followed by more judicious water use during the later stages when the water requirements are maximum.

Available information on groundnut rooting patterns and water-extraction rates suggests that if other conditions are equal, soils that hold more water in the top 60 cm confer a comparative advantage. Where groundnut is grown under irrigated conditions this would mean more frequent but shallow irrigations. Under these conditions varieties that have a greater proportion of their root system in the top 60 cm may exhibit higher water-use efficiency. Also, research on agronomic practices that enable plants to use more of the water available in the soil for transpiration than evaporation should lead to improvements in WUE.

Plant measurements of drought stress such as stomatal conductance, transpiration, and canopy temperatures should be useful to assess the relative susceptibility of different varieties to drought stress in a given growth phase. The data collected in the studies described in this paper and elsewhere suggest adaptation of groundnut to drought stress. A range of adaptation mechanisms or crop acclimation to stress has been suggested by Turner (1979). Incorporation of such drought-resistant characters into groundnut may depend upon field evaluation of these techniques over a large number of varieties. However these techniques can only be limited to evaluation of advanced breeding lines in view of the time it takes to make these measurements. Hence as Turner (1982) suggests, there is a need to develop suitable visual techniques such as leaf rolling, wilting, or tip burning for screening large populations.

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Responses of Groundnut Genotypes to Drought

J. H. Williams, R. C. Nageswara Rao, R. Matthews, and D. Harris[1]

Abstract

Drought-stress effects on groundnuts depend primarily on the stress pattern because genotypic variation is usually of secondary significance. The differential responses of groundnut cultivars to drought are therefore assessed relative to the mean response of all genotypes to drought Since three major aspects of drought, (i.e., duration, intensity, and timing relative to crop phenophases) may vary independently, the main effects of these components on groundnut are described.

The timing of drought has a large impact on the variation about the mean response. In general, the sensitivity of a genotype to drought increases with yield potential, increasing the closer the drought ends to final harvest.

Genotypic variation in response to drought exists in the water-use ratio (WUR) of genotypes, with some being able to accumulate up to 30% more shoot dry matter than others with the same total transpiration. Variations also exist in the proportion of this dry matter that is used for pod growth.

Large variations in the response of genotypes to midseason droughts are due to recovery differences after the drought is relieved. The physiological reasons for recovery differences are under investigation.

In addition, a three-factor interaction of genotype, gypsum, and drought exists because the gypsum may increase early pod development, thus providing escape effects.

Résumé

Réponses des génotypes d'arachide à la sécheresse : ***Les effets du manque d'eau sur l'arachide dépendent principalement de la nature du manque, car les variations dues aux génotypes sont secondaires. La réponse différentielle des cultivars d'arachide à la sécheresse a été évaluée d'après l'effet moyen de tous les génotypes. Puisque trois caractéristiques majeures des sécheresses (durée, intensité, occurrence par rapport aux phénophases) peuvent être indépendantes, les principaux effets de ces composantes sur l'arachide seront décrits.***

La période où la sécheresse survient à un effet important sur la variation de la réponse moyenne. En général, la sensibilité à la sécheresse d'un génotype augmente avec son potentiel de rendement et s'accroît lorsque la sécheresse survient à la récolte.

Des différences de réponse des génotypes existent dans le taux d'utilisation de l'eau, certains étant capables d'accumuler jusqu'à 30% de matières sèches supplémentaires, avec la même transpiration. Des variations sont notées aussi dans la proportion de cette matière sèche utilisée pour la croissance des gousses.

Nous avons observé de fortes variations de la réponse des génotypes aux sécheresses de mi-saison, que

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nous avons attribué à des différences dans la récupération après la fin de la sécheresse. Les raisons physiologiques des différences dans la récupération sont étudiés.

De plus nous avons observé qu'une interaction génotypes-gypse-sécheresse existe, à cause de l'effet du gypse sur la phase initiale du développement des gousses, mettant en jeu un effet de "fuite".

Introduction

Agriculturally significant droughts usually occur when normally expected rains fail. This failure is largely random. Other speakers will discuss methods of determining expected amounts of rain, the probabilities of these amounts occurring, along with the factors that determine how long this water is able to support growth. Lack of rain may cause drought at any or many stage(s) of development (timing), may vary the evapotranspirational demand relative to the water shortage (intensity), and may also vary the duration of drought experienced by the crop.

There is also substantial morphological variation between groundnut genotypes. Plant types range from prostrate runners to upright bunch types. The valencias have only four branches, while the Virginia type may have numerous branches. Individual leaflet area may vary 10-fold, while the time to maturity may vary from 80-180 d. The size and nature of the root system may also vary substantially (Ketring 1984). Previous research has major limitations within this field since either only one genotype has been utilized for comprehensive physiological studies (Pallas et al. 1979, Nageswara Rao et al. 1985) or, when several genotypes have been tested, the results were not in sufficient depth to allow a comprehensive understanding of the crop within its environment. For this reason the bulk of the research results presented are those obtained from our research at ICRISAT Center.

General Responses

Of the many investigations of groundnut responses to drought, very few have been able to establish generalized response patterns. The response may vary with the timing of the drought. However, results have not been consistent because of differences in either genotypes or in growing conditions. Billaz and Ochs (1961) found that midseason drought decreased yields more than end-of-season drought, while Pallas et al. (1979) and Nageswara Rao et al. (1985) found that end-of-season drought yields were lower. The latter authors also reported the possibility of higher yields from stress during the preflowering phase.

Since there are innumerable combinations of the timing, intensity, and duration of drought, and these apparently elicit different responses from different genotypes, generalizations are necessary to describe both the droughts and the variations of genotypic response. In our drought screening we have examined some 800 genotypes, exposing them to three combinations of timing and duration (patterns) of drought, and to six or eight intensities of drought within each pattern. Our drought patterns have been designed to simulate commonly occurring droughts of the SAT (end-of-season, midseason, and long-term drought). In these drought patterns the pod yields generally decreased in a linear fashion as the intensity of drought increased.

Since this method involved screening of genotypes in only three selected 'typical' droughts, a further experiment examined the performance of a selected number of genotypes across a wider range of droughts. Twenty-two genotypes (of similar maturity) identified in the drought-screening process as either resistant, average, or susceptible to drought were used. The genotypes were then subjected to 12 different drought patterns (Fig. 1), which varied both the duration and the timing of single and multiple drought phases relative to phenological development. By using the line-source (LS) technique (Hanks et al. 1976), the drought intensity was varied progressively from a nonstressed control plot (nearest to the sprinkler line) to a plot that received no water for the duration of the drought. Irrigation was managed so that the control plot did not show wilting symptoms at midday.

When the drought intensity was expressed as the irrigation deficit relative to the Class A pan evaporation during the drought period, the nonstressed control treatments had deficits which ranged from 20-40%. This deficit level, despite the nonstressed condition maintained by irrigation, is due to incomplete canopy and to water-utilization pattern of the plants from the soil profile, which was fully charged at the start of the stress periods. For comparison

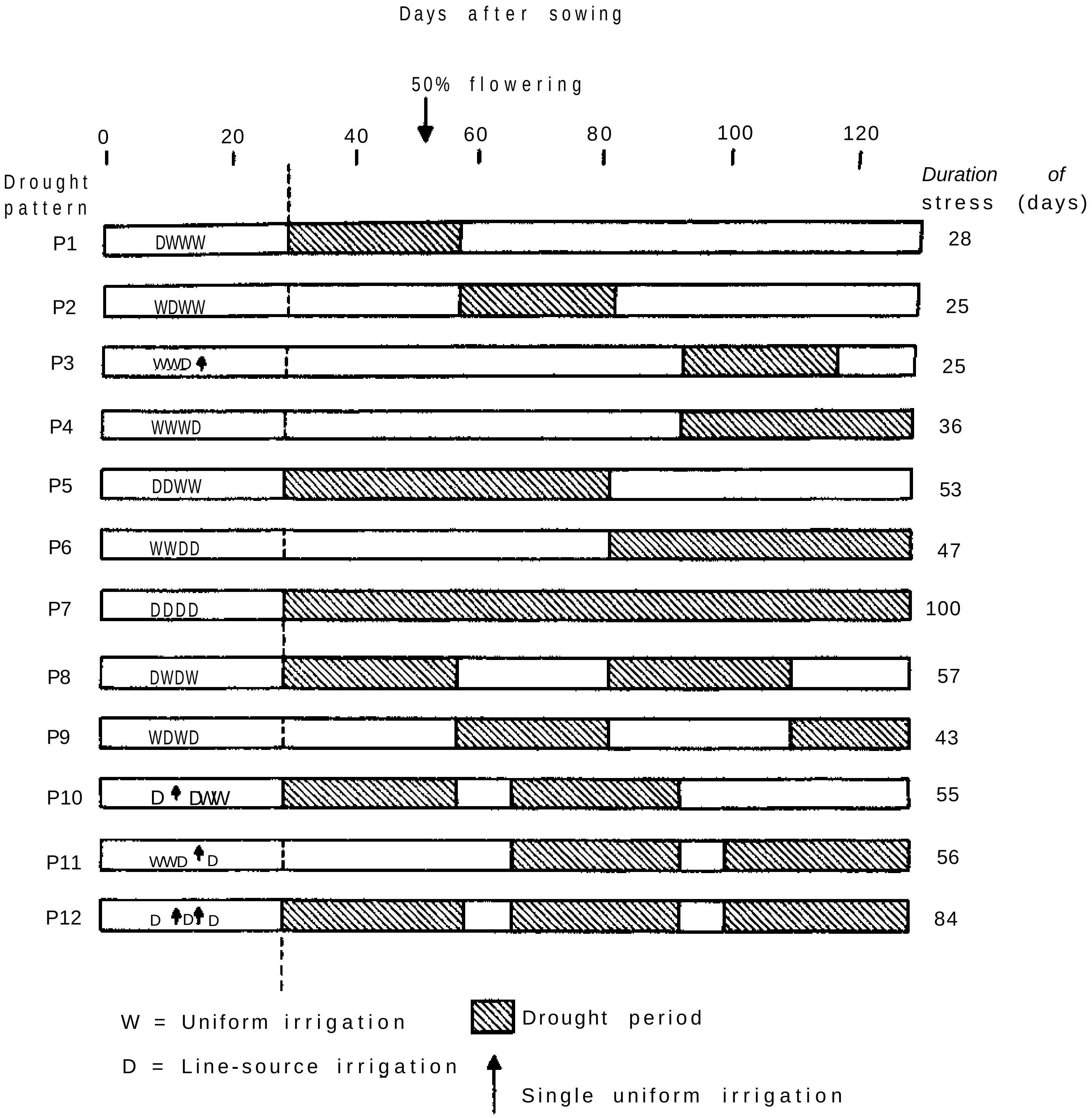

Figure 1. Timing and duration of single and multiple droughts.

purposes, yield potential achieved in nonstress control plots are estimated at 30% water deficit (Y_{30}). The pod yield decreased in most patterns in a linear fashion from yields in nonstressed conditions. Sensitivity to drought has been estimated using linear regression as the average yield loss per unit of water deficit ("b" slope or term of the regression).Only in the very long-term stresses was there a curvilinear response of pod yield to increasing drought intensity (Fig. 2).

When analyzing the mean response of these *fastigiata* genotypes, we found that depending on whether or not the early phase in crops' life (until shortly after the first flowers had been produced) had been stressed, the response to any subsequent droughts was modified (Fig. 3). Besides this, the timing of the drought had little effect on the mean response of all the genotypes to drought. Ninety percent of the yield variations were accounted for by the intensity (I) of drought, and the cumulative duration of stress(es)

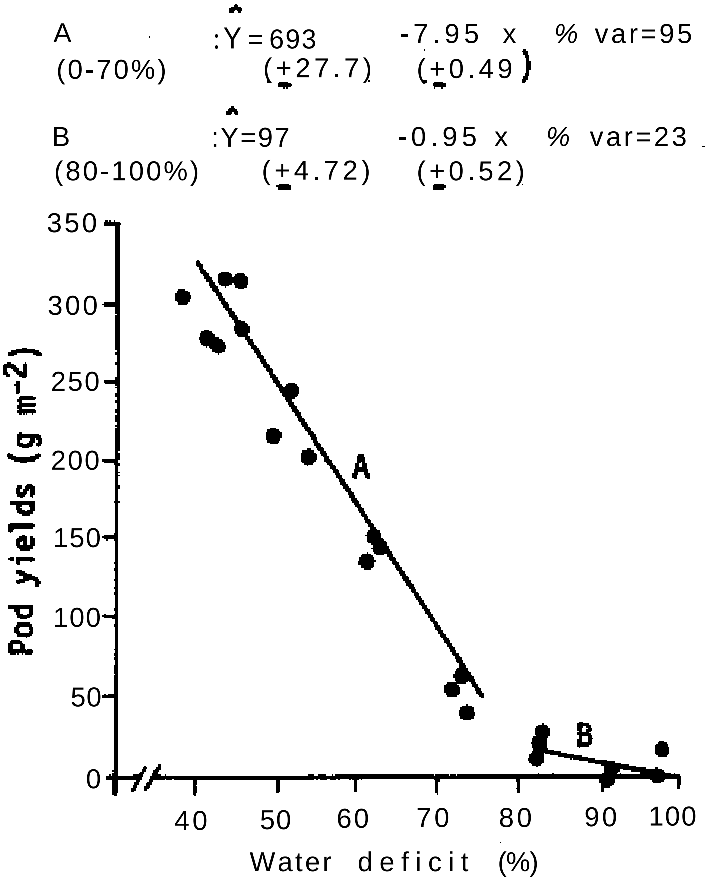

Figure 2. The effect of drought intensity on pod yields in a long-duration drought (P7).

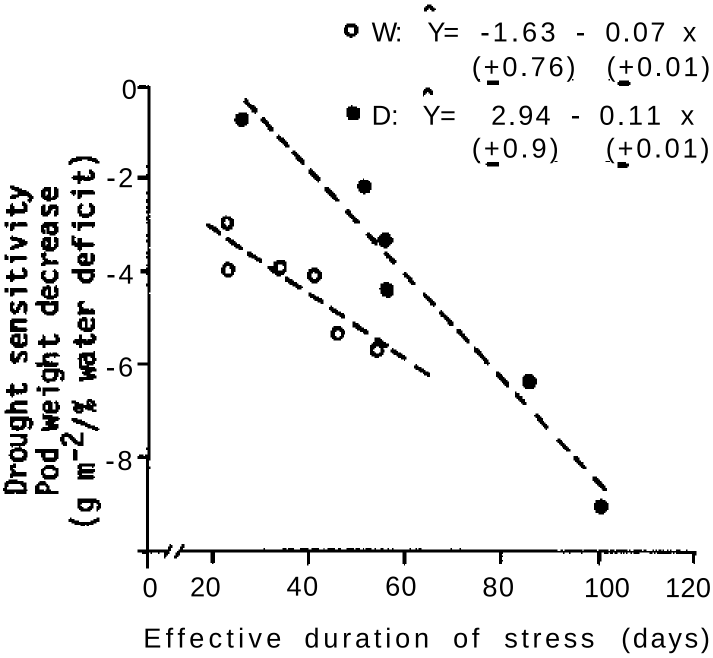

Figure 3. Effect of irrigation or drought during the preflowering stage on the sensitivity of groundnuts (mean of 22 cultivars) to droughts of different durations.

(D). Depending on whether or not the early phase was stressed, the predicted yield (Y) was indicated by one of the following two equations:

Equation 1 (early stress)

$$\hat{Y} = 306 + 1.52\ I \bullet 3.087\ D - 0.085\ I \times D.$$

SE: (±29.4) (±0.433) (±0.476) (±0.0069)

Variance accounted for = 87%

Equation 2 (no early stress)

$$\hat{Y} = 370 + 1.331 + 3.676\ D - 0.0761 \times D$$

SE: (±23.6) (±0.33) (±0.625) (±0.008)

Variance accounted for = 93%

Genotype Yield Responses

To examine the relative performances of these genotypes in all these drought combinations is a formidable task. To simplify the process, the yields from nonstressed conditions and the relative yields when the irrigation deficit was 70% (Y_{70}) are discussed. (Relative yield is based on the regression-estimated yield in these conditions converted to a percentage of the mean yield, which is also provided). In the droughts, the mean Y_{70} varied significantly between the patterns of drought, which is why relative yields (Tables 1 and 2) allow an easier evaluation of varietal performance across drought patterns.

It is apparent that the lines tested could be classified into three groups: those with below-average yields in all types of drought, those either resistant or sensitive to specific drought patterns, or those resistant to all droughts.

However, it is not useful to compare the relative performance of genotypes at a 70% irrigation deficit and examine drought responses without considering yield in nonstressed conditions (Y_{30}). A genotype may perform poorly in both a drought and a nonstressed condition. For instance, yield of genotype JL 24 was 18% below average at 30% deficit and at 70% deficit in five other patterns. The Senegalese genotype EC 109271 (55-437) yielded 10.7% above average in nonstressed conditions, only 2% above average in pattern 1, but 25% above average in pattern 2, 20% in pattern 3, and 87% in pattern 4.

TMV 2, that yielded 12.7% above average in nonstressed conditions, was 20% above average in drought pattern 1, 10% above average in drought pattern 2, and 3% above average in drought pattern 3.

Another feature of these results was that the genotypes with high yields in the nonstressed conditions were sensitive to many of the drought patterns. This

Table 1. Changes in pod yields (as a percentage of the mean of 22 genotypes) in nonstressed conditions (30% water deficit) and stressed conditions (70% water deficit) in different drought patterns.

Cultivar	Relative mean pod yield at 30% deficit	Relative mean pod yields at 70% deficit in drought patterns P_1 to P_6					
		P_1	P_2	P_3	P_4	P_5	P_6
CGC 4063	-9.0	-18,4	-4.1	-13.4	-15.2	-12.1	5.5
J 11 x Robut 33-l	8.5	15.8	4.1	1.8	8.7	14.6	21.5
ICGS 24	11.2	3.3	8.6	7.9	5.9	5.3	-1.2
ICGS 36	-10.0	-5.0	-14.0	-4.1	-0.6	-6.6	-11.0
ICGS 11	4.2	-3.9	-0.7	-8.8	-5.4	-11.1	17.7
ICGS 35	-4.9	-33.3	-3.2	-6.6	-21.3	12.1	-1.3
ICGS 21	-4.5	10.7	-11.1	1.4	-18.6	-7.3	3.9
X41 x 1 B x Goldin 1	11.9	10.3	7.2	5.0	4.1	10.1	1.5
Manfredi x X 14-4 B 19 B	-1.6	3.5	3.5	1.3	-10.3	-8.4	11.1
TMV 2	13.6	7.6	14.7	25.3	12.9	16.4	12.4
Faizapur 1-5-2	-21.9	-7.3	-33.8	-10.7	-4.3	-19.3	-11.3
J II	-6.4	-4.7	-14.0	-9.8	-4.8	-7.7	-9.5
NC Ac 17090	8.2	5.9	7.3	8.7	-1.4	4.7	2.2
NC Ac 17142	9.2	7.9	1.6	15.3	0.7	15.4	7.3
Gangapuri	24.1	20.4	25.7	19.0	9.5	21.4	24.2
EC 76444	-0.3	-0.5	-9.6	1.1	-2.4	14.0	-16.4
EC 109271(55-437)	10.7	2.3	24.7	19.8	87.5	17.9	-4.6
EC 21024	13.3	4.9	-2.2	-8.8	-6.6	22.6	-16.2
Manfredi 107	12.4	-10.8	5.8	-18.1	-18.5	-9.8	-26.5
Krapovicas Str 16	-11.8	0.2	-1.2	0.7	-4.5	11.6	5.9
NC Ac 16129	12.7	19.8	10.3	3.3	16.7	9.6	5.0
JL 24	-18.3	-28.9	-19.7	-30.3	-31.9	-25.0	-19.9
Mean Pod wt (g m^{-2})	403.8	367.8	320.1	189.1	195.7	242.9	175.8

prompted us to examine the genotypes for a relationship between yield in nonstressed conditions and drought sensitivity. For some drought patterns the nonstressed yield was very closely related to drought sensitivity, while in others these two components were not closely related. When the interval between the release of drought and final harvest was large (i.e., early droughts), yield sensitivity generally was not well correlated to yield potential, but when stress occurred during the grain-filling phase, the correlation was good. The association between the time when drought ended and the correlation coefficient between genotype sensitivity to drought and yield potential is presented in Figure 4.

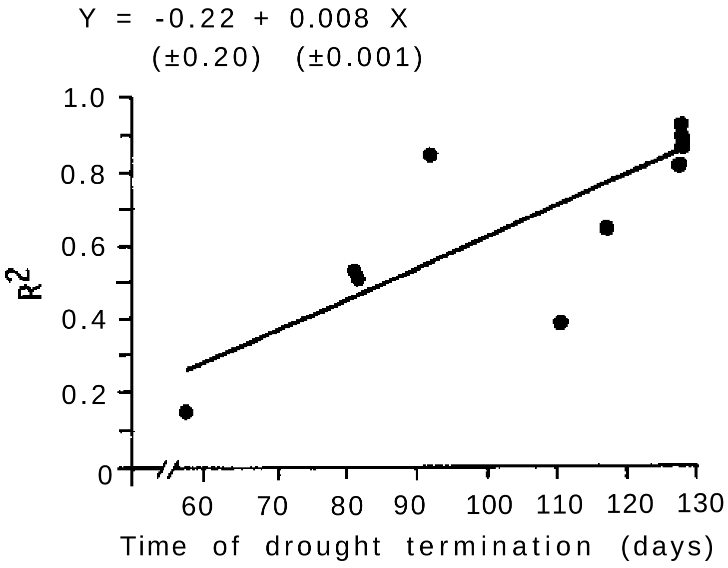

Figure 4. Effect of when drought ends on the amount of variation in drought sensitivity that is accounted for by the yield potential of genotypes. The Y axis is the regression coefficient for the relationship between sensitivity to drought and yield potential.

Physiological Differences between Genotypes

In addition to these agronomic studies, a more detailed examination was made of the basic physiological responses of four contrasting genotypes in a limited range of drought conditions. This was a joint research project with the University of Nottingham, funded by the British Overseas Development Administration (ODA) and ICRISAT.

By comprehensive measurement of the crop environment, the sources of yield variation between genotypes were examined in detail. Water-extraction patterns and total water use, radiation-interception patterns, and the growth and reproductive responses to the imposed droughts have been described (D. Harris, and R. Matthews, University of Nottingham, personal communication, 1985).

Although there was evidence for rooting variations in these four genotypes in an Alfisol, the total water transpired did not differ (Table 3). However, there were differences in the efficiency of water use from different soil horizons. NC Ac 17090 was able to use water in the surface horizons faster than the other cultivars, suggesting an advantage for this genotype when rainfall is likely to be confined to small showers that only wet the upper horizons. Robut 33-1 extracted water earlier from deeper horizons (Fig. 5), an ability which might be important where the soil depth does not limit root growth and the amount of available water.

The amount of dry matter accumulated by a crop is closely related to the amount of water transpired (WUR). For groundnuts, 1.7-1.9 g of shoot material are accumulated per kg of water transpired (Kassam et al. 1975, Nageswara Rao et al. 1985). However, the WUR of these genotypes varied significantly, with the drought-susceptible line EC 76446(292) accumulating 30% less shoot dry matter than the other genotypes, although the same amount of water was used. These differences in water-use efficiency (WUE) were associated with other responses to water-status, including effective-radiation load shedding by leaf folding during severe stress.

However, the largest differences between these genotypes were the effects of drought on their reproductive growth. TMV 2, that produced the highest

Table 2. Changes in pod yields (as a percentage of the mean of 22 genotypes) in nonstressed conditions (30% water deficit) and stressed conditions (70% water deficit) in different drought patterns.

Cultivar	Relative mean pod yield at 30% deficit	Relative mean pod yields at 70% deficit in drought patterns P_7 to P_{12}					
		P_7	P_8	P_9	P_{10}	P_{11}	P_{12}
CGC 4063	-9.0	-9.7	-10.1	-12.2	-4.7	-19.0	-11.8
J 11 x Robut 33-l	8.5	-4.4	-3.5	12.1	24.8	14.1	17.8
ICGS 24	11.2	-6.5	12.0	2.5	19.1	7.2	13.1
ICGS 36	-10.0	1.4	-8.0	-11.4	-21.1	-8.2	0.2
ICGS 11	4.2	24.9	12.7	10.3	-0.6	-7.9	-0.1
ICGS 35	-4.9	-20.6	-2.3	-10.7	-6.9	-0.9	-15.4
ICGS 21	-4.5	-11.3	-17.4	5.1	-0.2	-15.8	-1.4
X41 x IB x Goldin I	11.9	0.9	17.8	15.3	6.5	8.4	15.5
Manfredi x X 14-4 B 19 B	-1.6	3.4	0.0	3.4	3.4	-6.2	9.1
TMV 2	13.6	-1.1	-23.2	-9.6	-38.7	-9.7	-9.2
Faizapur 1-5-2	-21.9	21.0	24.7	27.2	0.7	23.3	15.4
J 11	-6.4	2.4	-21.4	-2.1	-15.5	-8.6	-1.7
NC Ac 17090	8.2	0.1	3.3	4.2	10.6	-5.0	0.5
NC Ac 17142	9.2	-2.6	16.9	2.7	2.1	12.8	10.6
Gangapuri	24.1	24.9	38.2	30.5	31.3	20.2	16.6
EC 76444	-0.3	10.5	-10.4	-11.1	-6.4	1.1	-0.0
EC 109271(55-437)	10.7	11.7	8.5	4.2	16.0	12.6	1.4
EC 21024	13.3	8.0	-7.2	-15.5	3.0	-6.8	-15.5
Manfredi l07	12.4	-16.6	-6.5	-25.9	-16.3	-0.0	-24.6
Krapovicas Str 16	-11.8	5.7	-5.8	-15.3	-7.5	-5.3	-2.6
NC Ac 16129	12.7	0.1	26.1	14.0	14.3	11.7	24.5
JL 24	-18.3	-26.1	-19.1	-17.6	-12.3	-19.6	-23.8
Mean Pod wt (g m^{-2})	403.8	120.6	203.5	209.3	213.9	199.2	161.9

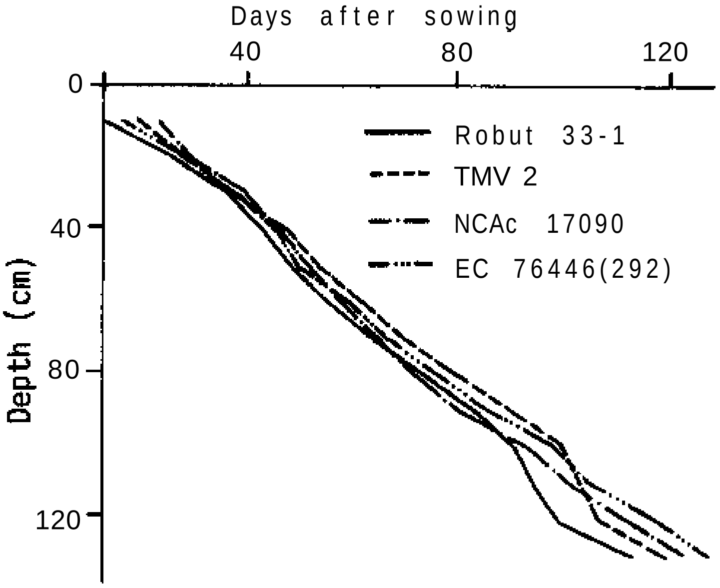

Figure 5. Water-extraction depth changes over time of four genotypes subjected to drought.

pod yield in the drought, had a harvest index 84% greater than that of EC 76446(292), the most-susceptible genotype (Table 3).

The reasons for differences in the drought sensitivity of reproductive growth are yet to be established, but it is apparent that superior yields under drought conditions may be based on two separate mechanisms: resistance and recovery. The initiation of pods by these four genotypes during a drying cycle and following the release of stress is presented in Figure 6. TMV 2 apparently achieved higher yield by producing pods despite the drought, while Robut 33-1 demonstrated a superior recovery response to the release of stress. The relative advantages of these two strategies will depend on the growth duration possible following the stress release.

The basis for these different responses of the reproductive initiation processes to drought is not fully understood, but very subtle differences in drought timing in relation to phonological development may result in substantial yield differences. The importance of small differences in pod initiation is best demonstrated by the interaction of drought with gypsum applied at flowering.

Table 3. Contribution of total water used, water-use ratio, and harvest index to cultivar yield differences, using EC 76446(292) as a reference, under water-deficit conditions, ICRISAT Center, 1983.

Cultivar	Total water use (%)	Water-use ratio (%)	Harvest index (%)
TMV 2	98	111	181
Robut 33-1	101	125	156
NC Ac 17090	101	118	125
EC 76446(292)	100	100	100

Gypsum applied at flowering increased the yield of genotypes subsequently subjected to drought, but there was no obvious response if there was no drought since the soils at ICRISAT Center have adequate available amounts of Ca (±600 ppm) (Rajendrudu and Williams, 1986a). In well-watered conditions the application of gypsum produced small (not statistically significant) but consistent (across three genotypes) increases in pods initiated within the first 2 weeks of pod setting. In a drought treatment the same gypsum application significantly increased pod initiation (Fig. 7) which generally increased yields until the drought stress was relieved by irrigation, (Rajendrudu and Williams, 1986b).

Conclusions

The responses of groundnut genotypes to drought have been shown to be influenced by the timing of drought relative to phenological development and by the yield potential in nonstressed conditions. The major sources of variation observed between genotypes have been associated with the reproductive physiology; where the ability to initiate fruit despite drought, or to recover rapidly after drought provides opportunities for the genotypes to better adapt to long-term drought probabilities. Genotypic varia-

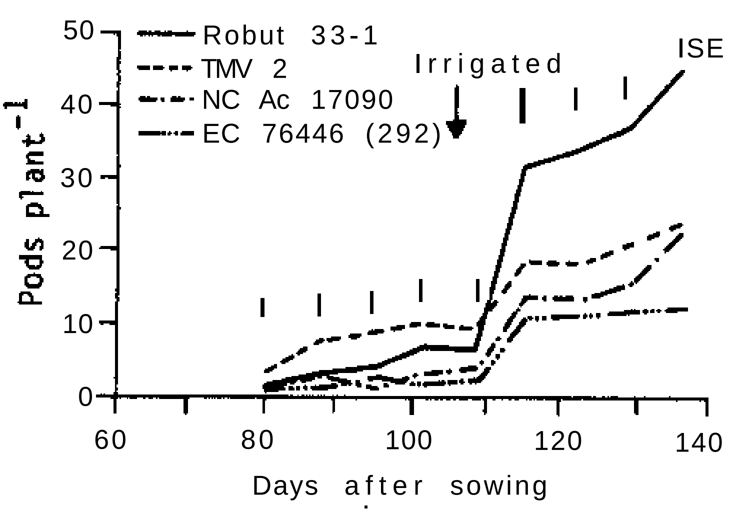

Figure 6. Number of pods developed over time by four groundnut genotypes during drought stress and after irrigation, ICRISAT Center, postrainy season 1982/83.

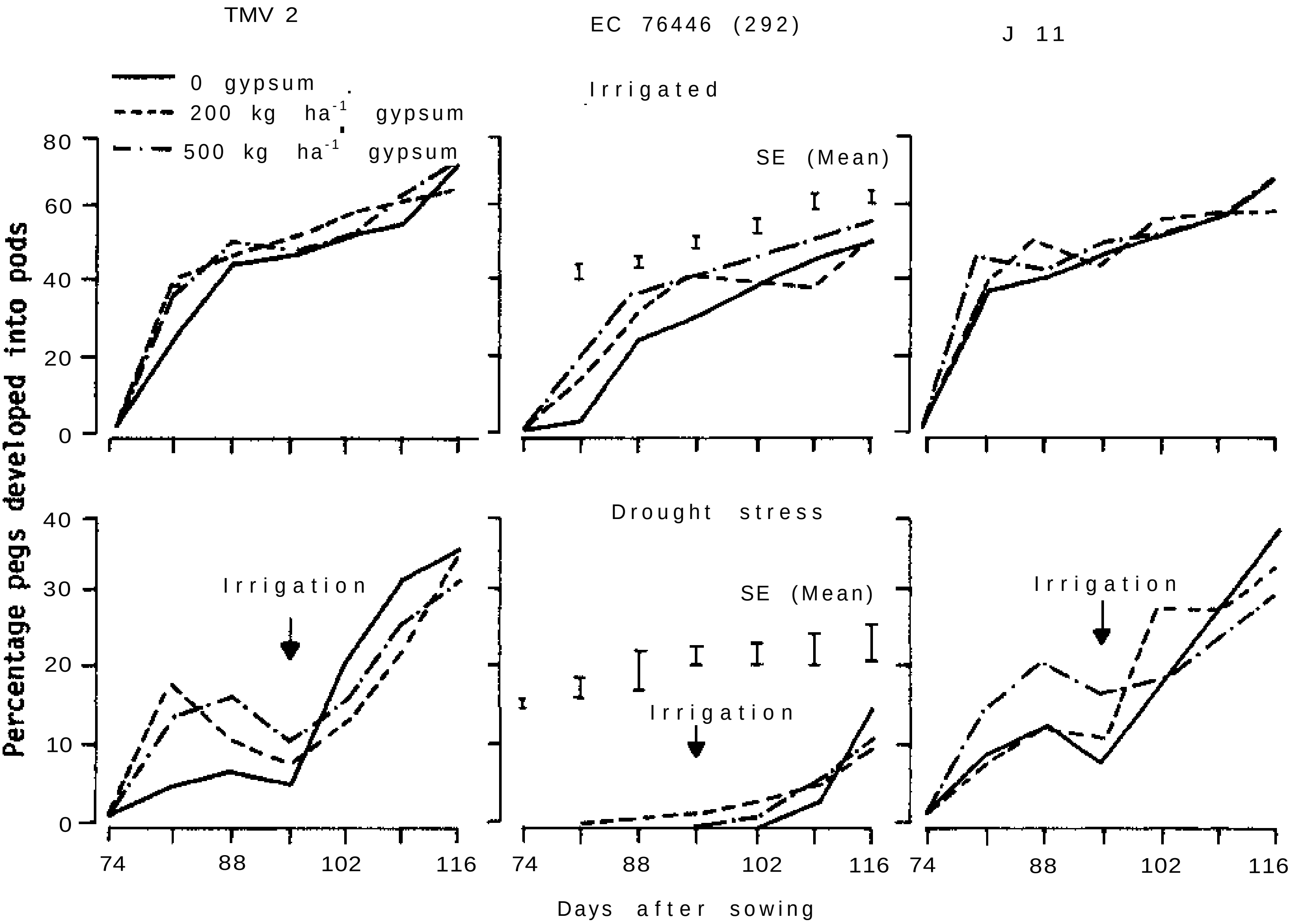

Figure 7. Changes with time in the percentage of subterranean pegs developed into pods for groundnut cultivars grown in wet (T1) and dry (T4) conditions after gypsum applications at early flowering, ICRISAT Center, postrainy season 1981/82. (Source: Rajendrudu and Williams 1986b.).

tions in the profile-water use patterns and in WUE were observed. There is scope for effective use of this information in crop improvement to select genotypes better adapted to different agroclimatological conditions.

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Water Relations of Groundnut

Discussion

D. Harris:
Do variations in harvest index between years and between sites fit well into your simulation model?

C. Dancette:
We worked to a limited extent on this subject and we were interested in pod yields only in the first stage. The dry-matter yield is also important from the physiological point of view. The pod and dry-matter yields were not well correlated. In future we will be much interested in the relationship between pod yield and total dry matter. Personally I think that the index of satisfaction of water requirements in the vegetative stages permits us to explain correctly and predict the dry-matter production between years and between sites.

M. Bernardi:
Given the rainfall regimes in the last few years which were very dry just after a series of good-rainfall years, what is the risk of utilizing short-duration varieties?

C. Dancette:
We showed that the water requirements of late varieties sown early were satisfied at an intermediate level. We have also shown that if we have irrigation facilities we can precisely define a sowing date, eg., 10 July at Bambey, Senegal. By the analysis of water balance over a 40-year period, we could achieve a higher water-use efficiency.

J. H. Williams:
You showed that varieties had different patterns of developing crop water-use coefficients. This presumably reflects differences in leaf-area development by those varieties. Would you consider the same agronomic practices of spacing to be suitable for these varieties?

C. Dancette:
Considering the results from our recent experiments, we feel that the crop geometry or density does not have a large influence on the resistance to drought. They show significant results only for the short-duration varieties that grow rapidly. In this case we can choose an optimum date of sowing in order to avoid the short rainless or drought periods, e.g., at Bambey, Senegal, between 5 and 15 July, but not earlier.

D. Smith:
If groundnut production were decreased in northern Senegal (Louga) and increased in southern Senegal (Casamance), would the average yield of groundnuts per hectare decrease or increase? I realize that this is a hypothetical question that requires a speculative answer.

C. Dancette:
It is always the yields per hectare that decrease in north and in central Senegal. In the South the cultivated area under groundnut has not increased. On the other hand in north and central Senegal, the farmers were discouraged by the droughts and the area under cultivation has certainly decreased along with the yields.

S. M. Virmani:
I think Mr. Dancette has made an excellent presentation of the relationship between climate or rainfall, evapotranspiration, and soils information through water-balance studies. He has integrated it with the risks to dependable crop production for crops of varying growth periods. Dr. Swindale made a point yesterday that we should start integrating the crop-production systems with the climatic environment as it exists. I suggest that Mr. Dancette, ICRISAT, and other agencies in Niamey should try to screen the groundnut-growing regions in West Africa using his model and the available rainfall data to look at the suitability of cultivars of varying lengths to different regions. It would be useful for breeders to know appropriate maturity duration suitable in different regions.

M. Frere:
For the crop coefficients, Mr. Dancette has pro-

posed the possibilities of standardizing or averaging crop coefficients for a given crop in different locations. I think that as far as we consider two or several varieties with a similar growing cycle, it is reasonable to use the same crop coefficients. But of course if you work on the one hand in a dry area like Louga in north Senegal, and on the other in Ziguinchor in the humid part of Senegal, you will certainly use varieties with different growth periods. One may be 90 days, the other 130 days. In this case you need to use different sets of crop coefficients.

As far as the relationship between the satisfaction of water requirements of the crop and the yield is concerned, I think that the reaction of different varieties to drought stress will be about the same as a trend. The final yields of the two varieties, however, will be linked to the genotypic characteristics. Tomorrow I intend to show some work of FAO concerning this aspect.

P. Sankara:

a. In your experiments you have worked on sandy soils using erect varieties. I would like to know the criteria for the choice of varieties and whether it is possible to obtain the same results with nonerect varieties.

b. In relation to sandy soils, can one get other coefficients suitable for other soils?

C. Dancette:

a. I never measured the water needs of erect or spreading varieties.

b. Generally, when working under a favorable water-availability situation, i.e., by irrigating frequently, one can avoid differences due to soil type.

R. W. Gibbons:

a. Did you protect your trials with fungicides, as there is evidence that they prolong the life cycles of groundnut cultivars ?

b. Did you vary the plant spacings of your early-maturing cultivars? Many of the old recommendations for early-maturing cultivars are based on trials where moisture was not limiting. Now early-maturing cultivars are grown in areas where rainfall has declined. We may have to modify traditional recommendations in the light of the present conditions to exploit available moisture.

C. Dancette:

a. We did not use any fungicides in our trials as there was no need for them. Hence I cannot answer your question on the prolongation of the life cycle.

b. In our studies we did not vary the plant spacing or the crop geometry. We used the recommended spacings. It is true that these spacings were adopted during the wet years (1951-60). It was found recently that we do not practically change the total water use by changing the spacing since there is a large compensation. In practice in Senegal, we have always used the recommended densities, i.e., higher densities (45 x 15 cm) for early varieties and lower densities (60 x 15 cm) for late varieties. In the dry zones, even for early varieties we use lower densities (60 x 15 cm). Our recent results in the dry zones showed that the high densities have not given significantly increased yields over the low densities.

N. R. Yao:

a. You reported that the neutron probe technique was used to determine soil-water content in your study. The problem is that you had to determine water content in the topsoil where we know that the neutron probe method is not accurate. I want to know why you did not use other techniques?

b. This question goes to Mr. Dancette too. You reported yield reductions associated with water-deficit intensities. Mr. Dancette even showed a reduction in pod yield while the vegetative growth was not much different. This means that the harvest index was reduced. I want to know if these yield reductions were due to a reduction in pod numbers or to a decrease in dry weight per pod?

M. V. K. Sivakumar:

a. I should have mentioned that the neutron probe measurements started from 30 cm downwards and the volumetric water contents presented for the top 30-cm soil were from gravimetric measurements.

b. In our study with the line-source sprinkler irrigation, we observed that not only the total number of pods but also the size and weight of pods was reduced with distance from the sprinkler line, or in other words, with increasing drought stress.

A. Ndiaye:

a. Can you explain the methodology for testing yield variations at different distances from the line source?

b. For obtaining maximum yields, how often do you have to irrigate?

M. V. K. Sivakumar:

a. The data presented came from different distances from the line source. The harvest was done from each bed, or every 1.5 m beginning from the line source up to a distance of 18 m from the line source.

Since the yields showed no significant differences between each bed or each 1.5-m harvests, we pooled the data over 4 beds or over a distance of 6 m. The yields were then significantly different for the three subtreatments. The number of pods as well as the kernel weights were different for the three subtreatments.

b. Dr. Williams would also probably emphasize the same point in his presentation. Maximum water application is not required to obtain maximum yields of groundnut. We have shown a yield advantage with a mild drought stress during the early vegetative period. This indicates that you need not apply water at regular intervals throughout the season.

M. Frere:

I wish to congratulate Dr. Sivakumar for his excellent presentation. I was in particular interested in the differences in the surface temperature of the crop in relation to water availability. With the technical capabilities that you have at ICRISAT Center, did you also consider monitoring the full energy balance of the crop?

M. V. K. Sivakumar:

We did not monitor the full energy balance of the crop. Since the subject of my presentation is restricted to water relations, 1 did not elaborate. We did measure net radiation and albedo in the fully-irrigated control and the fully-stressed crop. I would agree with you that the energy-balance measurements would have been interesting since the crop cover varied a lot with distance from the line source. However energy-balance studies need fairly large fields and this is not possible within the scope of line-source experiments.

B. Zeller:

Now that data on all the factors controlling water use such as stomatal resistance, leaf-water potential, etc., are available under different experimental conditions, could you propose a model that is sufficiently explanatory and could have a good predictive value of the crop behavior under water stress?

M. V. K. Sivakumar:

I think we have some measurements that would enable us to do that. But as Dr. Boote will probably show us on Friday, a fully functional model using the measurements that we made is not possible. As you know, we only made a few measurements and our interest was to use these measurements as an index of drought stress at different levels of water availability and at different intensities of drought stress. For a fully functional model you need to carefully consider all the parameters. We did have soil-water measurements, we did have estimates of stomatal conductance; but these would not be sufficient to construct a fully functional model.

C. Dancette:

The line-source irrigation technique performs well and allows to draw excellent response curves to water application. I would like to know if you are not obliged to carry out irrigations during the dry season in order to avoid excessive water supply. If yes, could you transpose what you have obtained during the dry season to the rainy-season conditions? Another method will be to have automatic rain-out shelters.

M. V. K. Sivakumar:

a. The study we reported was carried out during the postrainy season, i.e., from October/November to March/April. Your comment regarding the applicability of results from postrainy season to rainy season is valid. We also had the same question. So in 1983 during the rainy season, we imposed drought stress on the groundnut crop from emergence to start of pegging by covering the soil surface with a black polyethylene film. By doing this we were able to prevent any rainfall entering the soil in that period. At the start of pegging, we removed the black polyethylene film. By adopting this technique we were able to prevent about 233 mm out of 656 mm of total rainfall for the season from entering the soil and thereby were able to impose the desired water deficit. Here also we obtained a yield advantage as in the postrainy season. So we were able to reproduce the results observed in the previous postrainy season.

b. At ICRISAT Center there will be two rain-out shelters available to conduct drought-stress studies in the rainy season. I agree with you that it is pertinent to conduct such studies in the rainy season because that is more real for the farmers' situation. However studies conducted during the postrainy season are indicative of what could happen and it also enables you to get a level of control on the water application that is otherwise not possible during the rainy season.

M. Konate:

a. What is the possibility of relating water availability directly to yields?

b. Can we predict yields ahead of harvest?

M. V. K. Sivakumar:

a. It is possible to get some estimate of how water availability would affect yield. As Dr. Kanemasu showed in his presentation, a plot of the yield over maximum yield in relation to Et over ET_{max} could give you an idea of the relative importance of the reduction in evapotranspiration in relation to the reduction in yield. In our study, we have done this but the relationship has not been presented in the paper.

b. It should be possible to integrate the simple relationship described above with rainfall probabilities to enable you to predict yield a month before harvest. What you may have to do is to integrate the rainfall probabilities and compute these relationships at varying probability levels.

J. L. Khalfaoui:

Could you please explain the method you have used to measure the depth of water extraction by the root system?

J. H. Williams:

We have used the neutron probe method. The measurements were made at regular intervals over several depths in the soil. I do not consider this method viable over a large breeding program.

N. Morrel:

This concerns the explanation of the beneficial effects of gypsum application. Is it due to increased soil permeability, better infiltration of water, or supply of calcium or sulphur to the crop? Is it due to a simple or a cumulative effect of all of these?

J. H. Williams:

I am not able to separate out the effects. Based on the knowledge of physiology, we can guess that it is the calcium that explains the beneficial effects of gypsum application. But it is quite hard to supply these nutrients without changing other things. This study shows that there are other factors that can modify responses substantially. We need a good knowledge of soils and other details.

A.P. Ouedrago:

I did not completely understand the effects due to gypsum. I would like to find out if the 25 varieties had the same maturity duration.

J. H. Williams:

Yes, they did. We initially started with 25 varieties, but discarded 3 of these later because they were too long in duration. All the varieties flowered within a few days of each other.

A. Tekete:

Drought stress reduces harvest index but increases the root:shoot ratio. From an agronomic point of view this is a waste of energy. What kind of management would you advise to reverse this situation?

J. H. Williams:

I would not try to reverse it. It is a necessary investment to get the water. With groundnut you find that drought stress promotes the growth of roots. The plant is designed for survival primarily.

K. J. Boote:

I would like to make a comment on the previous question and then ask a question. Our experience with rooting in an area where you have frequent rainfall during the growing season is that a high root to shoot ratio is necessary under well-irrigated conditions before you get into drought stress. So what you have can get a head start during short stresses, particularly on a sandy soil, to continue to grow more rapidly during the stress.

You said that you have the same life cycle for the cultivars and that they flowered at the same time. I wondered if the rate of pod addition is more rapid on some cultivars?

J. H. Williams:

The point is well taken. We don't really know. We did our best to choose varieties in the same maturity group. One cannot discount that there are within that some escape mechanisms operating, because there are some cultivars which have their pods loaded more quickly. Differences could be there, but they would be relatively small.

D. Smith:

With reference to the role of sulphur in the PANS manual, there was a statement made that sulphur strengthens the attachment of the pegs and therefore contributes to increased recovery at harvest time. As I recall, it was not substantiated with any literature citation.

J. H. Williams:

Certainly by virtue of having a healthier plant, you would promote better peg attachment. I do not believe that sulphur was a phenomenon within this.

C. E. Simpson:
What was your measurement of maturity? Is it first date of flowering or 50% flowering?

J. H. Williams:
We based our selection of these cultivars on the time to 50% flowering. All varieties we used were within a couple of days of the mean value.

C. E. Simpson:
Do you feel this is well established in maturity or just in number of days to 50% flowering? Are you using it as a measure of maturity?

J. H. Williams:
I am using it to discard obviously different genotypes. We selected our varieties out of a large collection to try and get interesting material, and within those we tried to eliminate as much as possible the confounding effects due to days to flowering.

Session III

Climatic Requirements of Groundnut

Chairman: J.Y. Yayock
Co-chairman: I. Also

Rapporteur: L.K. Fussell

Agroclimatological Factors Affecting Phenology of Groundnut

C.K. Ong[1]

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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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT.

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 hypogaeah 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).

Phonological 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

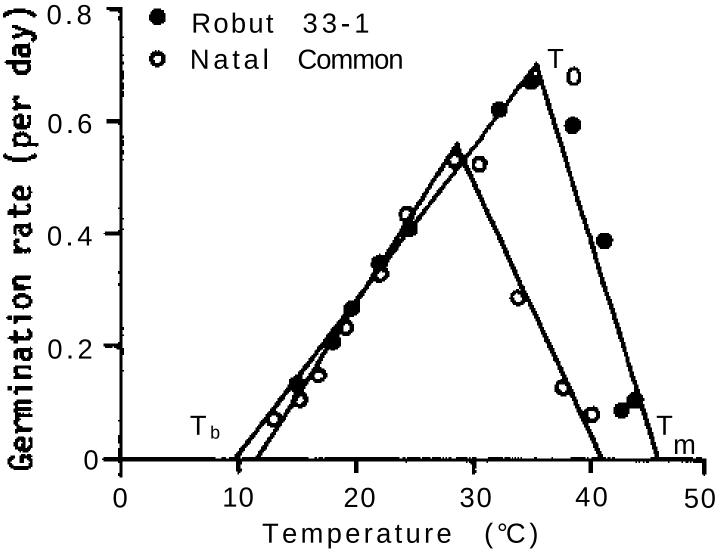

Figure 1. Germination rates for groundnut cultivar Robut 33-1 and Natal Common at various temperatures (°C). Base (Tb), optimum (To), and maximum (Tm) temperatures are indicated for Robut 33-1. (Source: Mohamed 1984.)

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 Young et al. 1979 for groundnut). But there is still uncertainty 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℃ 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 (0) in ℃ d for each process in Table 2 are calculated from results at five temperatures between mean temperatures of 19 and 30°C. *6* is the reciprocal of the slope of the rate/temperature relationship. Tb ranged from 9.5-11.4℃, 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 2. Values of base temperatures (Tb) and thermal time (0) in ℃d of several developmental processes of groundnut cv Robut 33-1. Results from 5-10 treatments.

Developmental process	Tb(℃)	0(℃d)
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.

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

	Temperatures (℃)		
Cultivars	Tb	To	Tm
Valencia R2	8	35	43
Flamingo	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
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.

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℃, To from 29.0-36.5℃, and Tm from 41-47℃ (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 (Tm) 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℃) 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℃. The selection for a heat-tolerant groundnut cultivar is therefore possible in many tropical regions where soil temperatures regularly exceed 40°C.

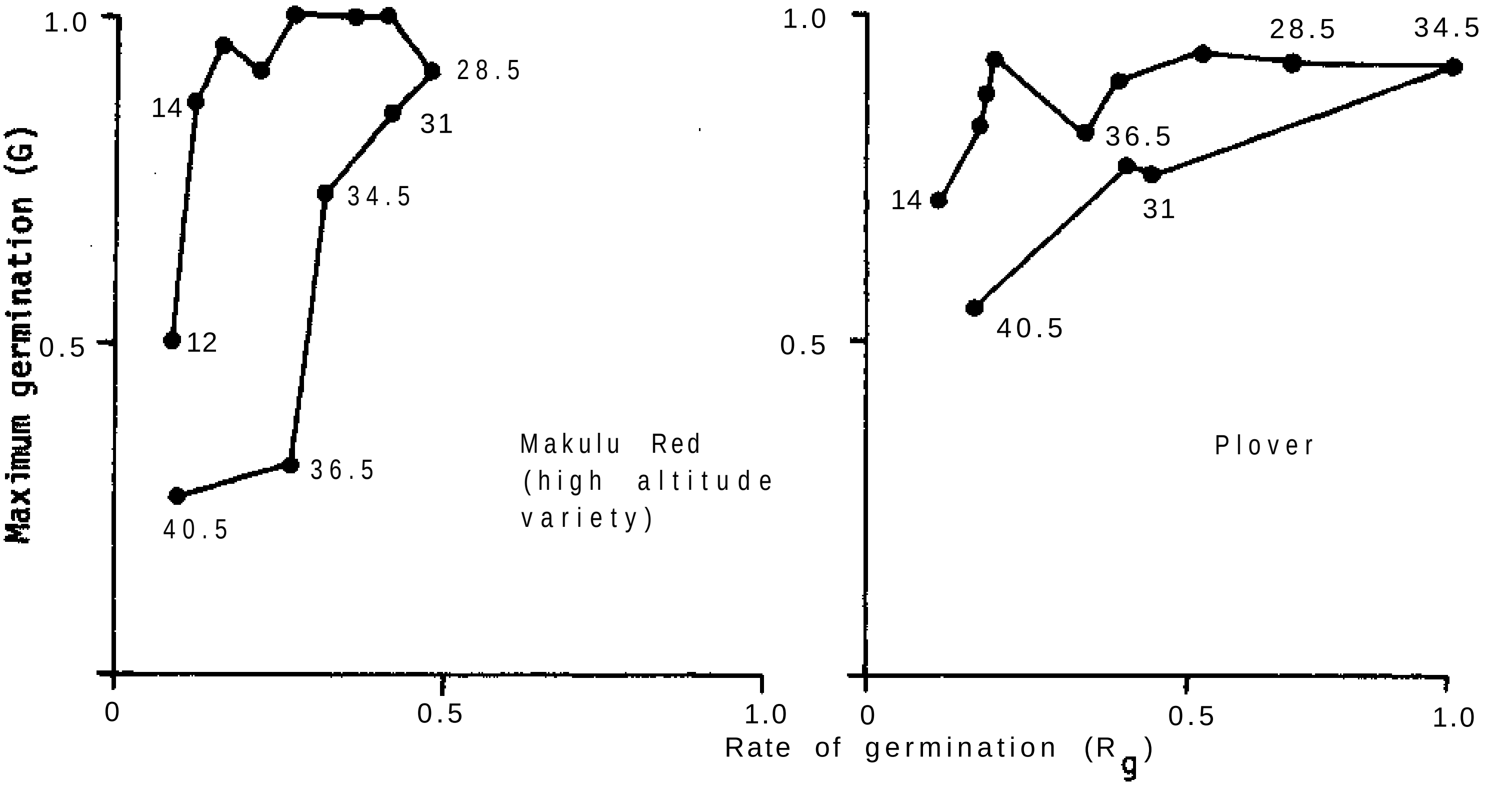

Figure 2. Relationship of maximum germination and rate of germination to temperature (°C) of groundnut cultivars Makulu Red and Plover. (Source: Mohamed 1984.)

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

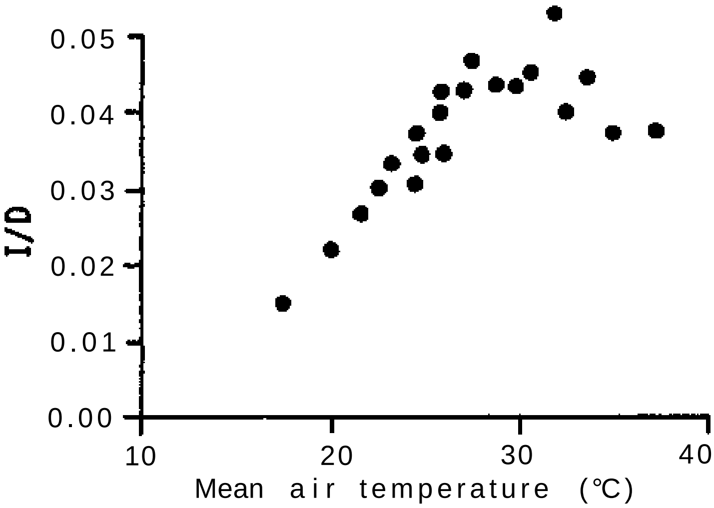

Figure 3. Rate of flowering (I/D) of groundnut cultivar Schwarz 21 as a function of mean air temperature (°C). Recalculated from Fortainier (1957). D is days for 50% of the population to produce the first flower.

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 (Fortanier 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-environmeat 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.

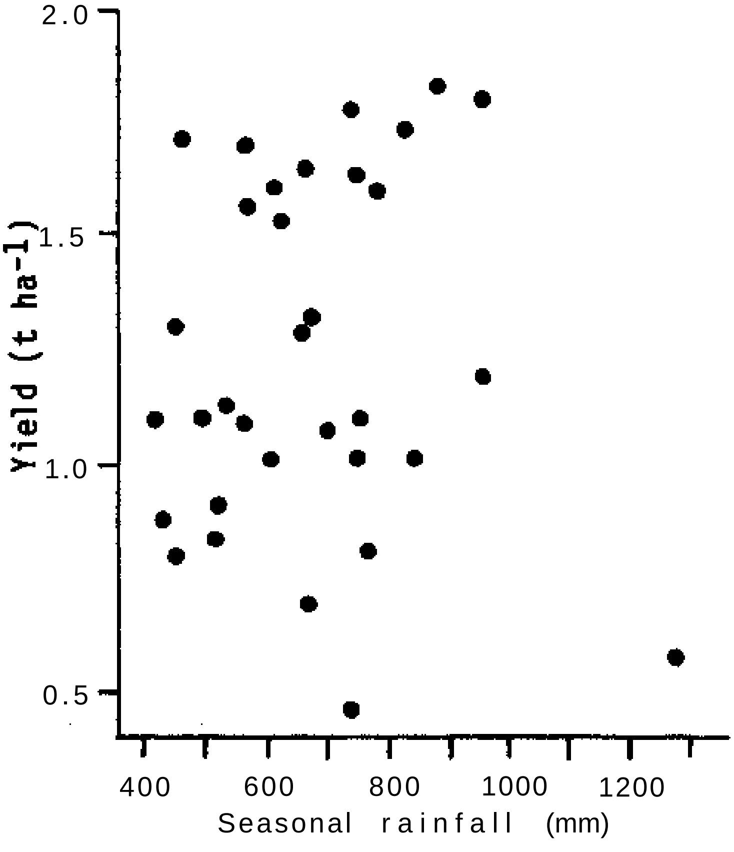

Figure 4. Comparison of groundnut yields (t ha^{-1}) and seasonal rainfall for 32 years (1932-1964), Bambey, Senegal. (Source: Popov 1984.)

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, Matlock et al. (1961) reported a yield of 2.7 t ha^{-1} with supplementary irrigation of 75 mm on 21 July, but only 1.81 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).

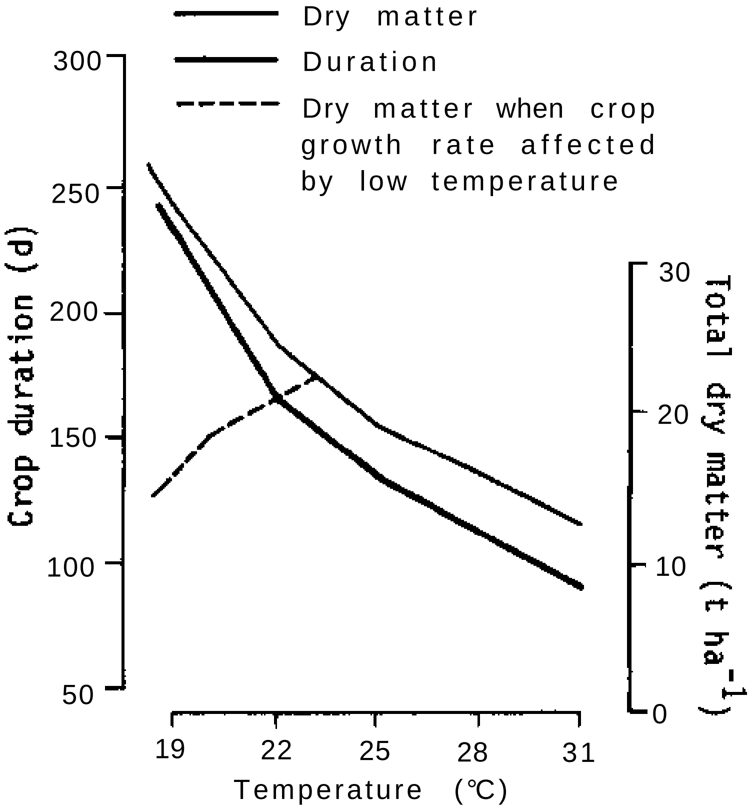

Figure 5. Temperature effects on the duration from sowing to end of pod filling and the final dry matter produced. The duration is calculated using a maturity index of 2000°C d and Tb of 10°C

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 To 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).

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

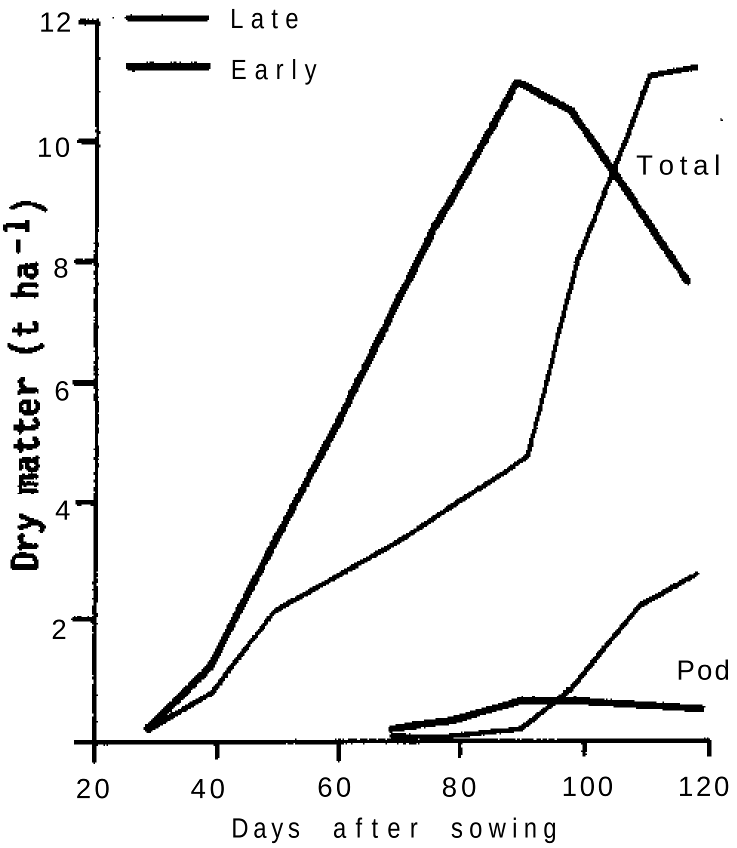

Figure 6. Comparison of the dry-matter production (t ha^{-1}) of groundnut cultivar Robut 33-1 with early and late irrigation. Both crops received the same amount of irrigation. (Source: ODA 1984.)

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 gm^{-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.

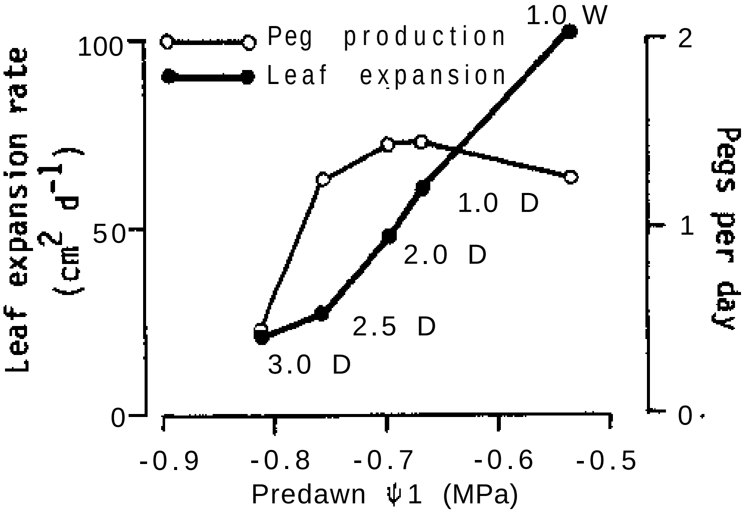

Figure 7. Relationship between predawn leaf-water potential (MPa) and rates of leaf expansion (cm^2 d^{-1}) and peg production. Treatments are identified by the maximum saturation deficit (KPa) and the soil regime: W for wet and D for stored moisture.

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℃) 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℃ 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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Création variétale d'arachide adaptée aux contraintes pluviométriques des zones semi-arides

J-L. B. Khalfaoui et D. Annerose[1]

Résumé

La bioclimatologie permet à présent de mieux cerner les paramètres liés à l'alimentation hydrique, essentiels à la mise en place d'un programme de création variétale pour les zones semi-arides. Notamment elle précise deux données fondamentales en fonction de la région où doit être diffusée la variété: la longueur optimale théorique de cycle et les risques dus à la répartition temporelle des précipitations.

L'illustration portera sur un programme d'amélioration génétique de l'arachide mené à l'ISRA, au CNRA de Bambey. Celui-ci vise à créer des variétés adaptées aux deux types de sécheresse sévissant dans la zone Nord et Centre du pays. Dans la zone Nord, l'hivernage se caractérise par sa faible durée par laquelle les variétés les plus précoces actuellement vulgarisées (90 jours) ne sont plus adaptées. Le but est de créer, par back-cross entre ces cultivars et un géniteur de précocité, des variétés dont le cycle plus court soit capable de s'inscrire dans les limites de la saison des pluies. Dans la zone Centre, l'hivernage y est davantage étalé dans le temps, mais entrecoupé de périodes de sécheresse plus ou moins longues. Le but est de créer, par sélection récurrente portant sur la production et différents caractères physiologiques d'adaptation à la sécheresse, des variétés de cycle précoce (90 jours) et demi-précoce (105 jours) capables de supporter des périodes de stress hydrique en cours de cycle.

Abstract

Breeding Groundnut Varieties for the Semi-Arid Zones: *At present bioclimatology helps to identify water-balance parameters that are essential for breeding varieties for the semi-arid tropics. It identifies in particular two basic data for the region where the variety is to be released: the optimal length of the growing season and the risks due to the temporal distribution of rainfall*

A groundnut breeding program at ISRA, CNRA, Bambey is discussed. This programme aims at developing varieties that are adapted to two types of drought conditions affecting the northern and central regions of the country. The northern region is characterized by a short rainy season, to which the early-maturing varieties (90 days), now available are no longer adapted. The purpose is to develop, through backcross between these varieties and an early-maturing parent, new varieties of shorter duration which would fit within the limits of the rainy season. In the central region the rainy season is longer, but is interrupted by relatively long droughts. Here, the objective is to develop, through recurrent selection on productive capacity and different features of physiological adaptation to drought, short-duration (90 days) and medium-duration (105 days) varieties that can withstand periods of drought stress during their growing cycle.

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Introduction

Parmi les facteurs climatiques prévalant dans les zones semi-arides, le facteur limitant est sans aucun doute l'alimentation hydrique qui, dans de nombreuses régions, approche le seuil minimum nécessaire à la pratique de l'agriculture.

Confronté à ce problème les questions que se pose le sélectionneur sont, dans un premier temps, les mêmes que celles des autres spécialistes de l'agriculture travaillant dans ces régions, à savoir essentiellement : combien pleut-il? et surtout comment?

La bioclimatologie permet de mieux cerner ces questions en précisant, notamment, deux données fondamentales en fonction de la région où doivent être vulgarisées les variétés :

- La longueur de la période des pluies qui conditionne la longueur optimale du cycle que l'on peut cultiver;

- Le volume et la répartition temporelle des pluies pendant cette période qui vont préciser les risques de stress hydriques en cours de cycle (Dancette 1986).

Choix de la longueur du cycle

Avant de débuter un programme d'amélioration, la première tâche du sélectionneur est de choisir la longueur du cycle qu'il va chercher à obtenir.

Ce choix est guidé par deux principes de base. Premièrement, permettre à la variété de pouvoir inscrire son cycle dans la durée de la saison des pluies. Deuxièmement, il est clairement établi que tout gain de précocité entraîne une perte du potentiel de production. Afin d'optimiser la culture, il faut donc faire coïncider le plus exactement possible la longueur du cycle avec celle de l'hivernage.

La principale difficulté réside dans les fluctuations importantes de la longueur de la saison des pluies qui rendent difficile la détermination de la longueur optimale du cycle. Une optimisation est donc nécessaire, qui consiste à fixer un certain pourcentage d'année où le cycle doit s'inscrire dans la saison des pluies, le principal critère devant être la rentabilité économique.

Dans la zone semi-aride du Sénégal, deux localités (région Centre et région Nord) vont permettre de fixer le cadre de ce choix des cycles et les méthodes de sélection permettant de les obtenir. Elles vont mettre également en évidence la tendance à la diminution de la durée de la saison des pluies que l'on observe depuis une quinzaine d'années.

Bambey (région Centre)

Si l'on observe la Figure 1, la longueur potentielle du cycle en fonction des années de 1960 à 1984, c'est-à-dire la durée entre la première pluie de semis et la dernière pluie utile plus dix jours correspondant environ à la période suivant la dernière pluie pendant laquelle la culture utilise la réserve en eau disponible dans le sol, on s'aperçoit qu'à partir de 1970 se produit une baisse de la durée potentielle du cycle qui rend une semi-tardive de 110 jours inadaptée 7 années sur 15 alors qu'elle ne l'était qu'une année sur 10 pour la période antérieure durant laquelle elle était vulgarisée.

Cela impose une diminution du cycle des variétés à créer pour cette région, cycle que l'on peut fixer à environ 100 jours qui aurait permis de satisfaire 12 années sur 15.

Ce cycle pourra être aisément obtenu par les méthodes classiques de sélection de l'arachide (généalogique, bulk, SSD, etc.) puisqu'il est intermédiaire dans la gamme de précocité disponible en collection.

Louga (région Nord)

En ce qui concerne Louga, la Figure 2 montre que pour cette région le cycle potentiel a très fortement diminué. A partir de 1972, on constate qu'une variété hâtive de 90 jours alors vulgarisée n'est plus adaptée que seulement 4 années sur 13 alors que dans la période précédente elle l'avait été 11 années sur 12.

Cette chute a été telle qu'après 1971 même une variété de 75 jours qui représente la limite inférieure de précocité actuellement disponible en collection, n'aurait pu achever son cycle qu'une année sur deux. Ce qui est loin d'être satisfaisant.

Pour l'instant, la création de variété d'arachide de cycle inférieur à 75 jours est extrêmement hypothétique. Elle passe, dans un premier temps, par la création d'un géniteur extrêmement précoce que l'on peut espérer obtenir soit par transgression entre des géniteurs très précoces, soit par mutagenèse. La tâche sera certainement ardue.

Si les conditions climatiques ne s'améliorent pas, il semble donc peu probable que l'arachide puisse, dans un avenir proche, se réinstaller dans la région de Louga.

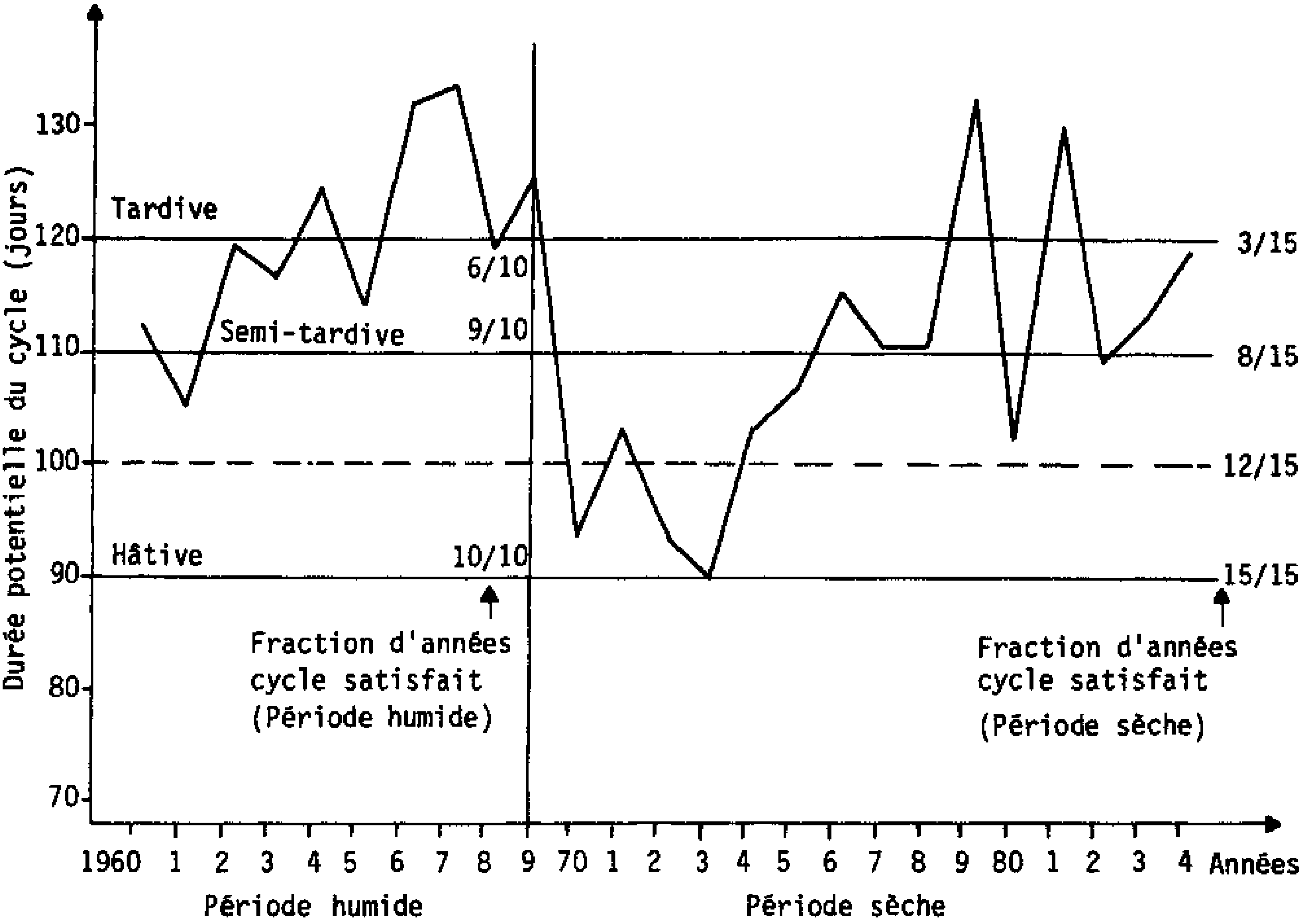

Figure 1. Durée potentielle du cycle en fonction du temps à Bambey, Sénégal.

On peut remarquer que le cycle exigé actuellement dans cette région, d'après la Figure 2 de l'ordre de 55 à 60 jours, correspond aux capacités du niébé, qui est donc appelé à avoir un développement très important dans la région Nord.

Région intermédiaire

De la région de Bambey à celle de Louga, on assiste à une chute de la durée potentielle du cycle. La limite Nord d'implantation de l'arachide sera fixée par la précocité maximale disponible en collection, à savoir 75 jours, que l'on peut espérer conférer aux cultivars.

La création d'une variété agronomique de 75 jours pose certains problèmes. Le géniteur le plus précoce dont on dispose, Chico, fait 75 jours, mais est agronomiquement peu intéressant : faible productivité malgré une certaine aptitude à la combinaison pour ce caractère, et qualités technologiques médiocres.

Par sélection généalogique, à partir d'un croisement entre Chico et une bonne variété agronomique, il est difficile d'obtenir une variété de 75 jours à qualités agronomiques favorables car la tendance avec une telle méthode, comme avec celles qui lui sont apparentées, est de créer des variétés de comportement plus ou moins intermédiaire entre les deux parents initiaux.

Pour pallier cet inconvénient, une autre méthode de sélection envisageable est actuellement tentée au CNRA de Bambey : il s'agit du backcross. Le principe est de transférer uniquement les allèles de précocité de Chico aux variétés agronomiquement valables, par une succession de rétrocroisements. Les deux variétés dont on cherche à diminuer ainsi le cycle sont celles vulgarisées dans le Centre Nord du Sénégal : 55-437 et 73-30 de 90 jours. Cette dernière possède une qualité supplémentaire importante : la dormance qui lui permet d'éviter les pertes par régermination en cas de pluies de fin de cycle survenant alors que les graines sont matures.

Le principe du backcross est simple. A partir du croisement entre Chico, le géniteur de précocité, et 73-30 ou 55-437 (les parents récurrents) on obtient une F1 dont l'autofécondation permet aux allèles de précocité de Chico, qui sont récessifs, de s'exprimer. Parmi les plantes F2, les plus précoces sont choisies et recroisées avec le parent récurrent. Au cours des backcross, on tend ainsi vers la variété agronomique intéressante tout en vérifiant à chaque étape que les allèles de précocité de Chico sont toujours présents. A partir du backcross 5 ou 6 on obtient un génotype pratiquement isogénisé par rapport à la variété agronomiquement intéressante. C'est-à-dire qu'il possède pratiquement tous les allèles de 73-30 ou 55-437, sauf ceux de précocité qui sont ceux de Chico.

Risques de périodes de sécheresse en cours de cycle

Le deuxième problème majeur, après la durée de l'hivernage, se situe au niveau de la répartition des précipitations pendant cette période.

En effet si l'on examine un exemple type, celui de la pluviométrie à Bambey en 1984 (Fig. 3) on constate que la longueur de l'hivernage a été favorable puisqu'elle aurait permis à une tardive de 120 jours de réaliser son cycle. Par contre deux périodes de sécheresse importante ont eu lieu en cours de culture. La première de 15 jours, entre le 45e et le 60e jour, est survenue durant la phase de développement de l'arachide la plus sensible à la sécheresse pour la production, celle de la fructification. La deuxième de 13 jours, entre le 68e et 81e jour, s'est produite durant la maturation des gousses formées et le remplissage des gousses correspondant aux dernières fleurs utiles. Ces deux périodes de sécheresse ont eu pour effet de sérieusement péjorer la production arachidière dans cette région.

Face à ce problème de stress hydrique en cours de cycle, la solution qu'offre la sélection est de créer des cultivars adaptés à la sécheresse, capables de supporter ces périodes.

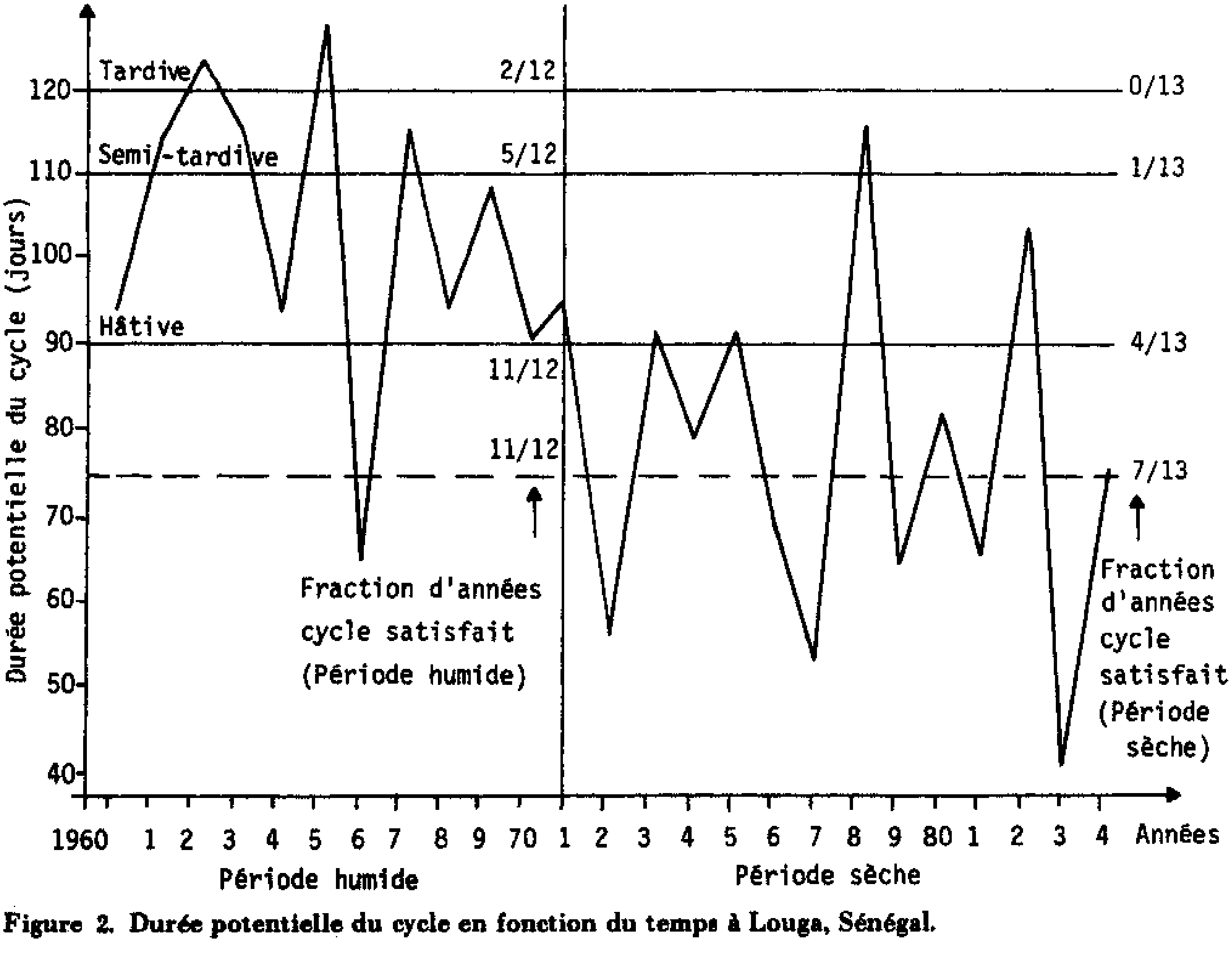

Figure 2. Durée potentielle du cycle en fonction du temps à Louga, Sénégal.

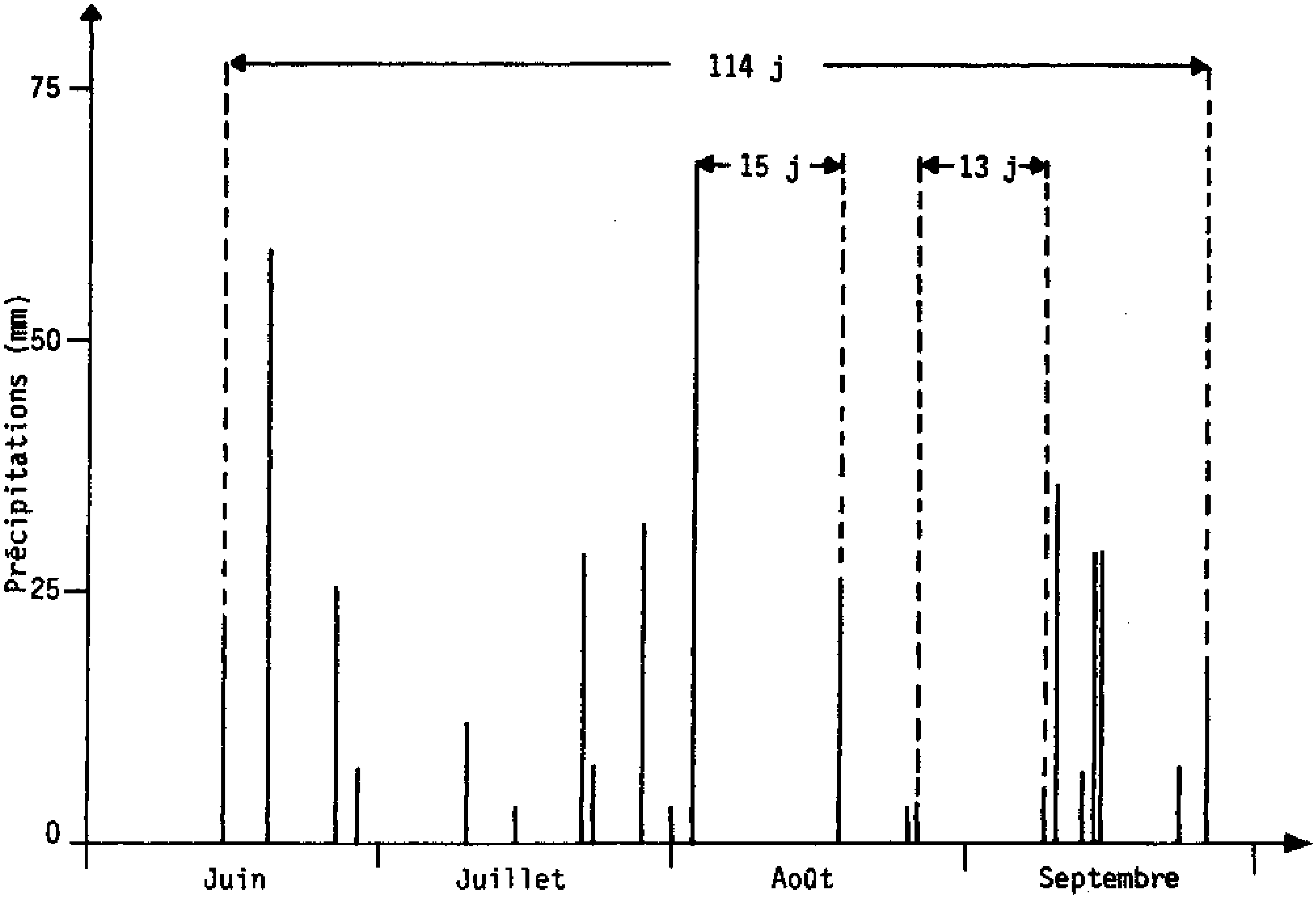

Figure 3. Pluviométrie à Bambey en 1984.

Principes de sélection pour l'amélioration de l'adaptation à la sécheresse

Sélection sur la productivité en conditions de sécheresse

Jusqu'à présent les variétés d'arachide adaptées à la sécheresse ont été créées par sélection basée sur la productivité en conditions naturelles comportant des périodes de stress hydrique, les génotypes les plus aptes à supporter ces périodes étant par conséquent ceux les plus productifs (Sullivan 1972, O'Toole et Chang 1977). Ce type de sélection peut être qualifié d'indirect puisqu'il n'évalue pas directement le degré d'adaptation proprement dite des individus.

L'amélioration de l'adaptation à la sécheresse basée sur la productivité présente de sérieuses limitations qui tiennent essentiellement au manque de constance, à la fois quantitative et qualitative, de la pression de sélection exercée d'une génération à l'autre (Lewis et Christiansen 1982).

D'un point de vue quantitatif, le degré de sécheresse sévissant d'une année à l'autre est extrêmement variable, pouvant même aller jusqu'à être nul.

D'un point de vue qualitatif, la productivité étant sous l'influence de plusieurs conditions environnementales, la réponse à la sécheresse peut subir l'interférence d'autres facteurs occasionnels du milieu, tel qu'une attaque pathogène, qui rendent difficiles, voire impossible, le dépistage des bons génotypes. D'autre part, il est à présent établi que les conséquences sur la vie et la productivité de la plante, ainsi que les mécanismes physiologiques d'adaptation impliqués, varient suivant le stade du développement qui subit le stress. Or d'une année à l'autre les périodes de sécheresse ne surviennent aux mêmes moments donc aux mêmes stades ontogénétiques. Par conséquent, au cours des générations de la création variétale, la pression de sélection va se déplacer de mécanismes physiologiques d'adaptation à la sécheresse à d'autres.

Ce manque de constance de la pression de sélection impose un progrès aléatoire et lent qui tend à plafonner.

Sélection sur les mécanismes physiologiques d'adaptation à la sécheresse

Les progrès de la physiologie dans la compréhension des mécanismes physiologiques impliqués dans l'adaptation à la sécheresse des espèces cultivées et notamment de l'arachide, offrent de nouvelles perspectives à l'amélioration génétique de ce caractère (Ketring 1986). En effet, en portant directement sur ces mécanismes physiologiques, elle permet de maintenir homogène la pression de sélection tout au long du programme de création variétale. Ce type de sélection peut être qualifié de direct.

Une telle méthode présente deux difficultés majeures : premièrement, l'adaptation à la sécheresse étant la résultante de l'intervention de plusieurs mécanismes morphologiques, anatomiques, biochimiques et physiologiques constitutifs ou inductifs (Ahmadi 1983), la sélection doit, pour être efficace, porter sur un certain nombre de caractères complémentaires parmi ces mécanismes. De plus la création de cultivars ne saurait se limiter à l'amélioration de ces caractères physiologiques, car ceux-ci présentent un coût fonctionnel et génétique pour la productivité. Cela implique, par conséquent, de sélectionner également la productivité sous peine d'aboutir à la création non pas d'une variété d'arachide mais, si l'on peut dire, à celle d'un "Cactus". On voit donc, en première contrainte, que c'est une amélioration extrêmement polygénique, donc complexe, que l'on cherche à accomplir.

La deuxième contrainte, corollaire de la première est que plus une amélioration est polygénique, plus elle nécessite une variabilité génétique importante. Elle impose de multiplier le nombre de géniteurs, donc le nombre d'intercroisements à réaliser, et de les choisir soigneusement pour leurs qualités complémentaires.

Cette approche n'est réalisable que dans le cadre d'une collaboration étroite entre le sélectionneur et le physiologiste. Celui-ci doit déterminer les stades critiques du développement et les caractères physiologiques à améliorer. Il met au point les tests de suivi de ces caractères qui doivent être reproductibles, non destructifs afin d'assurer une descendance aux individus retenus et capables d'évaluer rapidement un grand nombre de plantes.

Méthodes de sélection

Examinons brièvement, les méthodes de sélection disponibles pour l'amélioration de l'adaptation à la sécheresse (Khalfaoui 1985).

Méthodes de sélection classiques

Les méthodes classiques de création variétale (généalogique, bulk, SSD), employées directement, auront une portée limitée sur un caractère aussi polygénique que l'adaptation à la sécheresse car elles présentent deux inconvénients majeurs. Elles font intervenir :

- un nombre limité de géniteurs, le plus souvent deux rarement plus de trois, ce qui limite le nombre d'allèles favorables disponibles;

- un nombre limité de recombinaisons efficaces puisque l'on tend rapidement vers l'homozygotie, ce qui limite les chances de réunir les allèles favorables dans le même génotype en une bonne balance interne.

Sélection récurrente

Il existe une autre méthode de sélection utilisable au préalable : la sélection récurrente (Gallais 1977, 1978). Elle consiste à réaliser à partir d'une population de départ à variabilité génétique large, une succession de cycles de sélection comprenant chacun une phase de choix des meilleurs individus et une phase de brassage génétique où ils sont intercroisés.

Elle présente trois avantages majeurs :

- Elle assure un progrès constant et prolongé, en évitant les pertes de variabilité intéressante.

- Elle augmente la fréquence des allèles favorables dans la population.

- Elle multiplie les recombinaisons génétiques.

Les deux derniers points concourent à augmenter la probabilité de réunir les allèles favorables en un même génotype.

Lorsque le niveau atteint est jugé suffisant, chaque population peut être le point de départ d'une méthode classique de création variétale. La sélection récurrente, préalable aux méthodes classiques, est une voie d'amélioration exigeante en temps et en moyen mais souple d'utilisation. En effet, elle permet : de concilier l'amélioration à long et moyen terme, d'être "entretenue" par des apports contrôlés de variabilité génétique nouvelle et d'être "gelée" momentanément si la priorité est mise sur l'extraction de variétés à partir de la population améliorée.

Illustration : Programme d'amélioration de l'adaptation à la sécheresse au Centre national de recherche agronomique de Bambey

Ce programme a débuté en 1983. Dans un premier temps, huit variétés ont été choisies : premièrement, pour leurs bons comportements aux tests physiologiques d'adaptation à la sécheresse et leur bonne production au champ en conditions de sécheresse; deuxièmement, pour la distance génétique importante qui doit exister entre elles (Tab. 1).

Ces huit variétés ont été ensuite intercroisées en pyramide afin de brasser leur matériel génétique et créer une population de départ, à base génétique large, constituée d'individus au génotype équilibré entre les différents parents initiaux.

La sélection récurrrente proprement dite, qui débute cette année, s'effectue à chaque cycle sur les descendances issues d'autofécondation (Tests S1) afin de permettre aux allèles récessifs favorables de pouvoir s'exprimer.

La sélection des individus à retenir se fait selon deux processus qui se déroulent en parallèle. Le premier consiste en un essai de productivité au champ en conditions naturelles. Le deuxième comprend les tests en laboratoire de deux mécanismes physiologiques d'adaptation à la sécheresse jugés fondamentaux pour l'arachide (Gautreau 1982) :

- la résistance protoplasmique : c'est-à-dire la résistance des membranes cellulaires à la dislocation par les chocs qu'ils soient osmotiques ou thermiques;
- les réserves en amidon des racines : qui permettent à la plante de maintenir ses activités d'entretien et partiellement de croissance, en mobilisant ses réserves glucidiques, ceci en période de sécheresse au cours de laquelle, afin de limiter ses pertes en eau, elle ferme ses stomates, ce qui entraîne un arrêt des échanges gazeux et par conséquent de l'activité photosynthétique.

Tableau 1. Variétés choisies par le programme d'amélioration de l'adaptation à la sécheresse à Bambey, Sénégal.

Variétés	Cycle (jours)	Botanique	Origine géographique
47-16	120	Virginia	Inde
59-127	120	Virginia	Burkina Faso
57-422	105/110	Virginia	Etats-Unis
73-33	105	Virginia	Etats-Unis x Australie
55-437	90	Spanish	Argentine
TS-32-1	90	Spanish	Burkina Faso
79-40	90	Spanish	Inde (Mutagenèse)
68-111	90	Spanish	Afrique du Sud

D'autres tests sont en cours de mise au point, qui seront adjoints aux deux précédents, lors des cycles ultérieurs; notamment la vitesse de croissance et l'importance du système racinaire et le contrôle de la transpiration.

A l'issue de ces deux criblages, les meilleurs individus des meilleures familles sont intercroisés afin de créer la population améliorée.

Conclusion

Face au grave problème de l'alimentation hydrique qui se pose dans les zones semi-arides, l'amélioration génétique de l'arachide possède trois atouts majeurs : premièrement, les progrès de la physiologie permettent une approche plus rationnelle et efficace; deuxièmement, la sélection dispose d'une variabilité génétique importante qui n'a été jusqu'à présent, que très partiellement utilisée; troisièmement, l'utilisation d'une amélioration génétique de fond telle que la sélection récurrente devrait apporter un progrès nettement plus soutenu à moyen et long terme.

L'utilisation intégrée de ces trois données devrait permettre à la sélection de jouer au mieux son rôle, et un rôle certainement important, dans l'action pluridisciplinaire qui doit être mise en place et menée dès à présent.

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Physiological Response of Groundnut to Temperature and Water Deficits—Breeding Implications

D.L. Ketring[1]

Abstract

Studies have been conducted to evaluate groundnut germplasm for heat- and drought-tolerance traits. Genotypes differ in tolerance to temperatures above 35°C in tests conducted under controlled environments. They also differ in heat tolerance, indicated by membrane thermostability using the in vitro leaf-disc method with leaf tissue from field-grown plants. The means to improvement of hydration maintenance of this crop under soil-moisture deficits has been sought through genotypic diversity in rooting traits and water-potential components. Genotypes differ in rooting habit and ability to maintain plant-water transport under greenhouse conditions. Field measurements of water-potential components indicate differences in rate of decrease in water-potential components, osmotic adjustment, and apoplastic water fraction. The limited germplasm examined in these investigations shows potential for improved heat and drought tolerance.

Résumé

Réponse physiologique de l'arachide à la température et au déficit hydrique — considérations portant sur la sélection : *Des études ont été faites pour évaluer les ressources génétiques d'arachide pour leur tolérance à la chaleur et à la sécheresse. En milieu contrôlé, les génotypes ont présenté une différence pour des températures supérieures à 35°C. La méthode du "leaf disc" in vitro a révélé une différence de tolérance à la chaleur, au niveau de la thermostabilité de la membrane. Les moyens d'amélioration de la conservation de l'hydration de cette culture en conditions de déficit d'humidité du sol ont été observés par une diversité génotypique du caractère racinaire et les composantes du potentiel hydrique. Les génotypes ont des habitudes racinaires différentes et une aptitude de maintenir le transport d'eau de la plante en serre. Les mesures au champ des composantes du potentiel hydrique révèlent des différences au niveau du taux de diminution des composantes du potentiel hydrique, de l'ajustement osmotique et la fraction d'eau apoplastique. Le nombre restreint de ressources génétiques étudiées lors de ces recherches indiquent un potentiel d'amélioration de la tolérance à la chaleur et la sécheresse.*

Introduction

Crops are rarely grown under optimal conditions for plant growth and development. Temperature extremes and low water availability limit the world's crop production. Temperature and drought stress affect most plants, and the groundnut *(Arachis hypogaea* L.) is no exception. The U.S. Department of Agriculture (USDA), Agricultural Research Service, and the state Agricultural Experiment Stations through-

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out the groundnut-growing belt in the USA are expending considerable effort to improve both the productivity and quality of the groundnut crop.

The drought and high temperatures in 1980 that reduced groundnut production 40-50% throughout the U.S. groundnut belt will be long remembered. Although this was the most disastrous season in recent times, localized droughts cause reduced groundnut production nearly every year. As recent examples, the Virginia-Carolina mid- Atlantic area suffered drought and high temperature in 1983, while Texas in the southwest suffered in 1984. The results of these environmental extremes were reduced crop productivity and quality. In 1980 in Oklahoma, USA, there were 53 days with temperatures greater than 35°C and very low rainfall, particularly in July (Table 1). Number of days of high temperature were similar in 1981 and 1982, but rainfall in 1982 was only 41 % of that in 1981. Yields under rainfed conditions in 1982 compared to 1981 were severely reduced. The combined effects of more high-temperature days and further reduction in rainfall in 1983 and 1984 resulted in even lower groundnut yields (Table 1). Such effects of environment are well known throughout the semi-arid tropics (SAT). The objective of our research is to evaluate and select groundnut germplasm that is more tolerant of temperature and drought stress.

Temperature

Vegetative Growth

Temperature has an essential role in all aspects of plant growth and development. Temperature regulates the rate of plant development, and in combination with water availability sets the length of the growing season. When temperature permits crop growth, water is the major limiting factor affecting crop growth and development (McCloud 1984). However, field temperatures (Table 1) often exceed those optimum for groundnut growth. Estimates of optimum light/dark temperature regimes for vegetative growth of groundnut plants under controlled environments range from 30/26 (Cox 1979) to 35/25°C (Ono et al. 1974). Under field conditions in Zimbabwe, groundnut crop-growth rate, leaf area, and total dry matter produced were greatest at a site with mean daily maximum temperatures of 29.7°C and minimum temperatures of 17.3°C (Williams et al. 1975).

Reproductive Growth

Groundnut reproductive phases (flowering, pegging, pod formation, and kernel filling) may each have different temperature optima. Temperature optima for flowering range from 20 (Wood 1968) to 30°C (Ono et al. 1974). Temperatures for the greatest number of developing pegs ranged from 20/25 (Wood 1968) to 32/23°C (Cox 1979). Under field conditions, the greatest and least number of pegs were produced by plants grown at sites with mean daily temperatures of 23.2 and 17.9°C, respectively. However, highest yields were obtained at a mean temperature of 20.1°C where intermediate peg numbers and seed-growth rates occurred (Williams et al. 1975). The data indicate that optimum mean air

Table 1. Rainfall (mm) and number of days with high temperatures for July and August during six groundnut-growing seasons, Perkins, Oklahoma agronomy farm, 1979-84.

	July			August			totals		Yield range
	Temperature ^{0}C[1]			Temperature °C					
Year	35-38 (no. of days)	38	Monthly rainfall (mm)	35-38 (no. of days)	38	Monthly rainfall (mm)	Days	Rainfall (mm)	Rainfed condition (kg ha^{-1})
1979	10	0	129.0	12	0	41.1	22	170.2	
1980	6	24	1.3	10	13	39.6	53	40.9	
1981	12	6	124.2	2	0	128.5	20	252.7	2683-1595
1982	5	0	94.2	9	7	8.4	21	102.6	823- 293
1983	11	8	0.5	20	8	24.4	47	24.9	680- 540
1984	11	7	1.3	15	7	39.1	40	40.4	400- 26

1. The average maximum temperatures in July and August were 33.3 and 39.9°C in 1979, 38.9 and 37.7°C in 1980, 32 .8 and 30.0°C in 1981, 32.2 and 35.0°C in 1982, 35.6 and 37.2 ^{0}C in 1983, and 35.6 and 36.1°C in 1984, respectively.

Table 2. Changes in vegetative growth and mature seeds of Tamnut spanish-type groundnut cultivar, with time and temperature treatment.

	63 DAS[1]	91 DAS			
Temperature ℃	Individual leaf area[2] (cm^2)	Individual leaf area (cm^2)	Total plant-leaf area (cm^2)	Mature seeds (no.)	(g)
30[3]	39.17	23.79	1608	18.1	6.52
35	27.59	11.29	1203	16.5	4.88
LSD 0.05[4]	3.92	3.23	254	5.5	1.47

1. DAS = days after sowing. Plants were harvested at 91 DAS.
2. Eight leaves, the second leaf from the cotyledonory branch growing tip, were sampled at both times and temperatures.
3. Light/dark temperatures were 30/22 and 35/22℃.
4. LSD 0.05 = least significant difference at $P < 0.05$.

temperatures for vegetative growth of groundnut plants are in the range of 25-30℃, while temperatures for reproductive growth may be similar or somewhat lower (20-25℃). The data in Table 1 show that groundnuts are frequently subjected to field temperatures equal to or greater than 35℃. When this occurs at critical phenophases (pegging, pod formation, and kernel filling), yields are affected.

Heat Tolerance

Gautreau (1966) used a heat test to select genotypes more resistant to heat by treating seedlings at 61℃ for 1 h. In our studies with intact plants, they were subjected to 35℃ beginning 21 days after sowing (DAS) and continuing until harvest at 91 DAS (Ketring 1984a). The spanish-type cultivar Tamnut 74 showed reduced individual leaf area at both 63 and 91 DAS (Table 2). At harvest, total plant-leaf area and number and weight of mature seeds were reduced (Table 2). The data show that 35℃ inhibited growth and development of this cultivar and suggested that 35℃ could be used to test genotypes for heat tolerance. Table 3 shows that P1 405915 produced the most and Chico the least shoot dry weight. The lower shoot weight of Chico was expected since this is a genetically smaller plant. However, Chico and P1 404021 had the highest weight of mature seeds. There were also other differential effects on yield components. For instance, P1 405915 had the largest number of total pegs, and while P1 404021 had the fewest number of flowers, it had the largest percentage (50%) of flowers that produced pegs (Table 3). Thus these data show a differential response among genotypes to 35℃, and it seems possible to select more heat-tolerant germplasm.

Table 3. Comparison of diverse groundnut genotypes for high-temperature (35℃) effects on shoot growth and yield components.

Genotype	Total shoot dry weight (g)	Flowers at 45 DAS (no.)	Total[1] pegs (no.)	Mature seeds (no.)	(g)	Immature seeds (no.)	(g)
P1 405915	25.49a[2]	110b	50a	2c	0.81c	5a	0.89a
Pronto	25.31a	143ab	28bc	8bc	1.91bc	7a	0.32b
Comet	24.32a	117b	18c	9bc	2.46abc	8a	0.24b
Tamnut 74	19.02b	117b	18c	8bc	1.78bc	6a	0.14b
P1 404021 (73-33)	16.91b	56c	28bc	13b	4.19a	1.2b	0.05b
Chico	11.82c	183a	32b	19a	3.77ab	6a	0.34b

1. Sum of aerial, subterranean, and those with pods attached.
2. Mean values not followed by the same letter are significantly different ($P < 0.05$), as determined by Duncan's multiple-range test.

Another approach to study heat tolerance of plants is the in vitro leaf-disc method (Sullivan and Ross 1979). The procedure measures electrical conductivity of electrolyte leakage from heat-damaged leaf-tissue cells after exposure to elevated temperatures. The extent of electrolyte leakage, expressed as a percentage after correction for control tissue, indicates the degree of membrane injury. The advantage of this method is that it can be used to test comparatively large amounts of germplasm under field conditions. When groundnuts grown under rainfed conditions were tested over a 3-year period, differences among genotypes, between days after sowing, and seasonal effects on membrane thermostability were found (Ketring, In press). Further studies comparing genotypes grown under both irrigated (IR) and rainfed (RF) conditions confirm these results and show the interactions between genotype, DAS, and treatment (IR or RF) (Table 4). In Table 5, membrane injury of OK-FH15 (Comet x Florunner selection) was similar to the Comet parent at 54 DAS and the Florunner parent at 96 DAS. These data suggest that membrane thermostability is a heritable trait in groundnut as it is in other crops such as soybean *(Glycine max* L. Merr) and *Sorghum bicolor L.* Moench.

Selection for membrane thermostability (low percentage membrane injury) may be a means to improve heat tolerance of the groundnut crop. Also included in Table 5 for comparison is the plant introduction P1 404021, which according to our records is the cultivar 73-33 released in Senegal by Gautreau et al. in 1980. This drought- and heat-tolerant cultivar (Gautreau et al. 1980, and Table 3), had percentage membrane-injury values similar to those of the cultivar Comet. Comet is also considered comparatively drought-tolerant, while Florunner is considered drought-susceptible. However, Florunner consistently has lower percentage membrane-injury values than Comet and, as shown in Table 5, lower values than P1 404021. Thus the criterion of greater membrane thermostability as an indicator of greater heat tolerance appears to be a separate physiological phenomenon from those used to designate drought tolerance in groundnut. Also, the membrane-thermostability response as an indicator of heat tolerance appears to be separate from intact-plant heat tolerance as shown in Table 3. However, perhaps by appropriate crosses and selection a more drought-(relative to the susceptible parent) and heat-tolerant (as indicated by membrane thermostability and/or intact-plant heat tolerant)

Table 4. Randomized complete block Anova for percentage membrane injury under rainfed (RF) and irrigated (IR) conditions in 1984.

Source	DF	Sum of squares	Mean square	F ratio
Mean	1	382 576.639	382 576.639	
Blocks	3	264.558	121.519	
Treatments				
Genotype	3	852.099	284.033	4.681**[1]
Day	2	2075.532	1 037.766	17.104**
Treatment (IR or RF)	1	122.244	122.244	2.015ns
Genotype x Day	6	1462.081	243.680	4.016**
Genotype x Treatment	3	468.255	156.085	2.573*
Day x Treatment	2	1011.409	505.704	8.335**
Genotype x Day x Treatment	6	490.444	81.741	1.347ns
Error	69	4186.468	60.673	
Total	96	393 609.728		

Coefficient of variation = 12.34 %

1. The symbols * and ** represent significance of the F value at P = 0.10 and *P* = 0.01, respectively.

Table 5. Comparison of membrane thermostability among groundnut genotypes including parents (Comet x Florunner) selection (OK- FH15), and P1 404021 under rainfed (RF) and irrigated (IR) conditions, Oklahoma, 1984.

		% Membrane injury		
Genotype		54 DAS[1]	75 DAS	96 DAS
Florunner	RF	54.20fgh[2]	59.88cdefg	49.89gh
	IR	74.22ab	56.76efgh	56.95efgh
OK-FH15	RF	71.66abcd	64.44bcdef	44.02h
	IR	79.77a	57.94efg	56.80efgh
Comet	RF	69.56abcde	65.33bcdef	64.65bcdef
	IR	69.24abcde	55.09fgh	65.04bcdef
P1 404021 (73-33)	RF	71.67abcd	66.94abcdef	61.76bcdefg
	IR	66.72bcdef	59.46defg	73.11abc

1. DAS = days after sowing.
2. Mean values not followed by the same letter were different (*P*< 0.05), as determined by Duncan's multiple-range test.

cultivar could be developed. Some evidence of this is selection OK-FH15 which shows percentage membrane-injury values common to both parents. The water relations of these genotypes are discussed below.

Hydration Maintenance

Lack of water is the most limiting factor in crop production. Knowledge of plant responses to water deficits is critical to food production in developing countries in the SAT. The questions are: how much dehydration can plants tolerate before productivity is reduced, and can germplasm be chosen with traits to withstand or delay dehydration while remaining productive?

Vegetative Growth

Drought stress directly and physically reduces plant vegetative growth by reducing cell turgor (Hsiao 1973, Hsiao and Acevedo 1974). Growth of leaves, stems, and roots is reduced. Long-term drought stress, when crops are grown under rainfed conditions with little precipitation, results in both reduced vegetative (shoot and root) and reproductive growth. However, under drought stress there may be an increase in the root:shoot ratio. This may be due to the ability of the root to adjust osmotically in order to maintain growth (Hsiao 1973).

Roots

Extensive rooting with the ability to explore a larger soil volume for moisture is possibly a trait that can delay dehydration and thus prolong the effective productive period. Table 6 shows some data representative of differences among groundnut genotypes in root traits (Ketring et al. 1982, Ketring 1984b). Genotypes differed in root length, number of roots

Table 6. Root-growth characteristics of selected groundnut genotypes grown for 55 days in a greenhouse.

Genotype	Length (cm)	Number at 1 m (no.)	Volume (ml)
Spanish types			
Spancross	186.8a[1]	2.8a	
Pronto	164.9b	1.6a	27.7a
Chico	153.7bc	1.2a	20.6a
Comet	138.5c	1.3a	26.8a
Virginia types			
Florunner	192.6a	4.9a	23.5b
UF 77318	186.6a	4.9a	37.2a
Early Runner	183.3a	1.3b	·
Dixie Runner	1214b	1.6b	-

1. Means of each type within columns followed by different letters were significantly different (P< 0.05) as determined by Duncan's multiple-range test. Spanish and Virginia types were analyzed separately.

at 1-m depth, and root volume. Root volume is highly correlated with root dry weight.

In addition to determining differences in rooting characteristics, we are also attempting to ascertain differences in root function, i.e., the ability of roots to extract soil moisture. In field studies, soil-moisture extraction was followed by weekly measurements of soil moisture with the neutron probe. The soil was a Teller sandy loam (fine, mixed, thermic, Udic Arguistoll) with a clay layer at about 46-61 cm beneath the surface. Roots extracted moisture to a depth of 120 cm in this soil. In sandy soils, groundnut roots have been measured to a depth of 150 cm (Robertson et al. 1980). To date, no significant genotypic differences in field-moisture extraction have been found in our studies. This may be due to either insufficient number of replications or insensitivity of the technique. Also soil compaction was a major factor in limiting groundnut root growth (Taylor and Ratliff 1969). Thus the full potential for extensive root growth as shown in Table 6 was probably not expressed in the Teller sandy loam soil so that genotypic differences in water extraction could not be detected. Using an alternate procedure (Gray et al. In press) to measure apparent sap flow (Av), we have found that genotypes differed in their ability to maintain water flow through the plant under drought-stress conditions in the greenhouse (Ketring, D.L., USDA, Oklahoma, unpublished data).

Components of Water Relation

Long-term drought stress has been used to study the response of groundnut genotypes by comparing water-relation components: water (ψ_w), osmotic (ψ_π), and turgor potential (ψ_p), stomatal resistance, relative water content (RWC), percentage ground cover, and yield under IR and RF conditions. The RF/IR ratio indicates the relative capability of genotypes to maintain hydration under drying soil conditions. Also, allowing the plant to dry slowly under RF conditions provides for expression of adaptive responses rather than injury responses due to fast artificial drying. Under environmental conditions that prevailed during our tests, genotypes reached only about 50-60% ground cover in the RF treatment. About 5 cm of water was applied weekly to the IR treatment, and 100% ground cover was reached in about 80 DAS.

Water-relations component measurements were made weekly between 1300 and 1500 h when solar radiation, vapor pressure deficit, and canopy temperature were near maximum. The Spanish genotype Comet showed lower leaf ψ_w, ψ_π, and RWC than the Virginia genotype Florunner (Erickson and Ketring, in press). The RF/IR ratios in Table 7 show the more rapid physiological response of Comet to increasing drought stress. Florunner behaved more like its IR counterpart, and the selection OK-FH15 was much like Florunner. The genotypes were most affected between 50 and 63 DAS, a critical period of groundnut growth and development, when pegging and pod development are occurring.

Data from a 2-year study were used to evaluate the ψ_w/ RWC relationship of field-grown plants. Regression analysis indicated that a cubic polynomial function best fits the data, accounting for 62±1 % of the total variance. This regression provided the best correlation and the lowest standard error between $1/\psi_w$ and RWC for all genotypes. Table 8 shows that the selection OK-FH15 had $1/\psi_w$ values similar to both parents until 80% RWC was reached, where it was significantly different from both of them. At

Table 7. Genotype ratios of rainfed/irrigated (RF/IR) leaf-water potential (ψ_w) osmotic potential (ψ_π), and relative water content (RWC) for plants grown in 1983.

	ψ_w			ψ_π			RWC		
DAS[1]	Comet	OK-FH15	Florunner	Comet	OK-FH15	Florunner	Comet	OK-FH15	Florunner
50	1.18a*	1.01b	1.07ab	1.11a	0.96a	1.00a	0.92a	0.91a	0.93a
56	1.47a	1.39a	1.21b	1.25a	1.13b	1.00a	0.83a	0.84ab	0.92b
63	1.60a	1.69a	1.63a	1.14a	1.32b	1.15a	0.79a	0.87b	0.81ab
77	1.25a	1.27a	1.29a	1.09a	1.16a	1.08a	0.76a	0.81ab	0.91b
$LSD_{0.05}$		0.143			0.18			0.15	

1. DAS = days after sowing.
2. Means followed by different letters in the same row of each variable ratio are significantly different (*P*< 0.05).
3. Least significant difference for data columns, i.e. DAP LSD values were calculated from error-mean squares of the analysis of variance.

Table 8. Predicted water-relations values of groundnut genotypes determined by polynomial regression analysis using least squre for ($1/\psi_W$ vs. RWC), (ψ_π vs. RWC), and (ψ_p vs. ψ_π), where ψ_W is leaf water-potential, and RWC is relative water content.

	RWC	95%	90%	85%	80%	75%	
$(1/\psi_W)$	Comet	-1.64a[1]	-1.20a	-0.90a	-0.69a	-0.57a	MPa
	OK-FH15	-1.07ab	-0.87b	-0.73b	-0.62b	-0.56a	
	Florunner	-1.15b	-0.94ab	-0.78ab	-0.66a	-0.58a	
(ψ_π)	Comet	-0.90a	-1.18a	-1.47a	-1.65a	-1.76a	MPa
	OK-FH15	-1.46b	-1.56b	-1.66b	-1.76a	-1.86a	
	Florunner	-1.46b	-1.54b	-1.62b	-1.70a	-1.77a	
(ψ_p)	Comet	0.71a	0.45a	0.26a	0.12a	0.02a[2]	MPa
	OK-FH15	0.54a	0.36a	0.22a	0.12a	0.05a	
	Florunner	0.56a	0.41a	0.27a	0.16a	0.07a	

1. Means followed by different letters in the same column within ($1/\psi_w$), (ψ_π), (ψ_p) are significantly different ($P < 0.10$) as determined by t-test.
2. At 70 % RWC and below, the plants were at zero turgor, and there were no significant differences in any of the potential components among the genotypes.

75% RWC and below, there was no significant difference among the genotypes. However, over a range of RWC from 95-45% the estimated difference in ψ_W was highest for Comet (2.33 MPa), intermediate for OK-FH15 (1.70 MPa), and lowest for Florunner (1.40 MPa). The more negative ψ_W of Comet suggests a greater relative drought tolerance for this cultivar according to the criteria of others (Gautreau 1977, Turner 1979). Both OK-FH15 and Florunner had lower ψ_π values than Comet until 85% RWC was reached. Below 85% RWC there were no significant differences among the genotypes. There were no significant differences in ψ_p among the genotypes at any RWC. The genotypes approached zero turgor at 75% RWC where ψ_π was -1.76 to -1.86 MPa. These values are somewhat lower than those reported by Bennett et al. (1984). The predicted values for water-potential components ($1/\psi_W$, ψ_π, ψ_p), showed highly significant correlations with RWC. This suggests that RWC alone could be a measurement to select genotypes for hydration maintenance under low soil-moisture conditions.

A component of RWC that could aid in maintaining cell hydration is apoplastic water content (A_w). The A_w fraction of RWC was calculated according to Zur et al. (1983). It is possible that A_w could contribute to hydration maintenance under drought-stress conditions when ψ_p approaches zero. Comet, the most drought-tolerant genotype, had the largest percentage A_w. The selection OK-FH15 was intermediate, and Florunner, the drought-susceptible genotype, had the least percentage A_w.

Table 9 shows a summary of the water-relation components of Comet, OK-FH15, and Florunner. The genotypes reached zero turgor at an average of 72% RWC (RWCo). Florunner and OK-FH15 had lower at zero turgor (ψ_π^0) and lower ψ_π at full turgor (ψ_π^1) than Comet. Thus, they showed a somewhat higher degree of osmotic adjustment due to drought stress than Comet under RF conditions. Osmotic adjustment is one means to at least maintain partial turgor under water-deficit conditions.

Ultimately, selection of germplasm with drought-tolerance traits, crossing these with high-yielding but more susceptible genotypes, and selection for both drought-tolerance and yield traits should result in cultivars with improved performance under RF conditions. Table 10 shows that in 1982 Comet

Table 9. Summary of seasonal water relations for three groundnut genotypes.

Genotype	Na[1]	RWCo (%)	ψ_π^0 (MPa)	ψ_π^1 (MPa)	$\psi_\pi^1-\psi_\pi^0$ (MPa)
Comet	43	73.9a[2]	-1.82a	-0.90a	0.92a
OK-FH15	25	69.3a	-2.01b	-1.35b	0.66b
Florunner	43	72.9a	-1.96b	-1.37b	0.59b
X		72.0	-1.93	-1.21	0.72

1. N = number of observations, RWCo and ψ_π^0 = relative water content and osmotic potential at zero turgor, respectively, ψ_π^1 - osmotic potential at full turgor (100% RWC).
2. Means within a column followed by different letters are significantly different ($P < 0.05$).

Table 10. Yield (kg ha^{-1}), quality, and value (\$ t^{-1}) of three groundnut genotypes grown under rainfed (RF) and irrigated (IR) conditions in Oklahoma, 1982 and 1983.

	Yield (kg ha^{-1})	SMK^1 (%)	Value (\$ t^{-1})
1982 RF			
Comet	684.4a^2	69.3a	605.80a
Florunner	293.1b	49.5b	444.80b
1983 RF			
Comet	501.1a	15.5a	159.30a
OK-FH15	441.2a	2.7b	58.48b
Florunner	302.9a	2.2b	50.64b
1983 IR			
Comet	2894.9a	68.7a	538.69a
OK-FH15	4034.9b	71.3a	559.49a
Florunner	4025.7b	68.8a	539.17a

1. SMK+SS = Sound mature kernels plus sound splits.
2. Means within a column for the same year and RF or IR followed by different letters are significantly different ($P < 0.05$).

yielded significantly more than Florunner under RF. In 1983 there were no significant differences among the genotypes under RF, but the selection OK-FH15 was intermediate between the parents. However Comet, probably due to earlier maturity, had a higher percentage of SMK+SS (sound mature kernels plus sound splits). Both runner types yielded more than Comet under IR. The selection OK-FH15 has good yield potential under IR and somewhat better yield than the susceptible parent Florunner under RF. Although OK-FH15 was originally selected for plant type (runner) and yield, it possesses some of the drought-tolerance traits of Comet and may prove useful in further breeding for drought tolerance.

Conclusions

There are many aspects to improving the yield potential of crop plants to stress environments through physiology. Techniques are needed that can assess the progress of physiological traits related to temperature and drought stress during breeding and selection. Heat-tolerance tests in controlled environments could prove useful for advanced breeding lines, while the in vitro leaf-disc method could be used with larger plant populations as well as advanced lines. Extensive root systems combined with the ability to extract moisture under soil-moisture deficits can delay dehydration and prolong the effective productive period. Diverse rooting traits and ability to extract moisture under drying conditions have been identified. Both of these can be evaluated at the seedling stage of early and advanced breeding lines. The water-relations component that seems most directly related to cell hydration is relative water content (RWC). Other factors such as osmotic adjustment and apoplastic water content contribute to cell turgor through maintaining high RWC. RWC can be readily measured for large plant populations. A selection OK- FH15 from Comet x Florunner has attributes of both parents, which indicates that traits for heat and drought tolerance are genetically transferable.

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Discussion

N. R. Yao:
I am a little surprised that Dr. Ong talks about the climatic factors that affect the phenology of groundnut but has not covered anything on photoperiod. What are the effects of photoperiod on phenology and the interactions between photoperiod and phenology because these two are sometimes related?

C. K. Ong:
This is a very appropriate question. The literature on photoperiod and temperature is very confusing because we now know that genotypes are very important. Some genotypes can have greater yield in long days and some have double the yield in short days. So we have to be very careful. If you look at the temperature responses, you can have different base temperatures, and different optimum temperatures. There is a lot of literature available but we should be careful in sorting out effects.

E. T. Kanemasu:
On your slide showing thermal growth rate, I did not quite understand how calculations were done for all the experiments. Could you explain some details?

C. K. Ong:
For most of these experiments 1 referred to, there are data on crop-growth rates. You can calculate the crop-growth rate during the reproductive phase or pod-filling phase, and then divide that by the mean temperature minus the base temperature. I have used 10°C as base temperature.

K. J. Boote:
I would like to pursue the same question. I wonder if it works because of some coincidence. I understand thermal crop-growth rate. But isn't relating pod number per m^2, a carrying capacity in effect, that is, pod numbers after it has established a pod load? It may be a chance that they have roughly similar requirements per fruit per day.

C. K. Ong:
I agree that it is probably premature to say that it applies to all crops in all countries. But we were given the impression that it worked for all experiments. We still need to look into this very carefully. I would like to test this furthur, perhaps using data from Florida. It works for maize, sorghum, and millet. I don't know if that is some expression of supply and demand of assimilate at a crucial stage.

R. E. Lynch:
You mentioned that the effects of foliar diseases in your calculations may be more important than water or rainfall. Don't you feel also that insect damage can have the same relationship to plant growth? Preliminary work done at Georgia shows that leaf hopper or jassid damage can cut respiration rates almost to zero; growth then would be almost zero.

C. Dancette:
In the last slide showing research needs, are the priorities arranged in order of importance? Do you think temperature would be a research priority under rainfed conditions in West Africa?

C. K. Ong:
I think soil temperature during germination and pod-filling may be very important in West Africa but I do not have any soil-temperature data to justify this. At ICRISAT Center where temperature is much lower than in parts of the Sahel, soil temperatures commonly exceed 35°C during dry periods.

J. J. Owonubi:
A comment on what has just been said. Actually it would depend on the time at which you are examining in the West African subregion. If you are looking at groundnut during the dry season, high soil temperatures may become a major factor. But during the rainy season, our experience in Nigeria shows that you may actually have problems with low temperatures.

C. K. Ong:
This is a very good remark. For example, with sorghum in some areas, low soil temperatures are a problem. This has been illustrated for Zimbabwe by Dr. Williams.

S. M. Virmani:

I was very much encouraged by your remarks on drought. I think with the initial work that we have done at ICRISAT Center, we should now split drought work into temperature and water response and look at these two separately.

C.E. Simpson:

Some wild species have growth cycles shorter than cultivated groundnut varieties.

R. W. Gibbons:

a. I think that breeding for earliness is definitely necessary. By using Chico, which has small seeds, it is possible by normal breeding procedures to increase seed size without resorting to backcrossing. This has been done at ICRISAT Center and in Oklahoma.

b. We should also look at photoperiod effects. We have some preliminary evidence that although Chico is extremely early in India, some 70-75 days, preliminary results from Botswana show that it is later than some Spanish cultivars grown in that country.

c. We should also be careful about Chico because there are quite a lot of variations within it. Many cultivars are called Chico. We have a number of accessions of Chico at ICRISAT Center and they do vary quite a bit.

d. There are other sources of earliness than Chico. The germplasm has not been exploited so far. There are some Spanish cultivars that have better agronomic characteristics than Chico. I think we have not exploited the Valencia groundnut. We have always looked at the Spanish variety. For earlier types, Valencia holds promise.

e. As far as mutogenesis is concerned, we have done some work at ICRISAT Center using Chico and some of the early derivatives, and treated them with chemical mutogens. We cannot say whether this has been successful so far.

f. A comment on your recurrent breeding program. I think it is an excellent idea. It has been exploited in the U.S. in Virginia. It is not easy because a number of crosses need to be made and crossing is not easy in groundnut. I think the essential thing is to get more than one generation in a year. In North Carolina, for example, they grow the progenies in the field during the rainy season, grow a population in the greenhouse during a second season, and then they send the nurseries to Puerto Rico during winter and get a third generation. Because peanuts are self-pollinated, recurrent selection is difficult, but holds promise if you have the time and resources.

J. L. Khalfaoui:

The method we have adopted consists of raising an off-season generation in Botswana to ensure F_2 seed production which is used for selection during the rainy season in Senegal.

R. W. Gibbons:

It depends on the other parents that you use. We have some lines that will mature at the same time as Chico. What you have to look for is the economic yield in a certain growth period. We have used a staggered harvesting system. What you must look for is the maximum number of mature kernels that you get at the same time as Chico. I think you can exceed the yield of Chico in 75 days using some of the hybrids.

J. L. Khalfaoui:

We are crossing Chico through pedigree selection. But in these programs and for reasons I already mentioned, we have little hope of obtaining varieties as early as Chico. What we do have are intermediate cycles of 80 to 85 days.

R. W. Gibbons:

Preliminary experience shows that in the Botswana region you may get photoperiodic effects. Your selection in that cycle may not be for earliness. I think you may have to find an area that may give you a photoperiodic effect similar to Senegal.

J. H. Williams:

a. In the selection for earliness, we see varieties that give an appreciable yield at 70 days, but they have the ability to carry on adding to that yield. So you have a variety or a system which has a flexible maturity period. It is not reaching what would be classically called a mature crop. It is giving the farmer something very early and has the ability to respond to added season length if it is available. I think this flexibility within the system has considerable merit when you see the variability in the environment.

b. One of the main attributes of Valencia is that they have lots of kernels in each pod and one of the major advantages is that they can, by virtue of this, very rapidly establish the sink that they are going to fill. This means that within the context of establishing earliness, they have the advantage that a few pods can have twice the sink effect that the same number of pods on a Spanish type would have.

J. L. Khalfaoui:

Rooting is an essential mechanism in the sense that it controls water supply. It is also true that water saving, to limit transpiration, is essential under drought conditions.

M. Frere:
As you have mentioned, transpiration is a delicate trait to determine for drought adaptation. We rather believe in characters associated with rooting, not only for groundnut but also for other crops.

C. K. Ong:
I would like to respond to Dr. Frere's remark about looking for deep-rooting varieties. At ICRISAT Center we have now established a soil-depth gradient which allows you to look at deep-rooted cultivars without actually looking at roots. If you have a gradient from 0.5-2 m for instance, and a cultivar fares better at 1.5 m when compared to others, then we can select this easily without having to extract the roots.

C.E. Simpson:
With regard to your backcrossing program, my comment relates first as a caution and second as an encouragement. The caution relates to what Ron Gibbons said: be very certain of your selection criteria for your parents. I'm sure the backcrossing program with *Arachis* can be a success.

C. K. Ong:
Could you start the screening for the heat tolerance much earlier than 56 days after sowing?

D. L. Ketring:
One of the reasons I don't start earlier is because the plants are too small. We can't get sufficient leaf material to test.

C. K. Ong:
The work on heat tolerance with sorghum indicates that the environment during seed maturation has a profound effect on seedling heat tolerance. Do we have this evidence for groundnut?

D. L. Ketring:
We have not looked at that.

J. J. Owonubi:
You have taken a close look at plant hydration and heat tolerance together. Are these not related in any way to drought tolerance?

D. L. Ketring:
I think we are in a situation where we have a confounding relationship between heat and drought tolerance. I think we have to look at both of these in order to come up with a variety that is tolerant to both environmental extremes.

J. J. Owonubi:
I notice that you took canopy temperatures. Were you able to look at canopy temperatures of different varieties?

D. L. Ketring:
We did this for 2 years but found no significant differences between genotypes. We found significant differences between the irrigated and rainfed treatments. If we include the vapor-pressure deficit as is being done with the recent methods of looking at canopy temperatures as explained by Dr. Kanemasu, I think we may come up with something better.

J. H. Williams:
You have measured roots in a large number of groundnut varieties. Would you care to comment about the relationships or benefits that you might see that are associated with the rooting patterns in terms of the amount of water extracted by the plant?

D. L. Ketring:
We measured lengths, numbers, volumes, and dry weights. We attempted to use the neutron probe in the field to see if we can find significant differences between genotypes. We compared plants with long roots with large volumes and large numbers of roots. Under the compact soil conditions with which we are working, I have not been able to see any significant differences among any of the factors we are looking at. The only encouraging aspect is the differences in the ability to transport water through the stems, i.e., increased sap flow under stress conditions.

N. R. Yao:
My question is about methodology. You mentioned that you used control tubes in an area where you did not have any plants. How many replications did you have to ensure that you had the same water content?

D. L. Ketring:
We put one control tube in each block. The plots were 30 by 80 ft. wide.

R. W. Gibbons:
Did you attempt to correlate the root growth and root volume in the tubes to the growth of the cultivars in the soil?

D. L. Ketring:
We measured them in two different places.

C. K. Ong:
If you were talking about a soil that has a low amount of water, I do not think it makes any difference even if you have deep-rooting cultivars. They will get all the water out. Perhaps you will see bigger differences in a deeper soil.

D. L. Ketring:
In Florida, roots were shown to go up to 240 cm in approximately 120-130 days. They grow deeper in sandy soils. In heavy clay soils, rooting potentials do not show up.

Session IV

Climate and Groundnut Production

Chairman: O.D. Smith
Co-chairman: G. Faustin

Rapporteur: J. Werder

Aflatoxine, rosette et rouille de l'arachide Environnement climatique propice à leur présence et développement

C. Picasso[1]

Résumé

Le développement des maladies des plantes est très souvent lié à différents facteurs climatiques. Ces maladies ont en effet pour cause des organismes vivants dépendant eux-mêmes de ces facteurs pour croître, se multiplier et se propager, soit directement, soit par des hôtes intermédiaires.

Trois affections de l'arachide en Afrique de l'Ouest, graves pour leur incidence sur les rendements ou la qualité de cette culture, sont envisagées ici.

*La contamination des gousses puis des graines par un champignon du sol, l'*Aspergillus flavus *L., générateur d'une substance très nocive pour la consommation tant humaine qu'animale, l'aflatoxine, est ainsi liée aux facteurs climatiques. La contamination au champ est notamment aggravée par des conditions de sécheresse en fin de cycle.*

La rosette est une maladie virale, véhiculée et transmise par un Aphis. Son développement et sa propagation sont en relation directe avec ceux de l'insecte, qui résultent eux-mêmes de conditions climatiques assez précises au point de vue température et humidité.

La rouille de l'arachide, maladie d'origine assez récente en Afrique de l'Ouest mais qui s'est rapidement étendue, est également due à un champignon, Puccinia arachidis *S., dont la forme de multiplication a pourtant une viabilité très courte sous climat tropical. La dissémination des urédospores, leur libération passive, leur transport par le vent à partir du foyer et les conditions d'une contamination sont présentés. En l'absence, jusqu'à ce jour, de la découverte d'hôte intermédiaire, qui permettrait d'expliqer la permance de l'existence de foyers à proximité des cultures, l'hypothèse actuelle est que cette maladie ne se perpétue que par la présence continue de pieds d'arachide sur le terrain soit par regermination au champ des restes de récolte soit par des cultures d'intersaison.*

Une bonne connaissance de l'environnement climatique de ces affectations qui est, pour certains paramètres, relativement strict, permet d'estimer les risques encourus et de déclencher des actions de protection. Elle permet aussi de limiter les dégâts de ces fléaux par l'application des méthodes de cultures telles que les parasites ne puissent trouver sur les plantes des conditions satisfaisantes pour leur développement,en attendant que ne soit mise en place la seule méthode de lutte vraiment efficace et à la portée de tous les cultivateurs l'utilisation de variétés résistantes.

Abstract

Aflatoxin, Rosette, and Groundnut Rust—the Climatic Environment that Promotes their Presence and Development: *The development of plant diseases is often linked to different climatic factors. These diseases are caused by living organisms that depend on climatic factors to grow, multiply, and propagate either directly or through hosts.*

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT.

The paper deals with three groundnut diseases in West Africa that are detrimental to yields and quality of this crop.

The infection of pods and seeds by a fungus Asperigillus flavus *L. that generates aflatoxin, a harmful substance for human and animal consumption, is linked to climatic factors. Field infection is increased by drought at the end of the growing cycle.*

Rosette is a virus disease transmitted by an aphid. Its development and propagation are directly related to those of the insect, which in turn result from well-defined climatic conditions, notably temperature and humidity.

Groundnut rust, a fairly recent but fast-developing disease in West Africa, is also caused by a fungus, Puccinia arachidis *S. This fungus has, however, a short viability period for its development in tropical climate. The spread of uredospores, their release, and transport by the wind and the conditions for infection are presented. Till now no intermediary host has been identified, which could explain the permanent existence of infection sources near cropped areas. The present hypothesis is that this disease is transmitted only through the continuous presence of groundnut stalks in the field, by regermination of the crop, or through interseason crops.*

A good knowledge of the agroclimatic environment that affects these diseases, well defined for certain parameters, facilitates assessment of risks and of the need to take protective measures. It also cuts down the loss caused by these diseases through appropriate cropping methods, so that the parasites do not encounter satisfactory conditions for their development on these plants. This is, however, an interim solution that awaits the use of resistant varieties, the only really effective method of control that could be employed by all farmers.

Introduction

Les maladies des plantes ayant pour cause des organismes vivants, que ce soit des virus, des bactéries, des champignons, des insectes ou des nématodes, dépendent de paramètres climatiques qui, outre le fait qu'ils déterminent l'existence des plantes concernées elles-mêmes, ont une influence marquée sur les modes de vie et de reproduction de ces organismes.

La majorité de ces maladies ont un cycle assez complexe faisant intervenir un enchaînement important de facteurs qui les déterminent. En plus de l'agent causal lui-même, interviennent souvent des agents vecteurs ou des hôtes intermédiaires. Ces agents et hôtes sont influencés différemment par le climat et ce n'est donc que dans de successions de valeurs, assez bien déterminées, des facteurs qui le compose, que ces cycles peuvent se dérouler.

On pourrait en penser que des barrières nombreuses devraient limiter considérablement l'occurrence de ces maladies. Cependant, la diversité des phénomènes naturels est très importante et d'autre part ces organismes sont très bien adaptés avec soit des formes de survie très résistantes ou des modes de dissémination permettant une extension rapide et importante.

Pour illustrer cela nous traitons ci-après de trois affections de cultures d'arachide pouvant être particulièrement graves, notamment en Afrique, et verrons comment la connaissance et l'environnement climatique qui leur est propice peut dans une certaine mesure contribuer à mettre au point des méthodes de lutte.

La vocation de l'Institut de recherche pour les huiles et oléagineux (IRHO) travaillant dans les structures de l'Institut sénégalais de recherche agricole (ISRA) et de l'Institut burkinabè de la recherche agronomique et zootechnique (IBRAZ) au Burkina Faso, était la création de variétés résistantes à ces maladies. Mais parallèlement à ces travaux certaines précisions ont pu être apportées concernant leur environnement. Les études plus fondamentales présentées ci-après ont été réalisées par Savary (1983, 1985a, 1985b) (rouille) at Zambettakis (1975, 1976, 1984) (*A. flavus* et rouille) avec qui nous collaborons pour cela.

Contamination par *Aspergillus flavus* L.

On trouve surtout les aflatoxines, substances toxiques élaborées par ce champignon, dans les productions d'origine tropicale. Ingérées par les animaux, elles se maintiennent dans leurs tissus, provoquent des hépatites aigües, des nécroses du foie et passent dans le lait (Adrian et Lunven 1969). Ces toxines ne sont pas liposolubles et donc pour l'arachide ne se trouvent pas dans l'huile, après extraction si la purification est suffisante, mais dans les tourteaux. Par ailleurs, on a pu établir certaines corrélations dans les régions tropicales productrices d'arachide et le cancer du foie chez l'homme.

Face à cela les pays européens, importateurs d'arachide ont réagi en interdisant l'introduction des tourteaux contenant plus de 50 ug kg⁻¹ d'aflatoxine.

Agent causal

Ce micromycète est un saprophyte et ne provoque pas de dégâts directs importants sur les cultures d'arachide. Il est présent dans le sol et très largement répandu sur l'ensemble du globe. Cependant sa présence sur les productions végétales ne signifie pas automatiquement que celles-ci renferment les toxines. En effet si le champignon peut se développer à des températures très variables, entre 10 et 45°C environ, la production de toxines n'apparaît que dans un intervalle de température plus étroit, entre 15 et 40°C et elle n'est réellement importante qu'à des températures de l'ordre de 30 à 35°C. Par ailleurs, la température conditionne l'intensité de la toxicité : plus elle est élevée, plus la proportion d'aflatoxines hautement toxiques (B2 et surtout B1) sera grande (Tab. 1). Enfin ce champignon requiert des conditions précises d'humidité pour se développer. Elle doit être au minimum de 85% dans l'air ou de 10 à 30% dans un substrat pour une température de 30°C. Cela explique que les productions végétales tropicales soient les plus touchées et à ce titre l'arachide constitue un support tout à fait propice au développement du champignon et à sa production de substances toxiques puisque les gousses renferment 30 à 35% d'eau aux environs de la récolte. Le champignon étant terricole, la contamination par pénétration peut donc avoir lieu dans le sol avant la récolte, lors du séchage au champ dans les andains ou les meules et se poursuivre dans les stocks.

L'étude de la mycoflore des gousses et des graines d'arachide au Sénégal (Waliyar et Zambettakis 1979) a montré la présence permanente de cet *Aspergillus*, prédominant même sur toutes les autres espèces. Par ailleurs des inoculations du sol (Darou) n'ont pas augmenté le taux de contamination. Il semble donc que ce taux de contamination du sol ne soit pas un facteur limitant pour l'infection des gousses d'arachide.

La gousse d'arachide est une barrière plus ou moins efficace à la pénétration du champignon (Tab. 2). On constate que son apparence et son intégrité sont des facteurs primordiaux (Gillier 1970). Une deuxième barrière est constituée par le tégument séminal de la graine (Zambettakis 1976). En effet, pour des variétés différentes montrant un taux identique de présence du parasite à l'intérieur de ces gousses, il y a des différences significatives à l'installation parasitaire sur les cotylédons. D'ailleurs pour toutes les variétés, les colonies progressent très facilement sur les cotylédons si ce tégument est enlevé. L'observation en microscopie électronique de la pénétration du mycélium dans le tégument montre que celle-ci est largement favorisée par les zones de moindre épaisseur et à plus forte raison de rupture (Waliyar et Abadie 1978).

Tout ce qui contribue à détériorer l'aspect et la qualité des gousses et graines, attaques de parasites, dégâts des outils, maturation difficile, favorisera donc la pénétration du champignon. En dehors de l'aspect variétal qui intervient de façon importante (Zambettakis et al. 1977), et permet justement d'envisager la sélection de variétés beaucoup moins sensibles, de nombreuses expériences ont montré l'influence considérable des conditions météorologiques durant la culture et surtout lors de la phase de maturation des gousses d'arachide, sur les teneurs des graines en aflatoxine.

Effets de la sécheresse en fin de cycle

Dans les conditions du Sénégal (saison des pluies de 3 à 5 mois du Nord au Sud suivie d'une saison sèche très marquée), il est apparu que la contamination par ce champignon, de loin la plus importante, est celle qui a lieu dans le sol, en fin de cycle de l'arachide. Après la récolte, les plantes sèchent rapidement sur le champ au soleil et la teneur en eau des graines tombe rapide-

Tableau 1. Sécrétion d'aflatoxines en fonction de la température sur des graines inoculées (ug 100 g⁻¹).

Température d'incubation	Aflatoxine B1	Aflatoxine G1	Aflatoxine B1/G1	Aflatoxine B1 + G1
20°C	460	4000	0,11	4460
30°C	5750	10000	0,57	15750

Tableau 2. Taux d'aflatoxines en ug kg^{-1} en fonction des catégories de gousses pour plusieurs lots contaminés à Darou, 1969.

	Lots							
	1	2	3	4	5	6	7	8
Bonnes gousses	<25	<25	<25	<50	<25	<25	<25	<25
Attaquées par termites	50	330	60	2600	500			
Attaquées par iules	100	100	2000		250	1250		
Gousses fendues	1000		12000		800	1500		
Bouts noirs					<25	120	<25	
Immatures								<25

Source: Gillier 1970.

ment en dessous de 10%. Le Tableau 3 montre que l'infestation augmente beaucoup entre le 25e et le 15e jour avant la récolte et ensuite se stabilise (Zambettakis 1975). Ce n'est que dans les derniers prélèvements que l'on trouve un nombre notable de colonies. Un décorticage en aseptie et 10 jours d'incubation montrent qu'une contamination secondaire est cependant possible s'il y a réhumidification.

Par contre, une irrigation débutant après l'arrêt des pluies et maintenue jusqu'à 10 jours avant la récolte limite considérablement les infestations des champignons (Fig. 1).

Suite à ces expériences préliminaires, des essais ont été réalisés aux champs sur deux stations du Sénégal (Zambettakis et al. 1982): Bambey dans le centre-nord, avec une pluviométrie de 650 mm sur 104 (±34) jours et Darou plus au Sud, avec une pluviométrie de 700 mm sur 115 (±18) jours. Plus que la quantité, c'est la longueur et l'irrégularité des pluies qui différencie les deux stations. Les variétés généralement cultivées dans la première ont normalement un cycle de 90 jours (hâtives) ou de 105 à 110 jours (semi-tardives) et de 120 jours (tardives) dans la seconde.

Cependant pour ces essais, on a maintenu en commun sur les deux stations un groupe de 12 variétés ayant des caractéristiques très diverses de type, de cycle, de grosseur des graines, de résistance à la sécheresse, et à la contamination à *A. flavus* en inoculation artificielle. Sur chaque station deux dates de semis sont réalisées. Le deuxième semis est décalé normalement d'un mois, moins si le premier est tardif à cause du retard des pluies et il est en principe exposé à une sécheresse en fin de cycle.

Les résultats obtenus (Tab. 4) montrent que l'influence de cette date de semis est en effet importante pour la contamination naturelle. Ainsi pour les trois années et les deux stations le semis de deuxième date est plus contaminé cinq fois sur six.

A Bambey en 1977, c'est le premier semis qui semble avoir été le plus touché, en fait les résultats sont très différents selon le type de cycle. Ainsi pour les semi-tardives la contamination est la plus forte pour le deuxième semis. L'analyse de la pluviométrie de 1977 permet de faire des hypothèses pour expliquer ces différences de comportement. Les pluies ont été très réduites (15 mm sur 20 jours) et à partir du 15 septem-

Tableau 3. Contamination de l'arachide par *A. flavus* au cours de son cycle. (Darou, 1973: 425,5 mm de pluies, avec arrêt 35 jours avant la récolte, pour une moyenne de 700 mm).

Nombre de jours par rapport à la récolte	-25	-20	-15	-10	-5	Récolte	+10
Nombre moyen colonies sur 200 gousses	5,5		10,6	9,2		11,31	
Nombre moyen colonies sur 1500 graines	0	0	1		11	39	88[1]

1. Après incubation.
Source : Zambettakis 1975.

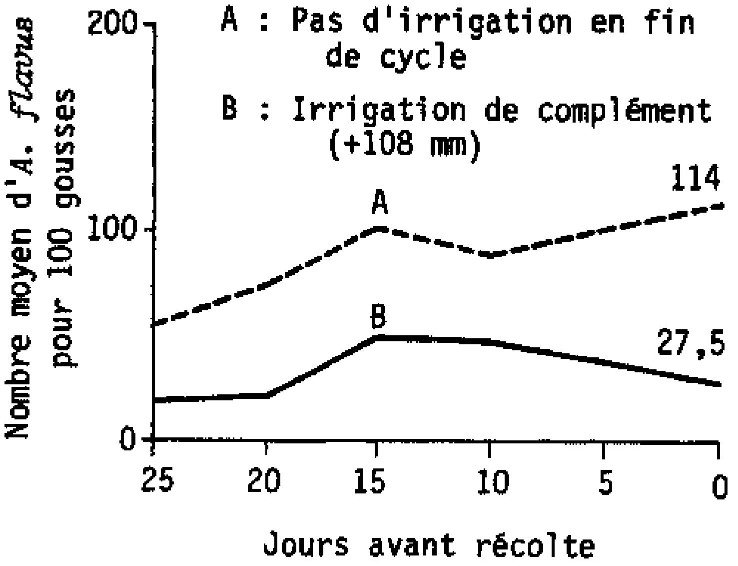

Figure 1. Nombre moyen de colonies d'*Aspergillus flavus* pour 100 gousses de 20 variétés selon la date de prélèvement. Arrêt des pluies (425,5 mm) 35 jours avant la récolte (Source : Zambettakis 1975).

bre toutes les variétés ont fortement souffert. Puis le 14 octobre il y a eu la dernière pluie de la campagne de 41,3 mm. Les hâtives du premier semis étaient déjà récoltées, après donc une sérieuse sécheresse d'où leur forte contamination, alors que celles du deuxième semis ont pu profiter de cette pluie. Pour les tardives du premier semis les gousses étaient déjà en fin de maturation donc de dessèchement et il est possible que la pluie du 14 octobre, en les imbibant à nouveau ait provoqué des distorsions et des cassures des fruits, favorisant la pénétration du champignon. Par contre pour celles du deuxième semis, récoltées plus d'un mois après cette dernière pluie, on pense que l'humidité du sol était tombée à un niveau trop bas pour que l'*A. flavus* ait pu contaminer les arachides.

Tableau 4. Contamination naturelle des graines d'arachide par *A. flavus*.

Lieu	Bambey			Darou		
Année	1977	78	79	77	78	79
	Semis 1re date					
Date semis	8/7	21/7	11/7	8/7	28/6	26/6
Valeurs[1]	23,5	39,4	9,2	9,9	14,1	3,2
	Semis 2e date					
Date semis	22/7	31/7	20/7	21/7	26/7	26/7
Valeurs[1]	9,01	42,5	20,3	12,2	30,5	18,1

[1] En p. 1000 à partir de 300 gousses × 12 variétés.
Source : Zambettakis et al. 1982.

Si l'on regroupe les résultats de ces trois années (Tab. 5) on s'aperçoit qu'il existe à Bambey comme à Darou, un gradient très important de contamination des gousses comme des graines entre les variétés hâtives, semi-tardives et tardives. Plus le cycle de la variété est long, plus elle est touchée, ce qui est logique en regard de ce qui vient d'être vu. Les variétés à cycle long subissent plus les effets de sécheresse en fin de cycle. Cette différence se fait d'autant plus sentir que le manque d'eau en fin de saison est plus prononcé. Ainsi à Darou dont la pluviométrie a été en moyenne de 135 mm supérieure à Bambey, les contaminations moyennes sur les graines y sont-elles nettement inférieures. La comparaison des types de cycle entre les deux stations confirme également cet effet de fin de cycle : il n'y a que peu d'écarts pour les hâtives entre les deux stations, cet écart provient essentiellement des semi-tardives et tardives. Par ailleurs le fait que les taux de contamination sur gousses soient sensiblement équivalents entre les deux stations et que le facteur variétal n'intervienne pas puisque ce sont les mêmes variétés dans les deux cas (sensibles et non sensibles), alors qu'il y a des différences importantes de contamination des graines permet de dire que c'est une altération supérieure des gousses et des téguments, à Bambey où les conditions de maturation sont plus difficiles, qui facilite la pénétration et l'installation du champignon.

L'inoculation artificielle réalisée sur les graines provenant de ces différents traitements montre d'ailleurs des résultats en accord avec la contamination naturelle.

Effets de la température

Des expériences d'autres chercheurs (Wilson et Stansell 1983; Sanders et al. 1981, 1984) ont corroboré ces résultats par la suite. Elles ont montré en plus que la température du sol pendant la phase de sécheresse en fin de cycle devait être au minimum de 25 à 27°C pour que la contamination ait lieu. Cette précision est importante à connaître pour des pays comme les Etats-Unis pour évaluer les risques; en Afrique cette condition est cependant pratiquement toujours réalisée.

Possibilités de limiter les teneurs en aflatoxine

Un moyen très efficace serait donc d'effectuer des irrigations de complément sur les cultures, notamment en fin de cycle. Cela est évidemment très

Tableau 5. Taux de contamination naturelle des gousses et des graines d'arachide par *A. flavus*.

Station (Pluviométrie)	Types de variété	Contamination naturelle des gousses[1]	Contamination naturelle des graines[1]
Bambey (530 mm)	Hâtives	32,8	13,9
	Semi-tardives	81,3	27,3
	Tardives	93,6	31,2
	Moyenne	69,2	24,1
Darou (665 mm)	Hâtives	32,6	10,4
	Semi-tardives	79,7	14,1
	Tardives	87,9	19,7
	Moyenne	66,8	14,7

1. En p. 1000 à partir de 300 gousses × 4 var. par type × 3 ans.
Source : Zambettakis et al. 1982.

onéreux pour les cultivateurs des pays en voie de développement. Cette technique peut cependant être envisagée dans le cas de spéculations très rémunératrices (arachide de bouche ou de confiserie).

Un moyen plus simple à mettre en oeuvre est d'utiliser des variétés dont les cycles correspondent exactement aux régimes pluviométriques de la région concernée, de semer le plus tôt possible, récolter exactement à la maturité, mettre à part les pieds désséchés avant la récolte et ne pas mélanger les restes en terre à la récolte elle-même. Il faut savoir également que 75% de l'aflatoxine des lots contaminés viennent des gousses percées par les iules et les termites, dont les attaques sont elles aussi favorisées par les fins de cycle sèches. Le triage de ces gousses permet donc de diminuer les teneurs des lots.

Enfin l'utilisation de variétés peu sensibles, en association avec les précédents, constituera le moyen le plus efficace de limiter la contamination des récoltes. Les expériences dont ont été tirés les résultats ci-dessus avaient aussi pour but de voir s'il existait un facteur variétal et elles ont été sur ce plan très concluantes. A l'heure actuelle, certaines variétés déjà largement diffusées en Afrique de l'Ouest se sont montrées peu sensibles et beaucoup sont en cours de création.

Rosette et pucerons de l'arachide

Signalée pour la première fois dans l'ex-Tanganyika en 1907, puis au Sénégal, au Congo, à Madagascar, la rosette de l'arachide s'est depuis répandue dans toutes les zones à pluviométrie importante de l'Afrique. En 1975 cette maladie s'est manifestée sur un million d'hectares au Nigeria entraînant une baisse de production estimée à 560 000 tonnes.

Symptômes, agent causal, agent vecteur

Il existe deux formes connues de cette maladie, la *rosette chlorotique* et *la rosette verte*. Toutes les deux se traduisent par un rabougrissement du plant d'autant plus général que l'attaque a lieu précocement. Dans la forme chlorotique, les folioles prennent une teinte jaune pâle uniforme, ou marbrée de vert. La forme dite verte est moins répandue et ne montre pas de décoloration du feuillage. Dans les cultures, les plants d'arachide atteints de rosette sont groupés en taches arrondies, la maladie s'étendant par zones concentriques à partir d'une touffe initialement infectée. Si on ne note aucune variation des pièces florales, la plante ne forme plus de fruits à partir du moment où elle est atteinte, de sorte que si l'infection est précoce, la récolte est nulle.

L'origine virale de cette maladie a été démontrée, même s'il n'existe que peu d'études sur le ou les virus. Elle est en effet transmissible par greffage mais non par la graine ni le sol. Des particules de virus ont pu être isolées et inoculées. De nombreuses plantes-hôtes, restant saines ou non, existent pour ce ou ces virus.

L'agent vecteur est un puceron : *Aphis leguminosae* Theo. (Syn. *Aphis craccivora* Koch). C'est lui-même un parasite de l'arachide pouvant causer de graves dégâts dans les cultures, par prélèvement de sève entraînant une moindre résistance aux déficits hydriques, par action irritative et toxique, par sécrétion de miellat provoquant le développement de champignons, et de fumagine. Les piqûres répétées, notamment au niveau du collet où les pucerons se concentrent pour se protéger des aléas climatiques, y provoquent des nécroses, des déformations et des réductions des racines et de la fructification.

Incidence sur la production

Une étude a été réalisée en 1959 à Niangoloko dans le sud du Burkina sur 1200 pieds d'arachide en utilisant des souches de pucerons virosés, l'apparition de la maladie étant notée tous les trois jours (Berchoux 1960), la récolte a été faite 150 jours après le semis. La Figure 2 rend compte de l'évolution des rendements moyens en grammes de gousses par pieds en fonction de cette date d'apparition. Ainsi pour une variété semi-érigée, la récolte est pratiquement nulle si la rosette se manifeste sur les pieds d'arachide avant le 40e jour après le semis. Son effet est très faible au delà du 101e jour.

Des observations réalisées au Niger entre 1975 et 1980 montrent qu'en l'absence de rosette, la présence de pucerons se traduit par des chutes de rendement importantes (Mayeux 1984).

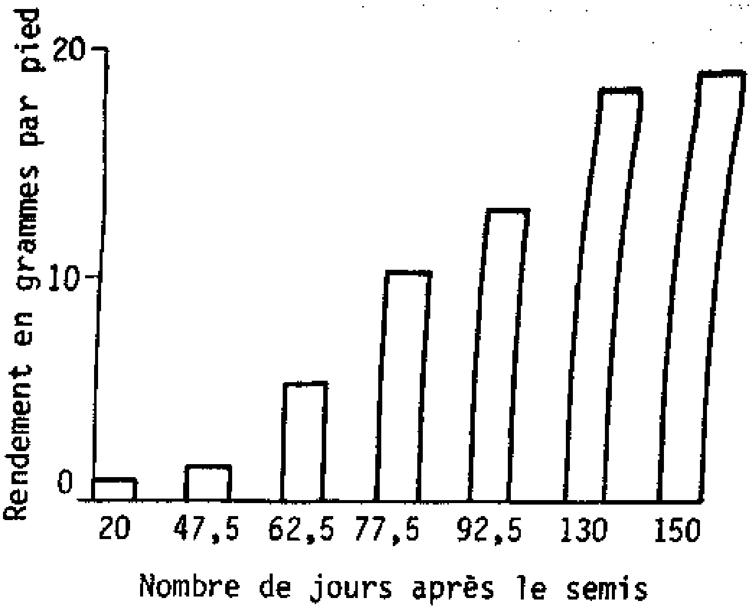

Figure 2. Rendement de l'arachide en fonction de la date d'apparition de la rosette dans le cycle pour une variété tardive (Source : Berchoux 1960).

Conditions de présence et de développement

Le puceron vecteur est dispersé sur les cinq continents, mais c'est principalement en Afrique que l'on rencontre la rosette. Elle est présente partout où les conditions climatiques permettent à la fois aux pucerons et aux plantes-hôtes du virus de survivre durant la saison sèche (nappe d'eau permanente à proximité ou humidité résiduelle suffisante), que ce soit pour les zones tropicales, subtropicales ou équatoriales. Pour les régions à une seule saison des pluies, l'expérience a montré que la hauteur d'eau minimum doit être de 900 mm pour que les risques soient permanents. Cependant, à partir de là, la maladie peu s'étendre largement plus au nord selon les années, dans des régions où les dégâts des pucerons seuls se font sentir régulièrement.

Le comportement de ce puceron est donc important à connaître et lié aux conditions climatiques.

Dans la zone tropicale, il n'y a que des femelles, soit aptères, soit ailées, qui se reproduisent toute l'année par voie parthénogénétique. Il est par ailleurs ovovivipare et donc extraordinairement bien adapté pour exploiter et coloniser de façon très rapide les plantes-hôtes.

La formation des ailés est dictée par plusieurs facteurs qui sont l'effet de groupe (stimulation tactile), la baisse de la qualité nutritionnelle de la plante-hôte et les conditions climatiques.

Le développement optimal de *Aphis craccivora* résulte de l'humidité relative qui doit se situer vers 65% pour une température comprise entre 24 et 28,5oC. Cette température prime également sur la fécondité car le nombre de larves pondues est fonction du poids des adultes et ce poids décroît en général d'autant plus que les températures sont basses. Le puceron se multiplie donc pendant la saison humide. S'il est exposé directement à la lumière la valeur de ses caractéristiques biologiques diminuent.

A Niangoloko, dans le sud-ouest du Burkina, on a pu montrer que la multiplication de la population aphidienne n'est importante que 35 jours après le premier passage de l'humidité minima diurne au dessus de 66% pendant une décade. On s'est rendu compte que les fortes tornades empêchent le vol des pucerons et peuvent même les détruire si les plantes sont jeunes et ne présentent pas un feuillage suffisamment important pour les protéger.

Protection des cultures

Le développement des pucerons est tel que les interventions doivent se faire avant la phase explosive. La prévision des infestations devra être axée sur trois domaines :

- Observations directes en culture;
- Surveillance des vols par piégeage;
- Interprétation des données climatiques.

Les moyens de lutte font appel aux techniques culturales, la protection chimique et au choix de variétés en cas de risque de rosette :

- Semis précoces permettant un développement suffisant des plantes et réduisant les zones nues des interlignes et l'arrivée au stade floraison avant l'apparition des pucerons.
- Semis serrés qui limitent la pullulation des insectes et les micro-turbulences entre les rangs favorisant l'atterissage des ailés.
- Protection chimique à bon escient, afin d'en limiter le coût (d'où l'intérêt d'un bon réseau d'alerte), par des produits systémiques à longue rémanence pour que le contrôle soit très efficace entre la levée et le 40e jour.
- Utilisation de variétés résistantes à la rosette dans les zones susceptibles d'être touchées. C'est dans ce cas le seul moyen de lutte radicale, et le moins onéreux. Depuis plusieurs années toute une gamme de variétés de divers cycles et aptitudes ont été mises au point et sont disponibles. Leur utilisation généralisée depuis une vingtaine d'années dans le sud du Burkina Faso a permis d'y éradiquer pratiquement cette maladie qui avait auparavant anéanti les cultures d'arachide (Dhery et Gillier 1971; Gillier 1978).

Rouille due à *Puccinia arachidis* S.

La rouille de l'arachide fut signalée pour la première fois au Paraguay en 1881. Elle s'est par la suite très largement étendue en Amérique du Sud et en Amérique centrale. Au début du siècle elle fut signalée à l'Ile Maurice, en Chine et en Union Soviétique, mais y resta d'une importance limitée. C'est à partir des années 70 qu'elle prit une extension mondiale s'étendant dans toute l'Asie, touchant l'Australie et toute l'Afrique au sud du Sahara. L'incidence sur les rendements peut être très forte : 75% de baisse au Texas en 1971, et 50% couramment, dans la plupart des zones touchées.

En Afrique de l'Ouest, elle est apparue en 1976 au Nord Nigeria (McDonald et Emechere 1978) et fut trouvée dès l'année suivante en Côte d'Ivoire, où elle fut signalée par M. Lourd et S. Digbeu du laboratoire de phytopathologie d'Adiopodoumé au sud du Burkina Faso et du Sénégal (IRHO et Zambettakis 1984) puis remonta jusqu'aux zones à isohyètes 600 à 700 mm. Dans ces dernières, elle ne se manifeste cependant pas en permanence et de toute façon son incidence sur les rendements y est négligeable, d'autant plus que l'on y cultive des variétés hâtives pour lesquelles elle ne survient qu'en fin de cycle. Par contre, dans les régions comme le Sud Burkina (IRHO) où elle sévit à l'état endémique, la baisse de rendement due à cette maladie est régulièrement importante (Tab. 6).

Symptômes de la maladie

La rouille de l'arachide est facilement identifiable aux pustules brun-orangé qui se développent à la surface inférieure des folioles. Lorsque les conditions climatiques lui sont favorables, les pustules peuvent atteindre toutes les parties aériennes de la plante exceptés fleurs et gynophores. Les feuilles infestées se nécrosent et se dessèchent tout en restant attachées sur la plante assez longtemps.

Le champignon parasite, d'une part diminue l'activité photosynthétique de la plante en réduisant la surface foliaire active et d'autre part soustrait aux gousses, pour son propre développement, une partie des substances élaborées. Il entraîne en outre une perte considérable de sève en raison de l'éclatement de l'épiderme par les pustules (Savary 1983; Zambettakis 1979).

Formes du parasite

Normalement ce type de champignon a un cycle complexe dans lequel il intervient sous plusieurs formes et fait intervenir plusieurs hôtes. Cependant pour *Puccinia arachidis*, sur cinq stades, seul le stade 2, urédospores, est couramment observé. Le stade 3, téleutospores, a été cependant rencontré par quelques auteurs sur la forme cultivée et des formes sauvages de l'arachide mais en Amérique latine et non en Afrique. Cela peut sûrement être relié au fait que l'on ne connaît pas non plus d'autre hôte de ce parasite alors que les Pucciniées sont hétéroxènes pour leur très grande

Tableau 6. Influence de la rouille sur les rendements (kg ha^{-1}) de l'arachide (var. RMP 12) au Sud du Burkina Faso.

Année	1978	1979	1980	1981	1982	1983	1984
Pluviométrie (mm)	1245	1135	1302	1175	1030	865	914
Date de semis	10/6	5/6	26/6	30/5	5/6	31/5	27/5
Date 1er sympt.	2/9	27/8	2/9	17/8	5/8	1/8	10/8
Témoin	700	1820	580	2143	1575	2468	2562
Daconil (5 trait.)	1075	3780	1054	2882	2208	2688	2950
Augmentation %	54	108	82	35	40	9	15
CV %	-	16,5	25,6	13,5	11,9	9,3	9,9
PPDS (5%)	-	442	313	385	282	n.s.	306
PPDS (1%)	-	589	420	517	385	-	-

Source : IRHO (Burkina Faso).

majorité. Des prospections et des inoculations sur un grand nombre de plantes sauvages, herbes ou arbustes, n'ont pas donné jusqu'ici de résultats positifs (Subrahmanyam et McDonald 1983).

Survie

Les urédospores de ce champignon ont une duré de vie très courte dans la nature, une fois libérées des pustules. Des expériences confirmées sur plusieurs années et menées par l'ICRISAT, font état d'un potentiel de germination des spores de 70% au moment de la récolte de l'arachide, de 30% après une semaine et de 1% seulement 15 jours après. Par ailleurs des tests en laboratoire ont montré qu'elles devaient être conservées entre 16 et 18°C pour que se maintienne leur faculté germinative.

Libération et dissémination

La libération des urédospores est passive, elles se détachent au fur et à mesure de leur maturation et se séparent progressivement de leur support. Aussi légère soit-elle, la vibration des feuilles suffit à rompre le contact de l'urédospore avec la base de son pédicelle. Cette libération est favorisée par la pluie ou la rosée en ce sens que les maxima de libération se produisent avec l'ensoleillement et la remontée de la température qui y fait suite. La turbulence de l'air balaie à son tour et arrache ces spores qui s'installeront "plus loin" et pourront germer sur d'autres feuilles. Ainsi libérées de leur base, les urédospores sont transférées par le vent et peuvent être déposées tout près de l'endroit de leur formation (attaques en touffe dans les champs ou dans des endroits très éloignés, selon la turbulence et la vitesse du vent (Zambettakis 1979).

Les études menées par Mallaiah et Rao (1982) à l'aide d'un capteur de spores montrent que les pics de concentration des spores dans l'air au-dessus de cultures infestées ont lieu à des moments et dans des conditions assez précises. La libération a ainsi lieu surtout entre 10 et 14 h, elle est négligeable ensuite, les plus fortes libérations se font pour des températures comprises entre 28 et 32°C et des humidités relatives de 60 à 80%. Les interventions dans les cultures (irrigation, désherbage, récolte) augmentent énormément, mais pendant peu de temps les concentrations de spores dans l'air.

La dissémination des spores par le vent suit quant à elle des lois bien définies (Zambettakis 1979). Une fois en suspension dans l'air, l'urédospore obéit à deux forces : la vitesse du vent (ascendant ou descendant), rarement horizontale et la vitesse de chute considérée en accalmie. Cette accalmie totale qui limiterait la dispersion du contenu de l'urédosore autour de la tache foliaire n'existe cependant jamais. La turbulence de l'air compense largement la chute et la plus grande partie des urédospores suivent les courants ascendants au-dessus des cultures. Ainsi très théoriquement, une spore soumise à la seule poussée d'un vent de faible vitesse, par exemple de 25 km h^{-1} se déplace presque à la même vitesse et peut couvrir une distance de près de 1000 km en un peu plus de 2 jours, à 1000 m d'altitude. Un cas bien connu est celui de la rouille du blé qui peut se déclencher en Europe centrale à partir de foyers au Pakistan ou en Afghanistan.

Outre l'action constante du poids de la spore, plusieurs causes peuvent être à l'origine de sa chute. Les précipitations en sont une, importante.

En Afrique sahélienne et sud-sahélienne, les infestations qui ont lieu généralement fin juillet à début août peuvent ainsi provenir de zones plus au sud où les conditions climatiques sont différentes et permettent des cultures plus ou moins continues d'arachide ou de maintenir en vie des repousses après la récolte. Les cultures de contre-saison par irrigation ou dans les bas- fonds peuvent également contribuer au maintien permanent de foyers de contamination.

Contamination, développement, effet des facteurs climatiques

Une fois déposées sur les feuilles d'arachide, si le délai depuis leur libération des foyers est suffisamment court pour qu'elles soient encore viables, les urédospores peuvent alors contaminer de nouvelles plantes. Après déclenchement du processus de germination dans la spore, le tube germinatif apparaît et sort par un pore. Il peut s'allonger jusqu'à 10 à 20 fois le diamètre de la spore et dans le cas où durant son avancement il trouve un stomate, il y pénètre et l'infection est assurée (Zambettakis 1979).

Les conditions climatiques interviennent cependant d'une façon très importante et influencent considérablement aussi bien cette germination que le développement ultérieur du parasite.

Besoins en eau au moment de la germination

On pense souvent que la germination des spores sur les feuilles d'arachide ne peut se faire qu'en présence de gouttelettes d'eau, après une pluie ou en présence de rosée. Les expériences d'inoculation à sec (Savary 1985a) par un mélange de spores et de kaolin, sans aucune trace d'eau à la surface de ces feuilles prouvent qu'une humidité saturante suffit très bien pour assurer la germination. L'efficacité de l'inoculum, mesuré par le nombre des lésions obtenues par spore déposée est même dans ce cas nettement supérieure (possibilité d'existence d'un auto-inhibiteur de germination).

Effets de la lumière sur la germination

La lumière a un effet inhibiteur sur la germination. Pour qu'elle puisse se dérouler correctement, une phase nocturne doit avoir lieu après la contamination.

Effets de la température sur le développement du parasite

Résultats obtenus par Savary en 1983 (Savary 1985b) :

Germination et nombre de lésions par spore déposée

Le pourcentage de spores germées après 20 heures est maximal à 27°C et décroît de 80% pour 3° au-dessus ou 9° au-dessous (Tab. 7). Par contre l'efficacité de l'inoculum est assez stable entre 18 et 27°C (0,27 à 0,34 lésion par spore déposée), elle chute à 28,5°C et devient nulle à 30°C, même après 40 jours d'incubation.

Evolution des lésions, périodes de latence et d'incubation

Au-delà et en-deçà de 27°C, il apparaît un retard dans l'apparition des lésions et leur évolution est plus lente. C'est d'autant plus marqué que l'on s'écarte de cet

Tableau 7. Effets de la température sur la germination des spores et l'efficacité de l'inoculum de *P. arachidis*.

°C	18°C	22°C	24,5°C	25,5°C	27°C	28,5°C	30°C
G[1]	1:11,6	1:40,0	2:57,0	2:62,7	1:71,0 2:81,3 3:83,2	3:67,0	3:14,0
E[2]	1:0,286	1:0,278	2:0,337	2:0,274	1:0,274 2:0,266 3:0,269	3:0,109	3:0

1. G : % de germination sur 200 spores après 20 heures.
2. E : Nombre de lésions par spore déposée.

1, 2, 3 : Numéro de l'expérience.

Source : Savary 1985b.

optimum. Il y a ainsi accroissement des périodes d'incubation (durée inoculation à apparition des premiers symptômes) et de latence (durée inoculation à formation des premières spores) à mesure que l'on s'écarte de 27°C (Fig. 3).

Intensité de la sporulation et durée de la période infectieuse

Il y a une variation très significative des valeurs observées dans la sporulation évaluée au 30e jour, en fonction de la température (Tab. 8). De même la période infectieuse estimée par le dernier accroissement significatif du nombre de spores produites est la plus longue (26,5 jours) à 27°C. En-deçà, elle diminue mais assez lentement, mais chute brutalement au-delà (12,9 jours à 28,5°C).

Conclusion

La température de 27°C constitue donc un optimum pour la contamination, le développement et l'extension de la rouille de l'arachide. L'effet de la température sur l'allongement de la période de latence au-delà de cet optimum et en-deçà de 24,5°C, corrélativement à la diminution de la période infectieuse et de l'intensité de la sporulation permet ainsi de mieux comprendre le développement ou non des épidémies de rouille.

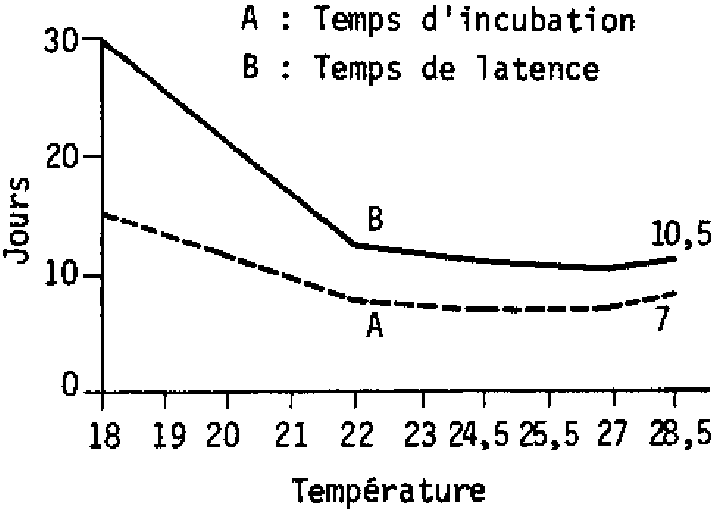

Figure 3. Evolution des temps d'incubation et de latence de *Puccinia arachidis*, suivant la température (Source : Savary 1985b).

Les observations que nous avons pu faire au Burkina Faso nous amènent à penser que la dissémination de la rouille est très large, et remonte très au Nord, couvrant pratiquement toutes les zones arachidières du pays. Cependant, le suivi de son évolution dans les cultures nous indique que les contaminations primaires, d'origine éolienne, sont quantitativement très faibles. De même l'enregistrement du potentiel mycosporifère de l'air à l'aide d'un capteur de spores (Spore trap de Hirst) ne nous a pas permis jusqu'à présent de déceler ces premières infestations (Zambettakis 1984). La date d'apparition de la maladie a toujours été déterminée par celle des symptômes sur les plantes. Dans les régions situées au sud où l'humidité est élevée et les maxima de température ne le sont pas trop, ces premières infestations sont suffisantes pour permettre ensuite à la maladie d'atteindre un niveau très important et préjudiciable, par contaminations successives à partir de ces premiers foyers. Par contre, plus au Nord, les conditions n'étant plus propices, la rouille reste généralement limitée à quelques pustules sur un petit nombre de pieds. On peut cependant penser que des modifications artificielles du climat au niveau de la culture comme celles qu'entraîne l'irrigation pourrait permettre son développement.

Les possibilités de lutte sont pour le moment réduites. La lutte chimique est efficace avec certains produits (chlorothalonil) mais son coût est très lourd d'autant plus qu'il faut un minimum de trois traitements pour assurer une protection suffisante pour les variétés à long cycle des régions les plus touchées (IRHO). La création de variétés résistantes est possible puisqu'il a été découvert, dans les zones d'origine de l'arachide, des plantes restant pratiquement indemnes de rouille. Elle est en cours pour l'Afrique de l'Ouest (Sénégal et Burkina Faso) mais est rendue

Tableau 8. Effets de la température sur la sporulation totale et la durée de la période infectieuse de *P. arachidis*.

	18°C	22°C	27°C	28,5°C
ST[1]	460 (±245)	17000 (±4100)	40500 (±69000)	11300 (±1700)
PI[2]	13,5	21,6	26,5	12,9

1. ST : Nombre total moyen de spores produites par pustule au 30e jour après inoculation.
2. PI : Période infectieuse estimée en jours.

Les valeurs sont suivies de leur intervalle de confiance à 95%.

Source : Savary 1985b.

très complexe notamment par le fait qu'il faut tenir compte, dans la sélection, de la résistance à plusieurs maladies. Ainsi nous avons obtenu au Burkina Faso des lignées montrant une bonne tolérance à la rouille comme à la rosette tout en ayant, pour certaines, de bonnes potentialités agronomiques. Elles semblent par contre avoir une sensibilité accrue, par rapport à leurs variétés parentales, aux cercosporioses, qui bien que n'ayant pas été abordées ici, n'en sont pas moins négligeables.

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Incidence of Aflatoxin in Groundnuts as Influenced by Seasonal Changes in Environmental Conditions—A Review[1]

R.E. Pettit[2]

Abstract

This paper reviews the influence of changing environmental conditions on the activity of Aspergillus flavus *and / or* Aspergillus parasiticus *on groundnuts. Aflatoxin contamination of groundnuts, a serious problem in the warm to hot subtropical moist regions of the world, is more serious during and following alternating dry and wet periods, i.e., droughts followed by showers. When temperatures range from 20-35°C and the relative humidity in the pod microenvironment ranges from 85-95%, fungal growth and aflatoxin production is favored. Invasion of groundnut can occur during flower and peg formation, gradually as the pods mature, and rapidly as the pods become overmature. Mature intact pods with thick sclerotized cellular components, and kernels with compact seed coats (testa) are less susceptible. Alternating dry and wet periods may slow pod development, cause pod cracking, favor insects, nematodes, and pod rot fungi which damage the pod, thus increasing kernel susceptibility. The most economical solution is to develop groundnut varieties with flowers, pegs, and pods that resist fungal invasion, and pods and kernels that remain intact during changing environmental conditions. In addition, aflatoxin contamination can be reduced by harvesting to a void moist environmental conditions during curing, and sorting out insect- and mold-damaged kernels by hand or electronically.*

Résumé

Influence des changements saisonniers sur l'aflatoxine dans l'arachide — une revue : *La contamination de l'arachide par l'aflatoxine, un sérieux problème dans les régions subtropicales chaudes et les régions tropicales humides du monde, est plus sérieux encore pendant et après l'alternance de périodes sèches et humides, par exemple, des sécheresses suivies d'averses. Quand les températures varient entre 20 et 35°C et que l'humidité dans les micro-environnements de la gousse varie entre 85 et 98%, la croissance et la production d'aflatoxine par* Aspergillus flavus *et* A. parasiticus *est favorisée. L'invasion de l'arachide peut avoir lieu durant la formation des fleurs, ralentit quand la gousse mûrit et croît lorsque les gousses sont trop mures. Les gousses matures avec des composants cellulaires sclérosés et les graines avec des téguments compacts sont moins sensibles. L'alternance de périodes sèches et humides peut ralentir le développement de la gousse, lui causer des fissures, favoriser les insectes, les nématodes, les champignons qui endommagent la cosse, et ainsi accroissent la sensibilité des graines. La solution la plus économique consiste à développer des variétés d'arachide dont les gousses et les fleurs résistent aux invasions de champignon et dont les gousses et*

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graines restent intactes lors de changement de condition d'environnement. En outre, il faut réduire la contamination par l'aflatoxine durant la récolte pour éviter les conditions humides pendant le traitement et trier à la main ou électroniquement les graines endommagées par les insectes et les moisissures avant leur préparation comme aliment.

Introduction

Aflatoxin contamination of groundnut *(Arachis hypogaea* L.), caused by the growth of *Aspergillus flavus* Link ex Fries and/or *Aspergillus parasiticus* Spear, continues to be a serious problem to groundnut producers, industrial processors of groundnut, and consumers. Because of the complex nature of the problem a series of production, curing, and handling techniques will be required to prevent aflatoxin contamination. A series of economically feasible procedures should be implemented to help reduce the chances of contamination during production and drying, all moldy and insect-damaged kernels should be sorted out by hand or electronically, and products contaminated with aflatoxin should be treated to destroy the toxin.

The aflatoxin problem is more serious in geographical regions considered to be subtropical or tropical because of the warm to hot temperatures and variations in moisture levels that favor growth of these Aspergilli. Temperature and moisture variations are controlled by larger weather patterns that influence wind velocity and direction, radiation intensity as influenced by cloud cover and air composition, atmospheric relative humidity, and the frequency and amount of precipitation. Changes in climatic conditions during the growing season, in combination with the soil's edaphic characteristics, and the activity of a constantly changing biotic community, create the environment in which the groundnut plant parts and the Aspergilli develop. The extent to which the groundnut plant parts are invaded by the Aspergilli, and the levels of aflatoxin that accumulate within the kernels are determined by a combination of environmental conditions which favor mold growth, and the time span during which these conditions persist.

Researchers have for many years worked on defining the sequence of events that favor the growth of the Aspergilli and the most optimum conditions for aflatoxin production. Within this paper the author has reviewed several published reports on aflatoxin research and hypothesized some events that influence the *A. flavus group* of fungi to infest groundnut kernels and produce aflatoxin. Each hypothesis is based on the present state of knowledge or ignorance, thus must be tested, not accepted. Some hypotheses may be proven incorrect. In this review several excellent publications have been omitted because of the limited space, for this I apologize to the authors.

In the paper several synonymous terms are used interchangeably because of their common usage in different parts of the world. Some of these are: pod and shell, kernel and seed, testa and seed coat, digging and lifting, and curing and drying.

Aflatoxin Contamination During Groundnut Production

Aspergillus flavus and *A. parasiticus* (referred to as the *A. flavus* group) are common saprophytic fungi found in soils throughout the major groundnut-producing areas of the world (Joffe and Borut 1966, Pettit et al. 1973, Griffin and Garren 1974, McDonald 1969, and Barns 1971). These fungi survive in the soil in the form of sclerotia, conidia, and mycelial strands found in association with crop residues. The incidence of the *A. flavus* group of fungi in the soil is influenced by the soil type, cropping history, organic-matter content, water-holding capacity, actual soil moisture, and seasonal temperatures (Menon and Williams 1957, Joffe 1969, Angel et al. 1982). Crop residues of corn (maize) and groundnut favor a relatively high incidence of *A. flavus* group of fungi (Pettit et al. 1973, Angle et al. 1982, Griffin et al. 1981). In soils where temperatures are relatively high during the growing season the isolation frequency has been reported as high as 1.5×10^5 propagules g^{-1} of groundnut soil (Bell and Crawford 1967), up to 2.8×10^2 propagules g^{-1} of corn soil in Missouri (Angle et al. 1982), and 57 propagules g^{-1} of groundnut soil in Virginia (Griffin and Garren 1974). Recovery rate of *A. flavus* group of fungi is obviously related to the isolation technique. The addition of Botran to a selective medium can increase the isolation frequency by inhibiting other fungi (Bell and Crawford 1967).

The incidence of *A. flavus* group of fungi is frequently quite variable within given producers' fields. Groundnut producers frequently note 'hot spots' where they observe *A. flavus* activity. Examination of the soil from these hot spots using the soil-dilution technique has revealed high levels of *A. flavus* (Taber and Pettit, Texas A & M University, USA, unpublished). The incidence of *A. flavus is* noted to increase within the soil on organic matter early in the spring. Examination of groundnut plants grown in soils with high *A. flavus* has indicated that invasion of various plant parts can occur throughout the growing season. The extent to which such invasion occurs appears to be related to the environmental conditions (Diener et al. 1982). It is believed that soil moisture (liquid water and water vapor in the soil atmosphere), soil temperature, and possibly the composition of the gaseous atmosphere (other than water vapor) influence the activity of these fungi. In general, those environmental conditions that favor groundnut growth help the plant maintain its defense mechanisms against these weakly parasitic fungi and favor the activity of other soil microorganisms. However, daily and weekly changes in the soil-moisture levels and changes in the temperature within the top few cm of the soil can periodically provide ideal conditions for *A. flavus* growth. Temperatures in the range of 20-35°C and relative humidities in the range of 85-98% favor *A. flavus* activity (Diener 1973, Diener et al. 1982).

Results from experiments where groundnuts were grown under controlled-environment conditions, defined as gnotobiotic, with attempts made to sterilize all equipment and isolators used, have provided additional insights into conditions that favor *A. flavus* invasion of groundnut plant parts. The temperature within the isolators was controlled at 29-31℃ with the lights on, and at 22-24℃ with the lights off. A diurnal cycle of 16 h light and 8 h dark was maintained throughout the experiment. The relative humidity ranged from 70-90% (Lindsey 1970, Wells et al. 1972). *Aspergillus flavus* readily invaded immature pods, mature pericarps, and testae. When *Trichoderma viride* pers. ex Frs. was introduced into the potting mix it reduced colonization of immature and mature pericarps by *A. flavus.* The addition of *Penicillium foniculosum* Thom. not only nullified this anagonistic effect, but also appeared to stimulate colonization of mature groundnut pericarps and testa by *A. flavus* (Wells et al. 1972). Throughout these experiments *A. flavus* caused no significant disease symptoms and groundnut embryos exhibited only limited invasion. In order to determine why the embryos were not readily invaded, acetone extracts were made from freshly harvested groundnut seed embryos. Chemical analysis revealed the presence of three different phenolic-like compounds that inhibited the growth of *A. flavus* in culture (Lindsey and Turner 1975). When noninjured embryos from cured seeds were inoculated with A *flavus* there was no growth inhibition. These observations indicate that immature developing embryos contain active compounds that play a role in protecting young embryos from fungal infection. When embryos of freshly harvested groundnut seed were treated chemically (with acetone, ether, or methanol) or thermally (placed in boiling water), *A. flavus* rapidly colonized these damaged embryos.

Field-grown groundnut flowers, pegs, and young developing pods have been reported to be colonized by a large number of different fungi. *Aspergillus flavus* has been isolated from 7% of washed groundnut flowers and 1.5% of washed aerial pegs (Griffin and Garren 1976a). Inoculation of dry conidia to aerial portions of greenhouse-grown groundnut pegs resulted in a low percentage of spore germinations (Griffin 1972). Under field conditions Griffin and Garren (1976b) observed *A. flavus* propagative units splashed on the agar surface of petri plates positioned against groundnut stems during a hard rain. Based on this observation they hypothesized that inoculation of groundnut flowers by *A. flavus* may result from rain-splashed infested soil. In earlier studies Hanlin (1969) reported that young groundnut pegs harvested before they enter the soil, surface-sterilized with sodium hypochlorite, then plated on nutrient media, contained up to 6% *A. flavus* infestation.

Based on these reports and others the author hyphothesizes that *A. flavus* can infect groundnut flowers, pegs, and young developing pods early in the growing season and that the fungus becomes quiescent or develops a resting state which persists during pod and kernel maturation. The isolation of *A. flavus* in this quiescent state appears to be difficult. Improved isolation procedures, which avoid the use of sodium hypochlorite surface sterilization and make use of selective isolation media, could help provide needed insights into the ecological status of *A. flavus* during kernel formation.

As groundnut pods approach maturity within the soil, a relatively high incidence of *A. flavus* can be noticed, especially when the groundnuts are grown under drought-stress conditions (Norton et al. 1956, Hanlin 1970, McDonald 1970, Dickens et al. 1973, Subrahmanyam and Rao 1974, and Davidson et al. 1983). Hanlin in 1970 reported that the incidence of *A. flavus* in freshly dug groundnut seed, 100 days after sowing (DAS) in Georgia, was 11-14%. Sixty days later the incidence of A. *flavus* decreased to 6-7%.

In studies in Texas the isolation frequency of A *flavus* and levels of aflatoxin in freshly dug Starr groundnut kernels harvested from dryland (rainfed) and irrigated plots from 1967 to 1969 revealed that climate had a significant influence on *A. flavus* activity (Tables 1 and 2) (Pettit et al. 1971). The incidence of *A. flavus* was highest in those kernels from dryland plots in south Texas in 1967 and 1969, years during which moderate and severe droughts occurred. In 1968 rainfall during the growing season helped maintain vigorous nonstressed plants. During the two years of drought (1967 and 1969) aflatoxin levels in freshly dug kernels harvested from dryland plots 120 and 130 DAS averaged from 694-10240 ppb aflatoxin. In adjacent irrigated plots freshly dug kernels harvested 120 and 130 DAS had *A. flavus* infestation levels of 4-20%. However, only 0 to trace amounts of aflatoxin were detected in these samples.

In comparison, the isolation frequency of *A. flavus*in freshly dug kernels from north Texas (Table 2) averaged less than 5% during the 3-year period. Maximum aflatoxin levels were detected in kernels from the dryland plots, where a maximum of 24 ppb aflatoxin occurred.

More recently, field-scale studies in Georgia were established to determine the extent to which *A. flavus* infestation occurred in the kernels from the groundnut varieties Sunbelt Runner and Florunner. The incidence of *A. flavus* in freshly dug sound mature kernels (SMK), harvested 110 and 116 DAS, from three growers' fields which experienced no, moderate, and severe drought stresses averaged 32% , 40% , and 42% infestation respectively. Aflatoxin contamination of comparable freshly dug kernels, 110 and 116 DAS, from the no, moderate, and severe drought-stressed fields averaged 6, 73, and 444 ppb aflatoxin respectively (Davidson et al. 1983).

These studies have provided evidence that *A. fla-*

Table 1. Isolation frequency of *Aspergillus flavus* and aflatoxin detected in freshly dug Starr groundnut kernels harvested near Yoakum, south Texas, 1967-1969.

	Dryland treatment				Irrigated treatment			
	120'		130		120		130	
Year	*A. flavus* (%)	Afla-toxin (ppb)	*A. flavus* (%)	Ana-toxin (ppb)	*A. flavus* (%)	Ana-toxin (ppb)	*A. flavus* (%)	Ana-toxin (ppb)
1967	(11)	649	(12)	960	(0)	Tr	(4)	0
1968	(-)[2]	Tr	(-)	Tr	(-)	3	(-)	2
1969	(21)	10 240	(28)	4601	(20)	0	(16)	Tr

1. Number of days after sowing.
2. (-) Isolation frequency less than 2%.
Source: Pettit et al. 1971.

Table 2. Isolation frequency of *Aspergillus flavus* and aflatoxin detected in freshly dug Starr groundnut kernels harvested near Stephenville, north Texas, 1967-1969.

	Dryland treatment				Irrigated treatment			
	120'		130		120		130	
Year	A *flavus* (%)	Afla-toxin (ppb)	A. *flavus* (%)	Afla-toxin (ppb)	A *flavus* (%)	Afla-toxin (ppb)	A *flavus* (%)	Afla-toxin (ppb)
1967	(3)	0	(2)	24	(1)	0	(1)	Tr
1968		Tr	(-)	Tr	(-)	0	(-)	Tr
1969	(5)	0	(2)	0	(0)	0	(0)	0

1. Number of days after sowing.
2. (-) Isolation frequency less than 2%.
Source: Pettit et al. 1971.

vus grows in soils with sufficient soil moisture to produce a groundnut crop and in soils where varying levels of drought stress have occurred. Invasion of groundnut pods and seeds may occur prior to digging when the pods are approaching maturity. Periods of drought in association with warm to hot temperatures can increase the chances of *A. flavus* invasion and aflatoxin contamination. Periods of drought that result in soil drying to the extent that the groundnuts dry in the soil before harvest, followed by as little as 20 mm of rain, can cause the groundnut kernels to swell, crack the pods, and allow invasion of the groundnut testa and embryos (Graham 1982).

Recent reports from research conducted at the USDA climate-control plots near Dawson, Georgia, have provided additional insights concerning the influence of soil-moisture levels on the extent of A *flavus* infestation and aflatoxin contamination (Cole et al. 1982, Hill et al. 1983). A portion of the data collected in 1980, from the use of these climate-controlled plots, is summarized in Table 3. In general these results indicate that neither temperature nor drought stress alone exert a primary influence on the degree of infestation and amount of aflatoxin contamination. Kernels harvested from those treatments with the greatest drought stress (1.8 and 2.1 MPa) contained the highest aflatoxin levels, 243-9234 ppb aflatoxin and 0-214 ppb aflatoxin respectively. Kernels harvested from the two treatments with the lower soil-moisture levels (0;3 and 0.8 MPa) were infested with *A. flavus*(7-42%), however, aflatoxin levels were much lower, from 0-122 ppb (Hill et al. 1983).

Aflatoxin Contamination During Field Curing and Drying

At the time of harvest, when a majority of the groundnut pods have matured, they contain a complex of microorganisms, termed the endogeocarpic microflora, several of which are capable of causing mycotoxin contamination (Garren et al. 1969). Once these infested groundnut pods are lifted from the soil, in order to permit curing and drying, they are subjected to rapidly changing environmental conditions that cause shifts in the dominant and subdominant fungal species present on and within the pods. In order to reduce the potential for aflatoxin contamination (following lifting), the groundnut producer must make every effort possible to prevent the endogeocarpic mycoflora from becoming active. Preferably the mycoflora should be kept in a stable or quiescent state.

Climatic conditions during curing and drying have a pronounced influence on the rate of pod and kernel drying and the extent to which *A. flavus* and other fungi can cause damage. The terms curing and drying have been defined as two distinct phases of

Table 3. Colonization of Florunner groundnut kernels and levels of aflatoxin contamination as influenced by soil temperature and soil moisture.

Treatment and kernel grade	Soil temperature °C			Soil moisture (Mpa)	*A. flavus* infestation (%)	Aflatoxin (ppb)
	Min	Max	Mean			
Dryland-edible	22	35	28	1.8	56	243
Dryland-other	22	35	28	2.8	75	9234
Irrigated heated-edible	30	39	34	0.8	26	0
Irrigated heated-other	30	39	34	0.8	42	4
Dryland cooled-edible	20	34	24	2.1	10	0
Dryland cooled-other	20	34	24	2.1	23	214
Irrigated-edible	20	31	25	0.3	7	0
Irrigated-other	20	31	25	0.3	25	122

Source: Hill et al. 1983.

change in groundnut composition following lifting (Blatchford and Hall 1963a and 1963b). Groundnut curing is generally considered to occur after lifting during the period when the groundnuts are attached to the haulms (stems). It has been hypothesized that during curing, several chemical and physical changes occur which influence kernel quality. The hypothesis is based on reported differences in seed germination and nutritional or taste qualities which develop during curing. Pods dried off the haulms are of a lower quality. Additional research is needed to test the hypothesis. As accepted by some researchers the term 'curing' relates to these yet undefined processes which terminate when the plants become dry or the groundnuts are removed from partially dried haulms (stems). The term 'drying' is used to describe all phases of moisture removal including the moisture lost during curing and from the groundnuts after thrashing (removal from the haulms). At lifting time, pod and kernel moisture can range from as high as 48% to below 15% when drying occurs within the soil prior to harvest.

The single most important environmental factor that influences the endogeocarpic microflora during curing and drying is pod and kernel moisture. When high-moisture groundnuts are lifted and placed in windrows on the soil surface, the potential exists for rapid invasion of the kernels by *A. flavus* group of fungi and aflatoxin contamination (McDonald and Harkeness 1963, Austwick and Ayerst 1963, McDonald and A'Brook 1963, Burrell et al. l964, Bampton 1963, Jackson 1965, Gilman 1969, and Troger et al. 1970). Windrow exposure for 3-7 days without adequate curing and drying is sufficient to cause significant aflatoxin contamination. A rain shortly after digging is not particularly harmful, but a rain after the groundnuts are partially dried, followed by poor drying is likely to result in aflatoxin contamination (Troger et al. 1970). The duration of rainy periods, their timing, and the amount of precipitation can directly influence curing and drying rates. Rains in the evening may allow the groundnuts to remain wet all night, thus providing the needed moisture to the fungi. Rains early in the morning are less likely to slow drying and accelerate mold growth, because of daytime drying.

Research concerning the influence of different curing procedures by Burell et al. (1964), carried out near Mokwa, Nigeria, illustrates the problem excess pod and kernel moisture can cause if not removed rapidly. When groundnuts were subjected to the following treatments: (1) left in windrows for curing, (2) picked after windrow curing for 2-4 d then left on the ground to dry, (3) picked at lifting and left on the

Table 4. Influence of different curing treatments on the moisture level and relative efficiency of each treatment in terms of kernel quality. Trial MI conducted near Mokwa, Nigeria.

Treatment	Lifting moisture (%)	Cured moisture (%)	Curing time (days)	Kernel[1] quality
Windrow 2-4 days, then picked, left on ground	43.2	17.9	20	US
Picked at lifting and left on the ground	43.2	17.6	20	US
Continuous inverted windrow in field	43.2	15.1	20	US
Windrow 2-4 days, then placed in small heaps	43.2	15.1	20	US
Windrow 2-4 days, then placed on poles	43.2	9.9	20	S
Windrow 2-4 days, then picked, placed on matting	43.2	6.7	12	S
Windrow 2-4 days, then picked, placed on corrugated iror sheets	43.2	6.7	12	S
Picked at lifting and placed on matting	43.2	6.5	12	S
Picked at lifting and placed on black plastic	43.2	6.5	12	S

1. US unsatisfactory (excess mold damage); S satisfactory (minor mold damage)
Source; Burrell et al. 1964.

Table 5. Influence of different curing treatments on the moisture level of groundnut kernels as influenced by climate. Trial M2 conducted near Mokwa, Nigeria.

	Days after lifting - moisture content of kernels (%)											
Treatment	0	2	4	6	8	10	12	14	16	18	20	22
Continuous inverted windrow in field	36.4	27.5	18.8	12.2	11.7	9.1	10.7	8.6	11.3	14.0	15.5	12.9
Windrow 2-4 d, then stacked on ground	36.4	27.5	18.8	11.5	10.2	8.2	8.9	7.9	8.9	11.4	11.5	9.5
Windrow 2-4 d, then placed on rack	36.4	27.5	18.8	11.5	10.2	8.2	8.9	7.9	8.9	11.4	11.5	9.5
Windrow 2-4 d, then placed on poles	36.4	27.5	18.8	11.5	10.2	8.2	8.9	7.9	8.9	11.4	11.5	9.5
Windrow 2-4 d, then picked, placed on matting	36.4	27.5	18.8	9.5	5.1							
Windrow 2-4 d then picked, placed on corrugated iron sheets	36.4	27.5	18.8	9.5	5.1							
Picked at lifting and placed on matting	36.4	24.4	11.3	6.1	5.8							
Picked at lifting and placed on black plastic	36.4	24.4	11.3	6.1	5.8							

Source: Burrell et al. 1964.

ground to dry, or (4) windrowed 2-4 d and then placed in small heaps, there was extensive mold damage (Tables 4 and 5). Groundnut vines with pods or the groundnut pods separated from the vines that were kept on the ground for 20 d had kernel-moisture levels which ranged from 15.1-17.9%. Windrow curing for 2-4 d followed by pole curing and drying for 16 d provided a mean cured kernel-moisture level of 9.9%. This treatment was intermediate in terms of drying rate, however with lower relative humidities, good drying winds, and protection from showers, pole curing and drying could have been satisfactory. All other treatments noted in Table 4, where the groundnuts were removed from the vines and dried on mats (grass or bamboo), iron sheeting, or black plastic were satisfactory, since little mold damage occurred. When rain threatened, groundnuts dried on these surfaces were placed under cover. In a second experiment conducted near Mokwa, Nigeria, the influence of rain showers on kernel moisture was evident. Groundnuts left in windrows within the field, placed in stacks, on a rack, or on poles in the open had their moisture levels increased following two rainy periods (Table 5). After 22 d , kernels examined from the inverted windrows had kernel-moisture levels of 12.9%, excessively high for safe storage. In contrast, groundnuts dried after picking from the vines then dried for 8 d on matting, corrugated iron sheets, or black plastic had moisture levels of 5.1-5.8%.

The use of inverted windrows, rows of lifted groundnut vines in which most of the groundnuts are held off the soil surface by the various positions within the windrow, has been shown to speed the curing and drying process (Pettit et al. 1971). Groundnut pods positioned at the top of windrows (inverted and/or random types) reside where air currents move more rapidly and where the atmospheric relative humidity is low compared to positions closer to the soil surface. When the soil is wet from recent rains the relative humidity near the soil surface exceeds 90%, especially on nights where there is little air movement. Obviously pods located on a wet soil surface dry much more slowly compared to those on an inverted windrow. When groundnut pods are lifted from the soil and placed at the top of an inverted windrow, changes in the pod mycoflora often occur. Isolations from freshly dug pods have frequently been reported to be higher in comparison to isolation from pods following windrow curing For example, Porter and Garren (1970) reported that the average isolation frequency of fungi from freshly dug pods was 79%, cured pods from random windrows 78%, and cured pods from inverted windrows 62%. On the basis of this report and others it is hypothesized that when groundnuts are exposed to intense solar radiation, lower relative humidities, and lower temperatures at the top of inverted windrows, some of the fungi present are killed and others become quiescent. When windrow conditions favor A. *flavus* activity the groundnuts should be removed from the vines, dried rapidly, and kept dry to prevent aflatoxin contamination.

In studies by Dickens and Khalsa (1967), they observed that the average difference in moisture content of groundnuts from inverted windrows, compared to those from random windrows, was 8% (Table 6). Their studies also illustrated the influence of using air with two different relative humidites, 85 and 50%, on drying rates. The drying rate was slowed when 85% r.h. air was used. As a result, 20-51% of the kernel samples examined from this treatment contained aflatoxin. In comparison, when the relative humidity of the drying air was 50%, only 1% of the samples examined contained aflatoxin.

The use of inverted windrows helps reduce the number of groundnut kernels invaded by various fungi, including those classified within the A. *flavus* group. In Virginia, Porter and Garren (1970), reported that groundnut seed harvested from inverted windrows over a 4-year period had 15% less mold-invaded kernels compared to those kernels from random windrows (Table 7). In addition, those groundnut kernels from the inverted windrows contained 2.6% *A. flavus* infestation, compared to 3.9% infestation for kernels from the random windrows. The inverted windrows also reduced the time in which groundnut kernel moisture and environmental conditions favor the production of aflatoxin by previously established *A. flavus* colonies. The use of inverted windrows shortens the time required to cure the groundnuts within the field. However, to avoid possible damage due to prolonged rainy periods, the groundnuts should be thrashed as soon as possible and the final drying conducted under more controlled conditions (Pettit and Taber 1968).

Table 6. Extent of aflatoxin contamination of NC 2 groundnut kernels harvested from random and inverted windrows in the field followed by drying in bins with heated forced air. Groundnuts were cured in random and inverted windrows for 16 days, combined, and forced-air dried at a temperature of 32℃ (90℉) and two relative humidities.

Type of windrow	Moisture following windrow curing (%)	Drying-air relative humidity (%)	Extent of aflatoxin contamination (%)
Random	25	85	51
Inverted	16	85	20
Random	25	50	1
Inverted	16	50	0

Source: Dickens and Khalsa 1967.

Table 7. Proportion of Virginia bunch groundnut seed harvested from random and inverted windrows infested with various fungi and *A. flavus.* Data collected in research plots near Holland, Virginia, 1966-1969.

	Windrow type			
	Random		Inverted	
Year	Total fungi (%)	*A. flavus* (%)	Total fungi (%)	*A. flavus* (%)
1966	32	-	21	-
1967	36	-	16	-
1968	42	-	25	-
1969	34	-	22	-
Mean	36	3.9	21	2.6

Source: Porter and Garren 1970.

The use of inverted windrows or placement of groundnut vines on poles or racks not only speeds up the drying process but also can protect the groundnuts from soil insects. Invasion of groundnut pods by insects following lifting, within randomly designed windrows, is generally not considered to be a problem. However, in some geographical regions insect damage of windrowed pods in contact with the soil surface is a problem.

Insect damage to groundnut pods has been reported to occur prior to lifting and creates openings for invasion by *A. flavus.* Pod damage caused by the lesser cornstalk borer *(Elasmopalpus lignosellus* Zeller) (Ashworth and Langley 1964, Dickens and Satterwhite 1973), the southern corn root worm *(Diabrotica undecimpuctata howardi* Barber) (Porter and Smith 1974), mites (*Caloglyphus* sp. and *Tyrophagus* sp.) (Aucamp 1969), white grubs *(Heteronyx* sp.) (Graham 1982), Lucerne seed web moth *(Etiella behrii)* (Graham 1982), African termites (unidentified, possibly *Termes natalensis)* (McDonald et al. 1964), and the burrowing bug *(Pangaeus bilineatus* Say) (Taber and Pettit, Texas A&M University, USA, unpublished) increase the isolation frequency of A. *flavus* and severity of aflatoxin contamination. In general these insects and mites are more active during drought periods.

Pod damage other than that caused by insects can also increase kernel susceptibility. Growth cracks in pods, pod splitting due to seed-moisture increase after drying, and mechanical injury during lifting and thrashing can open the pods and allow *A. flavus* penetration.

Aflatoxin Contamination During Handling and Storage

Groundnut kernels infested with *A. flavus* and free from aflatoxin when introduced into storage facilities can become contaminated with aflatoxin while in storage. Several environmental factors within the storage facilities influence the extent to which mold growth and aflatoxin contamination occur. Some of these factors are: seed moisture, relative humidity, temperature, time and gaseous composition of the storage atmosphere, and time in storage. When the seed moisture within storage exceeds 9% at the equilibrium relative humidity of 80% (30°C) (Table 8), then the chances that *A. flavus* growth will occur increase (Borut and Zoffe 1966, Diener et al. 1982). An increase in the relative humidity from 80 to 85% can, if conditions persist for sufficient time, cause the seed-moisture content to increase to 11%. Efforts must be made when the relative humidity is high or when rain occurs to protect groundnuts in transport containers or storage facilities from potential increase in seed-moisture content. Transport containers should be protected against wind-driven rain. The combined interaction of favorable relative humidities and temperatures triggers *A. flavus* spores present on the groundnut pods to germinate and initiate fungal growth. Even at a constant relative humidity a temperature increase can stimulate fungal activity. Spore germination can occur on the pod or seed surface in stored groundnuts when the relative humidity and temperature trigger the growth processes (Panasenko 1967).

Table 8. The moisture equilibrium of groundnuts.

Relative humidity at 30°C (%)	Seed moisture content (%)	Meal (wet weight)
98	30.5	-
95	20.0	-
90	14.3	23.5
85	11.3	19.0
80	9.3	16.3
75	8.0	14.0
70	7.0	12.3
65	6.5	-
53	5.7	-
44	5.2	,

Source: Blatchford and Hall 1963, Diener et al. 1982.

Some of the major causes of increased relative humidities and undesirable seed moistures within storage facilities are: leaking roofs, improper insecticide applications, condensation on roofs or coverings, sidewalls or floors without vapor barriers, and seepage of water into storage areas following rains (Dickens 1977). A study by the Peanut Administrative Committee and individual groundnut shelters within the United States found that moisture condensation on various surfaces within the storage facilities was the major contributing factor for increasing aflatoxin contamination. Based on these studies it was calculated that if 1000 t of groundnuts were placed in storage at a moisture content of 9.5% and the relative humidity was less than 70% then the groundnuts would have to lose over 22 700 L (6000 gallons) of water to reach an equilibrium moisture level of 7.0% (See Table 8). If this moisture was not removed from the storage facility, then a subsequent accumulation, of moisture on the groundnuts would occur (Dickens 1975).

Protection against aflatoxin contamination during handling and storage should start with the placement of groundnuts into storage when their moisture content is less than 9%. Once in storage the groundnuts should be aerated to prevent moisture build up or migration. Aeration with air containing less than 70% relative humidity can keep the groundnuts at a low moisture content, cool the groundnuts, prevent moisture buildup within certain areas of the groundnut mass, prevent moisture migration to condensation surfaces, and reduce the chances of insect activity. During periods of rain or excessively high humidity, the ventilation system should be turned off to prevent a buildup of kernel moisture. Prevention of aflatoxin contamination in storage requires a constant monitoring of the environmental conditions within the atmosphere and within the storage facilities.

Conclusions and Research Needs

The potential for aflatoxin contamination starts when groundnut flowers form and ends after the groundnuts are processed and consumed. Prevention of contamination is the most economical and practical approach to the problem. We hope that groundnut varieties with drought, insect, and aflatoxin resistance will be developed and help reduce the number of seeds contaminated. However, pod damage due to insect activity and other causes may result in some kernels being invaded; and therefore, a need to clean up contaminated lots of groundnut will continue. All segments of the industry must help solve the problem. Additional research is needed on the development of resistant varieties and control procedures to reduce insect and fungal activity. To protect animal and human health, better sorting and decontamination procedures are needed to remove or destroy the aflatoxin present.

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Insect Damage to Groundnut in Semi-Arid Tropical Africa

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Abstract

This paper reviews arthropod damage to groundnut in semi-arid tropical (SAT) West Africa in relation to plant phenology and drought stress, and presents preliminary results of groundnut insect research at the University of Ouagadougou, Burkina Faso. Research in Africa and the United States has shown that arthropod damage, drought stress, and delayed harvest increase Aspergillus flavus *and aflatoxin contamination in groundnut. The interaction of arthropod damage and the types of arthropod damage are important criteria for potential aflatoxin contamination in groundnut Methods to reduce aflatoxin contamination are being investigated.*

Résumé

Dommages causés à l'arachide par les insectes dans les régions tropicales semi-arides africaines : *Cet article passe en revue les dommages causés par les arthropodes à l'arachide dans les zones tropicales semi-arides de l'Afrique de l'Ouest, en fonction de la phénologie de la plante et des contraintes hydriques. Il présente les résultats préliminaires des recherches sur les insectes de l'arachide conduites à l'Université de Ouagadougou, au Burkina Faso. Des recherches faites en Afrique et aux Etats-Unis ont montré que les dégâts causés par les arthropodes, les contraintes hydriques et le délai de la récolte cause une augmentation de l'*Aspergillus flavus *et de la contamination par l'aflatoxine. L'interaction entre les dégâts causes par les arthropodes et les types de dégâts par les arthropodes sont un critère important du potentiel de contamination par les aflatoxines. Les méthodes permettant de réduire la contamination par les aflatoxines sont étudiées.*

Introduction

World hunger is an ever-increasing problem—a problem that requires the immediate cooperation of researchers around the world. Mass starvation, such as recently experienced in Ethiopia, occurs all too frequently and is, in part, due to erratic food production. Thus, stability in crop production has been recognized as the primary goal of the developing countries (Gibbons 1980). An example of the instability in food production is given by the groundnut-production reports of Niger from 1968-1978 (Mounkaila 1980). Yield ranged from 270000 t in 1968-69 to 42000 t ha^{-1} in 1975. Much of this instability can be attributed to the drought and the insect-borne rosette virus epidemic in 1975.

Groundnuts are recognized as one of the major cash crops, as well as a high-quality, protein-rich food for local consumption in SAT Africa. Groundnuts represent from one-third to one-half of the

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exports from Senegal (Jackson et al. 1981). In Niger, groundnuts accounted for almost 45% of the exports in 1972, but declined to only 5% in 1975 as a direct result of the rosette epidemic (Mounkaila 1980). In many of the West African countries, groundnuts are also one of the most important cultivated domestic and commercial crops. However, in many of these countries, groundnut production has declined due to the extreme yield variability from year to year.

Plant protection from damaging infestations of insect and related arthropod pests is vitally important for stabilized production. Over 450 species of insect pests have been recorded on groundnut (Smith and Barfield 1982, Redlinger and Davis 1982). Only a few of these pests are economically important worldwide, but many are severe pests in localized regions of the world (Feakin 1973). Damage by these insects may be devastating, as evidenced by the rosette virus epidemic spread by *Aphis craccivora* Koch in 1975 (Gibbons 1977, Rossell 1977, Yayock et al. 1976), or may be rather insidious, producing small, unnoticed losses that accumulate throughout production and storage. In either instance, insects and related arthropods should be recognized as a major constraint in peanut production in both developed and developing countries.

Developing countries in West Africa offer a tremendous potential for expanded food production. These countries have vast arable lands suitable for increased agricultural production. However, in these countries, most agriculture is characterized by small farms with little mechanization or advanced technology. Minor improvements, such as higher-yielding, disease- or insect-resistant varieties, or the implementation of pest-control strategies can have a tremendous impact on production and the local economy. Crop production can be improved through cooperative research and the practical application of this research on the small farms characteristic of this region.

One area that offers such potential is the development of an integrated pest management (IPM) program for insects. IPM can be readily adapted to the normal agricultural practices of these developing countries, since it integrates all components of the agricultural system into one program that offers potential for increasing stability in crop production through proper management of the insect pests that often cause the instabilities.

Integrated pest management can be defined as a "pest management system that, in the context of the total environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury (Glass 1975). The objectives of pest management are to create and maintain situations that prevent insects from causing significant problems—in other words, to provide stability in the insect ecosystem. These objectives may be achieved by preventing the establishment or spread of insect pests, controlling established infestations, or maintaining pest infestation levels at which little or no damage occurs (Subcommittee on Insect Pest Control 1969). Insect pests can be managed by using knowledge of pest ecology in relation to the phenology of the host, and integrating this knowledge with cultural, physical, mechanical, biological, microbial, and chemical control; insect-resistant plants; and other means of managing insect pest populations.

The pest-management concept is based on the precept that insects should be managed to maintain their populations below an economic level. Paramount in this concept is the determination of an economic insect. An economic insect is one that causes enough yield or quality loss to justify the expense to manage that insect. The basic concepts regarding the relationship between insect populations and economics of control were advanced by Stern et al. (1959) and Stern (1966). The authors pointed out the necessity for determining economic damage in agricultural crops. Economic damage is the amount of damage that, if prevented, will equal or exceed the cost of using artificial control measures. Two concepts are related to economic damage. First, for IPM programs to work effectively, the economic injury level (the lowest number of insects that will cause economic damage) must be determined for the host, i.e., the minimum number of insects required to reduce yield or quality equal to or greater than the cost of applying artificial control. Second, after the economic injury level is determined for a particular crop, the economic threshold or action threshold (the insect population level when action is taken to prevent insect numbers from reaching the economic injury level) must be established.

Stern et al. (1959) categorized insect pests in relation to their economic significance as "noneconomic pests, occasional pests, and severe pests". Most insect pests of groundnuts could probably be classified in the first two categories.

Noneconomic pests are characterized by an average density that only rarely, if ever, reaches the economic injury level. They are most common in crops with relatively low market values. In groundnuts, some of the minor defoliators would probably fit into this category.

Occasional insect pests are those whose average densities are generally below the economic injury level, but whose highest population-level fluctuations occasionally exceed the economic injury level. With these pests in particular, knowledge of the insect biology, prediction of future population trends, and knowledge of the economic injury level are vitally important. Awareness of these aspects of pest bionomics allows a preventive outlook rather than a curative one. Treatment of crops unnecessarily, without regard to the economic injury level for the occasional pest species, may be the difference between profit and loss in marginal operations. Also, the unnecessary use of chemical insecticides can produce undesirable side effects, such as resurgence of the pest, development of pest resistance to insecticides, or harmful levels of pesticide residues on the crop. Most insect pests of groundnuts are occasional pests; they are not economic in every generation of every year.

The severe pest is characterized by an average population density that exceeds the economic injury level. With this type of pest, insecticides are required almost continually and usually on schedules. This type of pest problem is generally associated with high-value crops. In all likelihood, groundnuts are not attacked by this type of pest in the developing countries. In certain areas, however, termites may inflict levels of damage that would characterize them as severe pests.

The basis for managing pests, such as the occasional pest, is the planned manipulation of the various processes that prevent pest populations from becoming economic, and thus minimize the economic impact of the pests (Southwood and Way 1970). These principles can be implemented in the developing countries to aid in the management of pests and thus aid in reducing the dramatic fluctuation in crop productivity. Four elements are basic to successful IPM programs for these countries:

- the development of reliable sampling procedures for estimating population density,
- the determination of economic levels for the various pests,
- an estimation of the influence of natural control agents, and
- a good knowledge of the insect biology and ecology (Moore 1978).

These four basic elements form the research core for the development of IPM programs for SAT Africa.

Groundnut Pests in SAT Africa

Over 400 arthropod species are reported as preharvest pests of groundnuts, of which 188 species attack groundnuts in SAT Africa (Smith and Barfield 1982). In addition, over 80 species are reported as pests of postharvest groundnuts (Redlinger and Davis 1982). The most frequently encountered arthropod pests are the beetles *(Coleoptera),* with 120 species that damage postharvest groundnuts, 49 of which are found in SAT Africa, and 70 species that damage postharvest groundnuts. The second most prevalent group of pests includes the leptidopterous larvae; 68 species are reported from preharvest and 6 species from postharvest groundnuts. The true bugs (Homoptera-Hemiptera) represent the third most frequently encountered group of insects, with 43 and 39 species, respectively, that attack preharvest groundnuts. Other major groups that attack preharvest groundnuts include the grasshoppers and locusts (Orthoptera), with 36 species; the termites (Isoptera), with 25 species; the thrips (Thysanoptera), with 19 species; the mites (Acarina), with 17 species; and the millipedes (Julida), with 13 species (all from SAT Africa).

Recent reviews by Amin and Mohammad (1980) and Wightman (1985) discussed major groundnut pests for the SAT. In Africa, 10 arthropods are considered as major pests of groundnuts (Amin and Mohammad (1980). These include the groundnut aphid, *Aphis craccivora* Koch; leafhoppers, *Empoasca dolichi* Paoli and *E. facialis* Jacobi; an armyworm, *Spodoptera littoralis* (Boisduval); the groundnut hopper, *Hilda patruelis Stal;* a termite, *Microtermes thoracalis* Sjostedt; the "Wang," *Aphanus (Elasmolomus) sordidus* (F.); millipedes of the genus *Peridontopyge;* and the groundnut bruchid, *Caryedon serratys* (01.). In addition to these, Wightman (1985) lists an earwig, *Anisolabis stali (Lucas);* white grubs, *Eulipida mashona* Arrow (appears to be the most important in Africa); and several species of thrips.

Several other species of insects are listed by Hill (1979), Feakin (1973), and Mercer (1977, 1978a, 1978b) as groundnut pests in SAT Africa. These include the African bollworm, *Heliothis armigera* (Hubner); a semilooper, *Achae finita* (Guenee); the beet armyworm, S. *exigua* (Hubner); the black cutworm, *Agrotis ipsilon* (Hufnagel); the brown leaf beetle, *Ootheca mutabilis* Sahlberg; the striped sweet potato weevil, *Alcidodes dentipes* (Oliver);

chafer grubs, *Schizanycha* spp.; and systates weevils, *Systates spp.*

Wightman (1985) lists the order of research importance for arthropod pests of groundnuts in Africa as: (1) termites, (2) aphids and the transmission of rosette virus, (3) *Hilda patruelis,* and (4) jassids. Millipedes were also listed at a lower priority.

Several minor pests of groundnuts become of prime importance when their ability to transmit virus diseases is considered. Amin and Mohammad (1980), Smith and Barfield (1982), and Wightman (1985) list 13 virus diseases of groundnuts and the insects that transmit the viruses. Aphids, thrips, and leafhoppers are the most common vectors of the virus diseases in groundnuts.

Termites appear to be the most destructive insect pests in SAT Africa. Harris (1971) lists 10 species and Feakin (1973) lists 14 species of termites that damage groundnuts in Africa. However, two genera *Microtermes* and *Odontotermes,* are reported to produce the majority of groundnut damage (Wightman 1985, Johnson et al. 1981, Johnson and Gumel 1981). Yield losses of up to 40% have been reported in Nigeria (Johnson et al. 1981). These authors noted that *Microtermes lepidus* Sjostedt damaged the tap root, tunneled into the stems, and scarified and invaded the pods. They also noted a linear relationship between tap root invasion and yield loss. Johnson and Gumel (1981) noted that pod scarification by *M, lepidus* is restricted to the more mature pods and that it is much greater (40.9-87.9%) in dead stands where the tap root is invaded, than in healthy stands (7.9-31.6%) without tap root damage. They also reported that 85-91% of the kernels from scarified pods were infected with fungi while only 67% of the kernels from unscarified pods were infected with fungi.

Groundnut pod damage by termites is accentuated by irregular maturity and delayed harvest (Feakin 1973). Planting a single variety rather than a mixture of varieties and selecting optimum harvest dates reduces termite damage. Mechanical cultivation for successive years may reduce termite populations and thus reduce damage, but hand or shallow cultivation has no effect on termite damage. Feakin (1973) also suggested that groundnuts should not be planted on newly prepared ground. Johnson et al.(1981) noted that in farmland that is cultivated continuously every year, the only food available to termites is the crops, their residues, and litter. This, according to the authors, combined with the restricted foraging of termites during the dry season, poses a serious threat to the survival of *Microtermes,* particularly in the drier areas. Thus, substantial food reserves, i.e., fungal combs, have to be built up rapidly during the wet season. This foraging occurs at the expense of susceptible crops, such as groundnuts, and is an important factor in explaining the pest status of *Microtermes.* Johnson et al. (1981) also reported that the initiation of severe groundnut damage by termites, particularly the invasion of the tap root, coincided with the depletion of water in the top soil, which forces the termites to restrict their foraging to levels below the soil surface. They hypothesized that the highest levels of damage would occur in locations with a short rainy season and with well-drained soils.

The groundnut aphid, *Aphis craccivora,* as well as other aphids that feed on groundnuts, is important primarily because of its ability to transmit virus diseases to groundnuts. A. *craccivora* was the major cause of the rosette virus epidemic that devastated groundnut yields in 1975 (Gibbons 1977). Seven viral diseases are known to be transmitted to groundnuts by aphids (Wightman 1985); *A. craccivora* is the only aphid that is known to transmit all seven of these viruses.

Several thrips species are reported to attack groundnuts. Okwakpam and Youdeowei (1980) reported that four species of thrips attack groundnuts and other edible legumes in Nigeria, and Smith and Barfield (1982) listed an additional six species of thrips that attack groundnuts. Lynch et al. (1984) evaluated four systemic insecticides for control of thrips, primarily *Frankliniella fusca* (Hinds), on groundnuts in the southeastern U.S. They found that controlling thrips did not significantly increase yields, that high thrips populations occurred too early in the season to be of economic significance, and that thrips control was primarily cosmetic. Similar results were reported by Tappan and Gorbet (1979, 1981). In Africa, however, high thrips populations occur throughout the growing season.

Demange (1975) reported 13 species of millipedes that damage groundnuts in Senegal. During the rainy season, over 50% of the millipedes are found in the upper 10 cm of the soil, whereas in the dry season, 90% of the millipedes are below the 10-cm soil level (Gillon and Gillon 1979a, 1979b). Populations of millipedes tend to be higher around or under stumps, and around and in termitaries. Six species, *Graphidostreptus tumuliporus* Karsh, *Haplothysanus chapellei* Demange, *Peridontopyge conani* Brolemann, *P. rubescens* Attems, *P. spinosissima* Silvestri, and *Syndesmogenus minmeuri* Bro1emann, are the most frequently encountered (Rossion 1976, Masses 1981). *P. rubescens* and *S. mimeuri* are the dominant species, with one-third of the population of these two species occurring in groundnut fields. Millipedes are the most important pests of groundnuts in central Senegal (Masses 1981, personal communication, H. Masses, Station ISRA de Darou, B.P. 75 Kaolack, Senegal). They damage young groundnuts just after plant emergence, reducing plant density up to 20%. They also feed on developing pods, reducing yields by 30-40%. Millipedes primarily attack immature, developing pods, while termites attack the more mature pods (Johnson et al. 1981, IRHO 1982).

In many parts of Africa, the groundnut bruchid, *Caryedon serratus,* tends to be the most important insect pest of groundnuts, especially after the pods are dug (Davey 1958, Green 1959). Losses may approach 10% in each of the 4.5 generations during the dry season; after 3 generations of infestations by this insect, the groundnuts are unmarketable. Damage is greater on unshelled groundnuts where the insect egg is laid on the pod surface and the emerging larva tunnels through the pod and feeds on the kernel. Populations often reach economic levels when the crop is left in open storage for a prolonged period. Mature fruits of several native trees, *Piliostigma thonningi, P. reticulatus, Tamarindus indica,* and *Cassia sieberiana,* provide a continuous source for infestation throught the year (Conway 1983). Groundnut infestations from insects that emerge from primary tree hosts in the field are of major importance, with residual infestations in storage facilities of little consequence. Allowing groundnuts to remain in the field to dry for extended periods increases infestation. Damage during storage is related to the degree of infestation while the groundnuts are drying in the field. Jute bags for storing groundnuts restrict entry or exit of bruchid adults and thus reduce infestation from one bag to the next.

The "Wang" *Aphanus sordidus,* also attacks groundnut pods while they are drying in the field. This lygaeid bug pierces the groundnut pod with its mouthparts and feeds on the oil in the kernel. Such feeding causes the seed to become wrinkled and darker, and reduces germination (Thomas 1983, Conway 1976).

Delbosc(1966), Gillierand Bockelee-Mowan(1979), Mbata and Osuji (1983), and Thomas (1983) discussed most of the principal insect pests of stored groundnuts in Africa. Two orders of insects, Coleoptera and Lepidoptera, are of primary importance. The major coleopteran pests of stored groundnuts are the red flour beetle, *Tribolium castaneum* (Herbst); the confused flour beetle, *T. confusum* Jacquelin duVal; the khapra beetle, *Trogoderma granarium* Everts; the merchant grain beetle, *Oryzaephilus mercator* (Fauvel); and the sawtoothed grain beetle, 0. *surinamensis* (L.). The major lepidopteran pests of stored groundnuts include the rice moth, *Corcyra cephalonica* (Stainton); the almond moth, *Ephestia cautella* (Walker); and the Indian meal moth, *Plodia interpunctella* (Hubner).

Peanut CRSP Research in SAT Africa

Collaborative research between the University of Ouagadougou and the University of Georgia to develop IPM strategies for reducing insect damage to groundnuts in SAT Africa is conducted in Burkina Faso. The major goal of this collaborative research is to develop research information and procedures based on sound IPM principles that will help stabilize and/or increase groundnut yield. Specific goals of the Peanut CRSP-Entomology Project in Burkina Faso are to:

1. Identify the major economic pests of groundnuts.
2. Determine the relationship between level and type of arthropod damage and aflatoxin contamination in both preharvest and postharvest groundnuts.
3. Develop economic injury levels for major arthropod pests by quantifying pest density with groundnut yield.
4. Develop reliable sampling procedures to estimate population densities of the major pests.
5. Determine arthropod abundance as related to groundnut developmental phenology and season.
6. Provide training opportunities for Burkina Faso students.
7. Develop bait attractants or other control strategies for major insect pests.
8. Evaluate promising breeding lines developed by the CRSP Breeding Project for resistance/susceptibility to major arthropod pests.

Research addressing objectives 1, 5, and 6 was initiated in 1984. Surveys of groundnut pests were conducted in the major groundnut-growing areas of Burkina Faso and included locations near the cities of Po, Fada, Boromo, and Niangoloko. During three survey trips in 1984, the following insect groups were collected on groundnuts: Orthoptera, Thysanoptera, Homoptera, Hemiptera, Lepidoptera, Coleoptera, Diptera, Hymenoptera, Isoptera, and Julida. Insects collected during the surveys are currently being identified by taxonomic specialists. It appears from these results that four groups of these insects are of potential economic importance (Table 1). Thrips (apparently three species) populations were relatively high on groundnuts during all three surveys. Lynch et al (1984) showed that in Georgia (USA), control of thrips with systemic insecticides did not significantly increase yield. However, in Georgia, damaging thrips populations occur primarily during the first 30 days after emergence (DAE). Once groundnuts begin to flower, thrips move from the leaf terminals to the flowers, the plant growth rate increases logarithmically, and thrips populations decline. However, thrips in SAT Africa may be of much greater importance since high populations are maintained during the critical pod-set and pod-filling stages of growth.

Jassids are another group of insects that are of potential importance to groundnuts in Burkina Faso. Two species, *Empoasca dolichi* and *E. facialis,* are major pests in Africa (Amin and Mohammad 1980). Populations of jassids showed a drastic increase from July to September, especially at Boromo and Niangoloko. These extremely high jassid populations occurred during the latter portion of the pod-filling stages when the kernels are rapidly developing. Reduction in photosynthetic area and/or production of photosynthate that is partitioned for development of kernels during the critical physiological stages could substantially reduce groundnut yield.

Termites are a third group of insects that have economic importance to groundnut production in Burkina Faso. Although surveys in July to September showed limited populations and damage, their damage to groundnuts at harvest on the Gampala Research Station plots was substantial; 50-80% of the pods were scarified. Thus, these preliminary observations on termite damage confirm the ranking of termites as the first research priority by Dr. John Wightman, Principal Groundnut Entomologist, ICRISAT. Collaborative research between ICRISAT and the Peanut CRSP is planned to evaluate the termite-resistant genotypes reported by Amin et al. (In press).

Millipedes are the most important groundnut pests in the major growing region of Senegal (Masses 1981; personal communication, H. Masses, Station ISRA de Darou, B.P. 75, Kaolack, Senegal). Millipede populations were relatively low in the surveys in Burkina Faso, but millipedes should still be considered of potential economic importance until additional data are collected.

Damage to groundnut pods by millipedes and termites has certain similarities to damage caused by the lesser cornstalk borer (LCB) *Elasmopalpus lignosellus* (Zeller), a major groundnut pest in the USA. Lynch (1984) reported that damage to groundnut pods by LCB is determined by the stage of pod development (Williams and Drexler 1981) at the initiation of attack. Groundnut pods in stages 1-3 are preferred and penetrated by LCB larvae that then feed on the developing kernel. This is similar to the preference of millipedes for immature pods (Johnson et al. 1981). Conversely, pods in stages 4-6 were not penetrated by LCB larvae, but were scarified externally, resulting in damage similar to that reported for termites (Johnson et al. 1981). The LCB

Table 1. Arthropod abundance on groundnuts in Burkina Faso in 1984.

Location	Survey date	Thrips/ 10 terminals (10 sweeps)	Jassids/ 10 sweeps	Termites m^{-1}	Millipedes m^{-1}
Po	7/7/84	.	-	-	-
Fada		67	72	0	0
Boromo		72	12	4	10
Niangoloko		36	9	0	0
Po	19/8/84	83 (4)	14	0	8
Fada		27	0	0	0
Boromo		32	0	0	0
Niangoloko		59 (32)	134	0	4
Po	25/10/84	9 (53)	150	37	0
Fada		97 (166)	87	0	21
Boromo		30 (433)	657	0	0
Niangoloko		0 (94)	606	0	0

is considered a dryland insect in the U.S., primarily because economic damage by the LCB is associated with drought. Johnson et al. (1981) and Johnson and Gumel (1981) also reported that termite damage was greatest in periods of inadequate rainfall during the latter portion of the growing season, and they obtained a significant correlation of -0.76 between the percentage of groundnuts with the tap root invaded by termites, and rainfall. Lynch and Wilson (1984) demonstrated that the LCB was an excellent vector of *Aspergillus flavus* (Link) and that pod penetration and delayed harvest increased *A. flavus* and aflatoxin contamination. Similar results have been suggested for termites (Diener 1973, McDonald and Harkness 1963, 1964, McDonald et al. 1964) and millipedes (personal communication, H. Masses, Station ISRA de Darou, B.P. 75, Kaolack, Senegal). The number of similarities between the LCB, millipeds, and termites in their damage to groundnuts and probable enhancement of aflatoxin formation under dry conditions warrants continued research. Methods to reduce aflatoxin contamination in groundnuts through proper harvest dates, short- season varieties, and chemical control of soil pests are currently being investigated in Burkina Faso and the U.S. by the Peanut CRSP-Entomology Project.

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Role of Agrometeorological Factors in Postharvest Quality of Groundnut

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Abstract

Postharvest quality of groundnut results from the particular set of environmental and cultural practices that influence physiology and maturation. Groundnut composition, although related to environment, changes dramatically as groundnuts mature. A biochemical basis exists for inferior quality in immature groundnut. Drought stress and soil temperature influence maturation rate and thus have an indirect effect on postharvest quality. Aspergillus flavus *invasion and aflatoxin contamination in groundnuts are related to drought stress, soil temperature, and maturity. Small, immature seed are more likely to be contaminated with* A. flavus *than larger, mature seed. The biochemical composition, fungal contamination, and the tendency toward higher moisture content complicate storage of immature seed. Each of these factors predisposes immature seed to rapid quality deterioration in storage. Agrometeorological studies must include an awareness of the relationships between environment, maturity, and postharvest quality.*

Résumé

Effet des facteurs agrométéorologiques sur la qualité de l'arachide après la récolte : *La qualité des arachides après la récolte résulte du jeu des facteurs environnementaux et des pratiques culturales qui influencent la physiologie et la maturation. La composition de l'arachide, bien que liée à l'environnement, change radicalement lors de la maturation. Une base biochimique existe pour la qualité inférieure des arachides immatures. Le stress hydrique et la température du sol influencent le taux de maturation et ils ont, par conséquent, un effet indirect sur la qualité de l'arachide après la récolte. L'*Aspergillus flavus *et les aflatoxines sont associés aux stress hydriques, aux températures du sol et à la maturité. Les petites semences immatures risquent plus d'être contaminées par* A. flavus *que les semences plus grosses et matures. La composition biochimique, la contamination fongique et la tendance vers des teneurs plus forte d'humidité compliquent le problème du stockage des semences immatures. Chacun de ces facteurs favorisent la détérioration rapide de la qualité des graines immatures après la récolte. Les études agrométéorologiques doivent tenir compte des relations qui existent dans l'environnement, la maturité et la qualité après la récolte.*

Introduction

Agrometeorological factors during groundnut production determine postharvest quality. Quality characteristics produced under certain environments can be predicted and modifications of the environment can be attempted to produce desirable characteristics. Regardless of the particular environment, genotype, or cultural modification, there are maturational factors which must be considered as signifi-

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cantly affecting postharvest groundnut quality. As groundnuts reach the metabolically quiescent, compartmentalized stage indicative of maturity, they are closest to meeting the full potential of total acceptance in almost all phases of groundnut production, handling, and manufacturing. This premise is not meant to be all inclusive since differences do exist in seed of the same physiological maturity due to environment, culture, and genotype. Groundnut plants are indeterminate and any set of environmental parameters and cultural practices that produce groundnuts will yield a crop in which various stages of seed maturity may be found. The particular maturational distribution of a groundnut crop is the result of environmental influences from the time of sowing until harvest. The many maturity methods developed to determine the appropriate time to harvest are aimed at obtaining the greatest percentage of mature pods (Young 1973, Holaday et al. 1979, Pattee et al. 1974a, 1977, Williams and Drexler 1981, Sanders et al. 1980).

As a simplified approach to addressing the postharvest topic and because of the obvious relation of maturity and quality, this report will emphasize the relation of groundnut maturity to composition, environment, seed size, *Aspergillus flavus* invasion, aflatoxin production, and storability.

Maturity

Studies involving groundnut maturity are complicated because maturation is a continuous process and not composed of distinct phases. Two excellent methods of physiological maturity classification have been developed, the Physiological Maturity Index (Pattee et al. 1974a) and the Pod Maturity Profile (Williams and Drexler 1981). The Physiological Maturity Index is based on internal hull and seed-coat characteristics. Although considerable time and effort are involved in examining the characteristics of each pod, the accuracy and reproducibility of the Physiological Maturity Index has been well documented (Pattee et al. 1974a, 1974b, Sanders 1980a, 1980b, Sanders et al. 1982).

The Pod Maturity Profile classification, based on physical characteristics and pod mesocarp color after partial removal of exocarp (Table 1), provides a novel approach to maturity classification since pods of different maturity may be separated without substantial damage to pod structure. Pod exocarp is usually removed by scraping or gentle abrasion to reveal the colored mesocarp. This method of maturity classification has been extended into a harvest-date predictor commonly called the Hull-Scarpe Method.

Maturity—Chemical Composition

Relatively few studies have been conducted to determine the relation of groundnut maturity to various chemical components thought to be related to quality. Oil is by far the most studied component of groundnuts, justifiably so since approximately 50% of the groundnut is oil. Early studies to quantify oil content as groundnuts matured were complicated by

Table 1. Pod-maturity profile class characteristics.

Class	Mesocarp color[1]	Exocarp characteristics
White	White	initial development through maximum size, soft, watery longitudinal venation, distinct net venation on basal segments beginning
Yellow 1	pale yellow	net venation nearly complete to complete, slightly rough, somewhat resilient
Yellow 2	dark yellow	somewhat rigid to rigid structure, distinct reticulation
Orange	orange to brownish orange	rough, rigid, reticulated
Brown	reddish brown to brown	rough. very rigid, reticulated
Black	black	rough, very rigid, reticulated

1. Median class color of mesocarp at or near the basal seed attachment point.

the lack of an adequate method of determining maturity; however, the fact that oil content increases to a point with groundnut maturity has been known for 50 years (Patel and Seshadri 1935). The work of Pickett (1950) and Schenk (1961) provided information on the rate of oil synthesis relative to time after the gynophore entered the soil, and suggested rapid oil synthesis during the early stages of seed development. Worthington (1968) noted changes in total oil and fatty acid composition in various groundnut parts as groundnuts matured. Pattee et al. (1974a) were probably the first to report separation of groundnuts into distinct physiologically identifiable categories to observe change in fruit parts.

Studies of groundnut oil-fatty acid composition and change with broad maturity levels have been reported (Senn 1969, Young et al. 1972, 1974); however, Sanders (1980a, 1980b) made an indepth study which demonstrated that not only did the relative weight percent of specific oil fractions change with maturity, but that the fatty acids of these fractions also changed. The data demonstrated that triacylglycerols increased to a physiological maturity stage commonly associated with a mature groundnut, while free fatty acids and diacylglycerols continued to decrease throughout maturation. This data and other works by Sanders et al. (1982) and Pattee et al. (1974a, 1974b) demonstrate that some changes continue through maturation, but many oil components reach a plateau before maturation is complete. Investigations in which composition or change in composition (Mohapatra and Pattee 1973) were described relative to maturity, indicate that there is a definite relation between oil composition, ease of composition change, and maturity. Oil composition studies from various aspects definitely indicate that maturity is related to quality and thus any agrometeorological factor that delays or enhances the maturation process also affects the inherent quality of the groundnut produced.

In addition to oil content and composition, carbohydrates, free amino acids, and proteins in groundnut are closely related to maturity (Schenk 1961, Pattee et al. 1974a, Oupadissakoon et al. 1980, Basha et al. 1976, Cherry 1974). Schenk (1961) noted that crude protein increased with maturation and Cherry (1974) later reported that large molecular weight storage globulins were rapidly deposited 9-12 weeks after pegging, and varied quantitatively among mature seeds grown in different environments. Basha et al. (1976) reported that very early in the development of groundnut seeds (possibly at the time of pegging) free amino acids are rapidly synthesized. As seeds mature, these stored free amino acids are converted to storage proteins and or nonprotein constituents. These latter changes were especially conspicuous between the immature and low-intermediate stages of seed maturation, when fresh weight rapidly increased. In addition, the precursor role of free amino acids during protein deposition in groundnut seeds is evident, i.e., maturing seeds containing high amounts of free amino acids deposited protein more rapidly than those with a low content of these constituents.

Total carbohydrate content of immature seeds of all cultivars included in a study by Basha et al. (1976) ranged between 25 and 35% and declined continuously thereafter to levels of approximately 10% at the most mature stage. These observations agreed with the findings of Pattee et al. (1974a, 1974b) which showed that immediately after pegging, carbohydrate content of maturing seeds increased and then declined. Maturing seeds probably used stored, nonstructural carbohydrates as a source of energy for synthesis of lipids and protein. Quantitative changes in free amino acids, carbohydrates, and total proteins in maturing groundnut seeds may be closely related to one another but may vary among cultivars (Basha et al. 1976).

This very brief and noncomprehensive review should adequately demonstrate a biochemical basis for reduced postharvest quality in physiologically immature groundnut. A biochemical basis for poor quality also sometimes exists relative to cultivar, growing location, and other factors; however, within defined parameters, maturity is a dominant quality factor.

Maturity—Environment

Groundnut maturation is affected by many agrometeorological factors, but two of the most influential are soil moisture and soil temperature. During stress from low soil moisture, the soil temperature increases. This may result from higher air temperatures or from the fact that in severe drought stress, groundnut canopies recede and expose more soil to direct solar radiation. During adequate-moisture conditions soil temperature below the groundnut canopy tends to be lower than unshaded soil but may vary due to season or elevation. We have used the maturity profile to evaluate the effects of end-of-season drought-stress duration, degree of drought stress, and soil temperature on maturation of Florunner groundnuts.

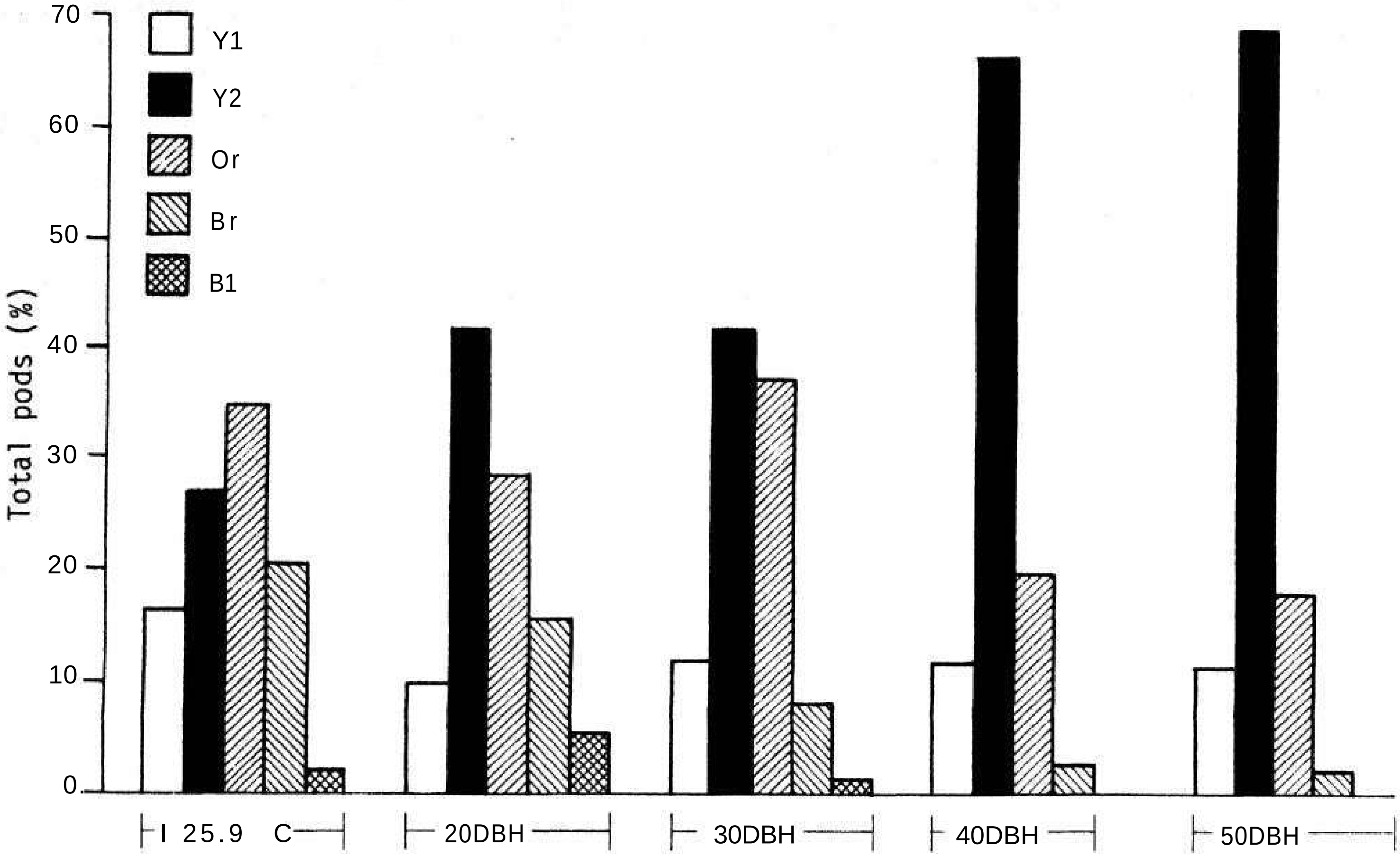

Figure 1. Effect of drought-stress duration on maturity distribution of Florunner groundnuts. (Maturity stages beginning with the most immature are Y1 =yellow 1, Y2 = yellow 2, Or = orange, Br = brown, and B1 = black. 1 = irrigated, 20 DBH, 30 DBH, 40 DBH, and 50 DBH = no water and 29-30°C mean geocarposphere temperature for 20, 30, 40, and 50 d before harvest).

Drought-stress durations of 30-50 d (mean geocarposphere temperature of 29-30℃) before harvest (142 days after sowing, DAS) produced marked delays in maturation of Florunner groundnuts (Fig. 1). In the 40- and 50-d treatments approximately 2% of the total number of full-sized pods were considered mature and no pods were present in the most mature category (black). The large number of pods in the yellow 2 category is consistent with numerous field observations from drought-stressed situations. The 30-d treatment provided some delay in maturation although more of the yellow 2 category did progress into the next most mature category than did pods in the yellow 2 category in treatments of longer duration. The fully-irrigated treatment was overall more advanced in maturity profile than the various drought- and temperature-stress treatments. However, from a harvest-date basis the profile indicated that they may have been dug somewhat early.

In a recent study (Sanders, T.H., USDA, ARS, National Peanut Research Laboratory, Dawson, Georgia, and Schubert, A. M., Texas A & M University, Yoakum, Texas, unpublished) various degrees of drought stress were induced in Florunner groundnut research plots by scheduling irrigation using a canopy temperature stress degree day index. All stress treatments were harvested 134 DAS and delay in maturation was directly related to degree of stress. Use of the Hull-Scrape method of harvest-date prediction indicated only a 4-10 d differential in digging date among the treatments, but number of pods in immature stages increased with increase in stress severity. Plants subjected to the most severe drought stress not only produced smaller yields but also had seed-size distributions containing the greatest percentages of small seed (Table 2). The effect on seed size would be masked by some current groundnut-grading procedures which use a 6.4-mm screen to determine sound mature kernel (SMK) percentages. Weight percentages of seed riding a 6.4-mm screen were 94.6% for minimum, 96.1% for moderate, and 90.4% for severe drought stress. However, differences are evident when percent weight of seed riding a 7.9-mrn screen are considered (minimum stress, 53.4%; moderate stress, 39.5%; severe stress, 25.2%). Temperature measurements were not made in this

Table 2. Effect of degree of drought stress on seed size distribution of Florunner groundnuts.

Stress	Screen size (mm)							
level	9.5	8.7	7.9	7.1	6.4	5.6	4.8	<4.8
	Weight (%)							
Minimum	1.8	13.0	38.6	31.8	9.7	2.8	1.2	1.1
Moderate	0.2	5.9	33.4	43.1	13.5	2.1	0.7	1.1
Severe	0.4	3.6	21.1	37.2	28.1	7.5	1.4	0.7

study and thus it cannot be assumed that drought stress alone accounted for these differences.

Although separation of the effects of soil temperature and soil moisture is difficult, we have conducted studies that demonstrated the effect of soil temperature on maturation of Florunner groundnuts (Sanders and Blankenship 1984). In these studies we attempted to maintain adequate soil moisture in the heated, ambient, and cooled soil treatments which were located in the same small-plot area. Soil temperatures followed normal diurnal patterns but heating cables and cooling coils were used to increase or decrease the temperatures. Mean geocarposphere temperatures were modified from 28 DAS through harvest. The heated treatment (29.2℃) had an advanced maturity profile, while the cooled treatment (23.1℃) was delayed compared to the control or ambient treatment (26.0℃) (Fig. 2). The study became intriguing when sizing revealed a seed-size distribution containing many more large seeds in the cooled treatment and overall smaller seeds in the distribution of size in the heated treatment.

The fact that the most immature maturity profile had a seed distribution containing the greatest percentage of large seed and the most mature profile contained more small seed indicated that the size-maturity relationship could be altered by the environment. Evaluation of the same specific size seed from each plot revealed that seed from the cooled plot were more physiologically immature than those from the ambient plot, which were more immature

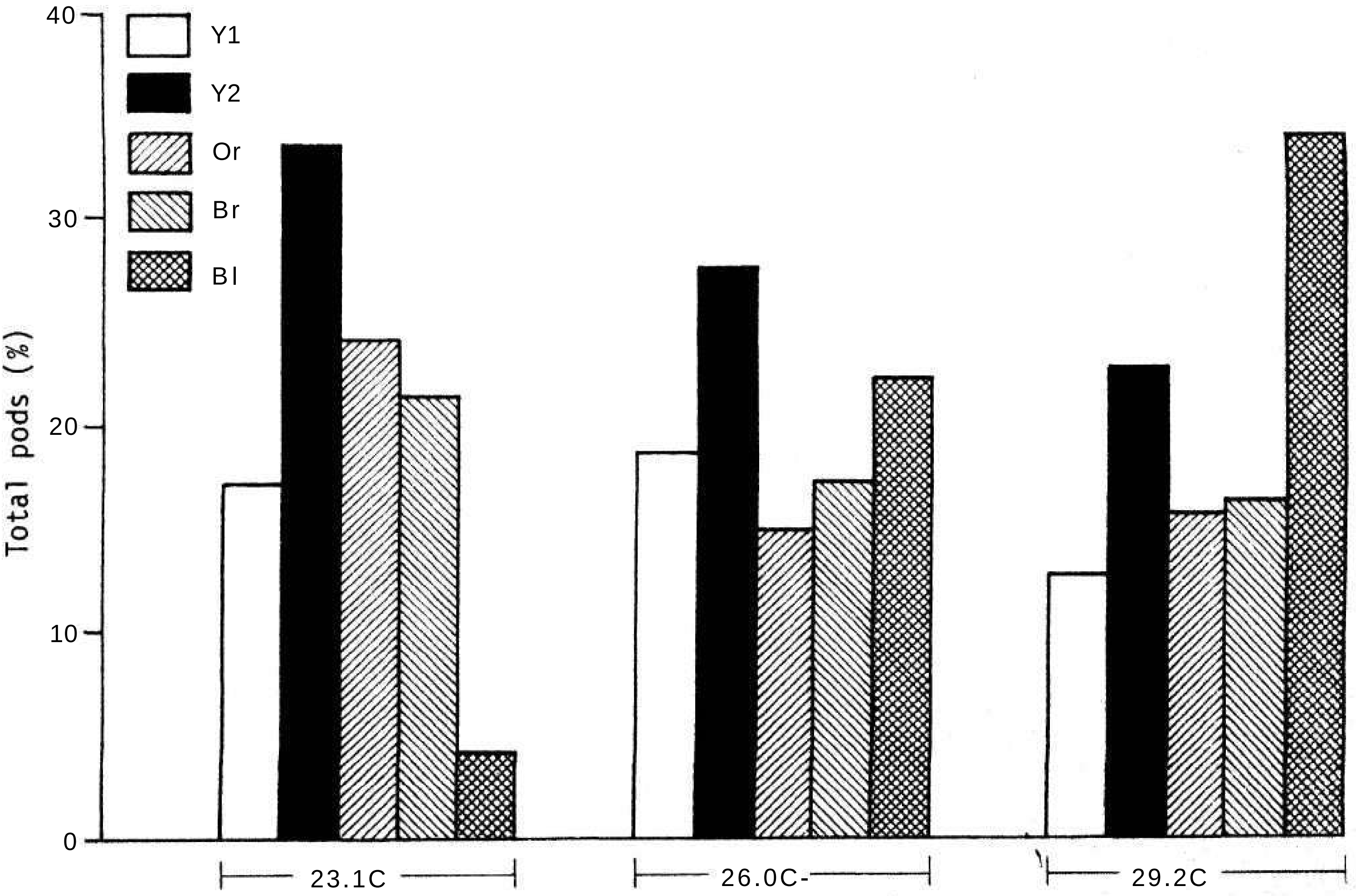

Figure 2. Effect of soil temperature on maturation of Florunner groundnut at 130 days after sowing. (Maturity stages beginning with the most immature are Y1 = yellow 1, Y2 - yellow 2, Or - orange, Br = brown, and B1 - black).

than those from the heated plot. These evaluations confirmed that a maturity-size relationship did exist within each lot. In studies with a spanish-type groundnut (cv Sellie), Dreyer et al. (1981) found that lower soil temperatures produced the greatest number of fruits and delayed maturation. No numerical estimate of maturity or seed-size information was provided in that study. Williams et al. (1983) reported a close relationship of seed size to pod maturity for nine different groundnut varieties. The maturity-size relationship for the Florunner variety is shown in Figure 3. Pod and seed weights reached a maximum at the beginning of the 'black' mesocarp color maturity class and pods had reached 90% of their maximum size by the end of the 'white' maturity stage. Increases in seed size were not measurable past the late 'brown' stage.

Maturity—*A. flaws*/aflatoxin

Groundnuts without obvious damage can be invaded by *A. flavus* and contaminated with aflatoxin in the field before digging. This phenomenon has been associated with drought for a number of years and recently precise temperature and time factors have been delineated. Research has shown that mean drought geocarposphere temperatures between approximately 26℃ and 31℃ for 30 d or more will produce aflatoxin-contaminated groundnuts (Sanders et al. 1981, 1983, Hill et al. 1983, Blankenship et al. 1984, Cole et al. 1984). This work demonstrated, contrary to early reports, that small immature pods and seed were the first to become contaminated, were the most heavily invaded, and generally contained the highest aflatoxin concentrations. Sanders et al. (1981) reported that the incidence of *A. flavus* in groundnut maturity stages of irrigated and drought treatments was obviously different 17 d after drought treatment began. Incidence of *A. flavus* in maturity stages in all treatments generally increased with time and at 144 DAS (50-d drought) pegs and small pods (white stage) were approximately 70% colonized and mature pods (brown and black stages) were approximately 30% colonized. From the same studies Hill et al. (1983) reported that aflatoxin content increased as seed size decreased.

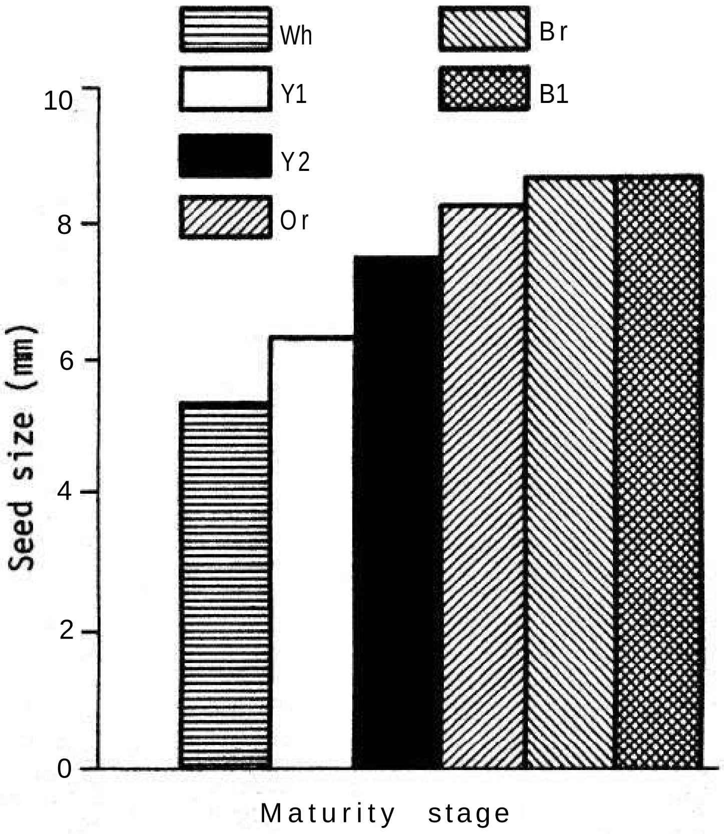

Figure 3. The relation of Florunner groundnut maturity stage to seed size. (Maturity stage beginning with the most immature are Wh = white, Y1 = yellow I, Y2 = yellow 2, Or = orange, Br = brown, and B1 = black.)

High aflatoxin content in small, immature groundnuts has been verified in subsequent plot studies (Blankenship et al. 1984) and in studies on separation and removal of aflatoxin-contaminated kernels in groundnut-shelling plants (Davidson et al. 1981). Cole et al. (In press) indicated that *A. flavus* invasion and aflatoxin production were separate events and suggested that some inherent mechanism preventing aflatoxin formation broke down under stress in response to increased growth of the fungus after invasion. It is possible that such a resistance mechanism operates, in fact, at the level of fungus invasion/growth and thus indirectly regulates aflatoxin production. The relation of maturity and size to colonization and aflatoxin content suggests that mature groundnuts are less susceptible to *A.flavus* invasion/aflatoxin production or have passed through the most susceptible maturity stage before drought conditions began.

Maturity—Storage

The fact that immature groundnuts are physiologically inferior to fully-mature groundnuts and more likely to be invaded by *A. flavus* serve amply to indicate that immature groundnuts also present a special problem in storage. Recently, Smith (Smith, J.S., USDA, ARS, National Peanut Research Laboratory, Dawson, Georgia, unpublished) measured the moisture content of immature groundnuts as they were moved from harvest through 158 d of farmers' stocks storage in a large warehouse. At harvest the groundnuts contained 68% moisture, which decreased to 49% after windrow drying and combining (5 d after digging). Moisture content of the groundnuts dropped to 26% after artificial drying and even after storage for 5 months the groundnuts contained 17% moisture. This moisture content is unacceptable for any storage period. All lots do not have the same moisture content but it is a common sight in inshell storage to find immature pods covered with some fungus growth. Immature groundnuts in cold storage can often be identified by the preponderance of visible fungus growth. The fact that immature seed are less metabolically quiescent at harvest suggests that biochemical changes may be more prone to occur in these immature seed (Mohapatra and Pattee 1973). Data in Table 3 demonstrate that small immature seed are more prone to deterioration in storage than are large seed. We must assume here a consistent maturity-size relationship. Pattee et al. (1982) found that a storage-moisture content difference of only 3% (6% vs 9%) produced significant differences in free amino acids and free sugar and suggested that the 9% moisture content allowed increased hydrolysis of complex constituents and caused significant deterioration of quality.

Table 3. Effect of inshell storage on increase in percent free fatty acid, and total carbonyl content of various sizes of Florunner groundnuts.

	Free fatty acid		Total carbonyls	
Size (mm)	Inital	Final	Inital	Final
	% as oleic acid		moles kg^{-1} oil	
> 8.3	0.10	0.15	0.88	2.09
> 7.1 < 8.3	0.10	0.19	0.84	2.14
> 6.4 < 7.1	0.11	0.23	1.12	2.59
> 5.6 < 6.4	0.10	0.27	1.25	2.94

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Cropping Systems with Groundnut: Resource Use and Productivity

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Abstract

In the rainfed semi-arid tropics (SAT) the relatively short growing season usually limits the choice of cropping systems with groundnut, either to sole-crop or intercropping systems. This paper examines some of the mechanisms associated with environmental factors that can enable intercropping systems to outyield sole-crop systems. Temporal intercropping systems, where the component crops make their peak demands on resources at different times, are illustrated with a groundnut/pigeonpea system. In this system higher yields from intercropping are associated with a fuller use of environmental resources over time. Spatial intercropping systems are illustrated with a 3-year rainy-season study on millet/groundnut. A higher yield from intercropping was most notably associated with improved light-energy conversion. Drought-stress studies on sorghum/groundnut and millet/groundnut showed no stress effects on the relative dry-matter yield advantages of intercropping. However, relative reproductive yield advantages of intercropping increased markedly with stress because the harvest index of sorghum and groundnut decreased much less in intercropping than in sole cropping. The importance of nitrogen fixation in intercropped groundnut and the likely benefits to nonlegume companions or following crops are also discussed.

Resume

Systèmes de cultures basés sur l'arachide en zones tropicales semi-arides — utilisation des ressources et productivité : *Dans les zones tropicales semi-arides, la durée relativement courte de la période de croissance limite, en agriculture pluviale, le choix de systèmes de cultures de l'arachide, tant en systèmes de culture pure qu'en association. Cette communication porte sur certains mécanismes associés aux facteurs environnementaux, qui permettent aux systèmes de cultures associées de surpasser les systèmes de culture pure. Les systèmes d'association de type temporel, où les membres de l'association ont des besoins maximum de ressources à des périodes différentes, sont illustrés pour l'association arachide/pois d'Angole. Dans ce système, les rendements supérieurs sont dus à une meilleure utilisation des ressources du milieu dans le temps. Les systèmes d'association de type spatial sont illustrés grâce à une étude de trois ans effectuée durant la saison des pluies, sur l'association mil/arachide. L'association a permis d'obtenir de meilleurs rendements grâce, entre autres, à une meilleure conversion de l'énergie. Les études sur le stress hydrique de l'association sorgho/arachide et mil/arachide n'ont montré aucun effet de stress sur les avantages relatifs du rendement en matière sèche de l'association. Cependant, les avantages relatifs de rendement reproductif de l'association ont augmenté sensiblement avec le stress car l'indice de récolte du sorgho et de l'arachide ont beaucoup moins diminué en cultures associées qu'en culture pure. L'importance de la fixation de l'azote par l'arachide associée et les bénéfices probables pour la non légumineuse et les cultures subséquentes sont aussi discutés.*

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Introduction

A cropping system growing annual crops is usually defined as the combination of crops grown on a given area within any one year. In humid areas with a potentially long growing period, several cropping systems may be possible. But in rainfed semi-arid areas the possible systems are much more limited. With groundnut, a relatively long-season crop that usually occupies all or at least the greater part of the potential cropping period, there are usually only two alternatives: either the groundnut can be grown as a single sole crop, or it can be interplanted with other crops in an intercropping (or mixed cropping) system.

Despite increasing research attention during recent years, intercropping systems are still poorly understood compared with sole-crop systems, but there is considerable evidence that intercropping can often provide substantial yield advantages over sole cropping. Some of the mechanisms that bring about these advantages are associated with environmental factors. These particular mechanisms and how they operate specifically in groundnut intercropping systems are considered in this paper. Sole-crop systems are considered only where they provide the basis for comparison with intercropping systems.

Use of Environmental Resources

Probably the most common cause of higher yields from intercropping over sole cropping is the improved use of environmental resources. Put very simply, if component crops in an intercropping system use resources differently than when grown together, the crops complement each other and make better overall use of resources than when grown as separate sole crops. For convenience such complementarity is often considered as either temporal or spatial.

Temporal Complementarity

Temporal complementarity occurs when component crops make their major demands on resources at different times during the season. In groundnut systems, this kind of complementarity is particularly evident when groundnut is intercropped with long-season crops such as cotton, castor, pigeonpea, or, in more humid areas, cassava. This kind of combination is common in most groundnut areas, although management of the system may vary considerably according to the relative importance of the component crops. With cotton or castor, which are often regarded as crucial, relatively high-investment cash crops, groundnut is commonly a supplementary crop grown with little or no sacrifice of the cotton or castor. In contrast, groundnut is usually the more important crop in the groundnut/pigeonpea combination commonly grown in India. In this system groundnut is usually sown as a reasonably full stand with only occasional rows or plants of pigeonpea.

Resource use and productivity in these temporal systems is illustrated by some work at ICRISAT Center on a groundnut/pigeonpea combination. Two-row arrangements, in which pigeonpea was grown in rows spaced at 1.2 m and 1.5 m with three and five intervening rows of groundnut respectively, were examined. Within-row spacings were adjusted so that each crop had a plant population equivalent to a full sole crop as an attempt to produce high yields in each. There was little difference between the two treatments so only mean yields are presented here. The groundnut (cv Robut 33-1) was harvested at 95 days after emergence (DAE) and the pigeonpea (cv ICP 1) at 175 DAE.

For most of its growing period the dry-matter accumulation of intercropped groundnut was only about 10-15% less than the full groundnut sole crop (Fig. 1A). At least in the early stages it is unlikely that this yield loss was due to competition from the pigeonpea, which established very slowly, and was probably because compared with sole groundnut, the intercropped groundnut was unable to utilize the space allocated to the pigeonpea. By final harvest, however, yield loss of intercropped groundnut was 24%. By this stage some of this effect may well have been due to pigeonpea competition. Dry-matter accumulation of pigeonpea was much more affected by intercropping. Yield loss for the first 110 d ranged between 40-50%, almost certainly due in part to competition from the groundnut. But in the later stages of its growth the intercropped pigeonpea was able to benefit from the removal of the groundnut and by final harvest the total dry matter was only 28% less than sole pigeonpea. Considering the combined intercropped yield, groundnut produced 76% of a full sole crop and pigeonpea 72%, i.e., there was an overall dry matter-yield advantage of 48%. Harvest indices were slightly higher in intercropping than in sole cropping, so reproductive yields were 80% and 78%, respectively, giving a yield advantage of 58%. This advantage was at a very high level of productivity: the intercrop absolute yields were 3287 kg ha^{-1} of groundnut and 1155 kg ha^{-1} of pigeonpea.

These results are from a single-season experiment, but they typify what is possible with this combination. A set of multinational stability experiments (5 locations x 4 years) with the same combination gave an average overall advantage of 53%. Other workers have regarded the pigeonpea as a supplementary component: Appadurai and Selvaraj (1974) reported a 37% yield of pigeonpea while still maintaining 99% groundnut yield; John et al. (1943) reported that groundnut/pigeonpea intercropping was 43% more profitable than sole groundnut. In contrast, in other temporal combinations the groundnut has been regarded as the supplementary component. Compared with sole castor, groundnut/castor was 62% more profitable (Reddy et al. 1965) and 32% more profitable (Tarhalkar and Rao 1975). Similarly, Joshi and Joshi (1965) and Varma and Kanke (1969) have shown significant increases in yield and profitability from groundnut/cotton intercropping compared with sole cotton.

The resource-use pattern in these temporal combinations is exemplified by the light interception observed in the ICRISAT groundnut/pigeonpea experiment (Fig. 1B). In the sole crops, the fairly rapidly establishing groundnut reached its maximum interception by about 45-50 d, while the much slower-growing pigeonpea took until 90-100 d. In the intercrops, early interception was as good as sole groundnut, which was obviously due to the presence of a high groundnut population. At groundnut harvest the interception fell to 50-60%, but by virtue of the high pigeonpea population, it stayed at a reasonable level until pigeonpea harvest. In total, therefore, intercropping intercepted more energy throughout the season than either of the sole crops. The conversion efficiency of total intercepted energy into dry matter in intercropping was the same as in sole cropping. Thus the higher total dry matter in intercropping was produced not by more efficient conversion of light, but by greater interception. Although other resources were not examined in this experiment, light, water, and nutrients have all been examined in detail in a temporal combination of a 90-day sorghum with pigeonpea (Natarajan and Willey 1979). For all three resources a large yield increase in an intercrop was due to the utilization of more resources, and not more efficient conversion into dry matter. Generally in an intercrop combination where there is a large temporal difference between the components, the simple effect is that the more rapidly growing crop ensures good use of early resources, and the slower-growing crop ensures good use of later resources. Higher yields are thus produced by the simple process of more complete resource utilization over time.

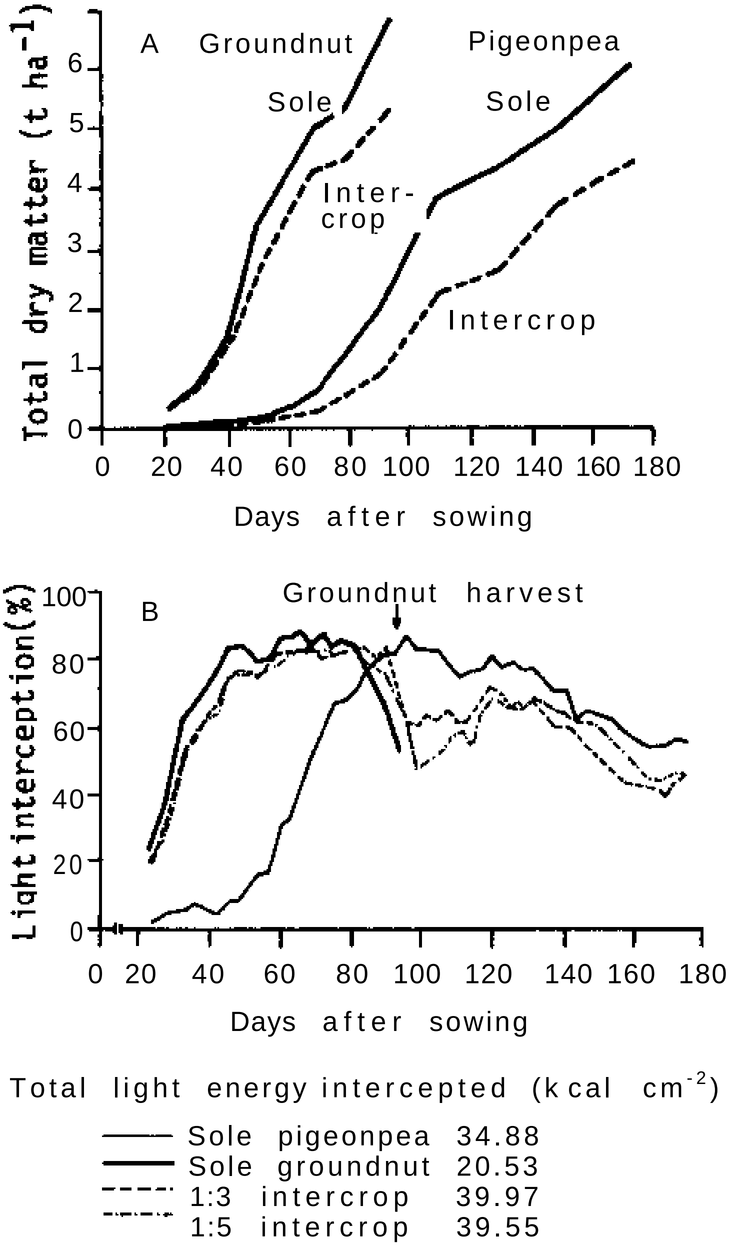


Figure 1. Dry-matter accumulation and light interception in groundnut/pigeonpea intercrop.

Spatial Complementarity

The commonest groundnut intercrop is with a cereal. In semi-arid areas, where the cereal is normally sorghum or pearl millet, the short growing season often means that there is little difference between the maturity periods of component crops and thus much less scope for the kind of temporal complementarity discussed in the previous section. Productivity and resource use in these cereal/groundnut systems is illustrated by some ICRISAT studies on a pearl millet/groundnut combination (Willey et al. 1983). Figure 2A shows a 3-year average for a

1-row millet/3-row groundnut combination in which within-row spacing for each component was the same as in sole crops. Plant populations were therefore the same as row proportions, i.e., 25%:75%. This arrangement is typical of systems where groundnut is the major crop, with several rows of groundnuts interspersed between only occasional rows of cereal. The millet was BK 560, harvested at 85 d, and the groundnut was Robut 33-1, harvested at 100 d. For most of the growing period the groundnut

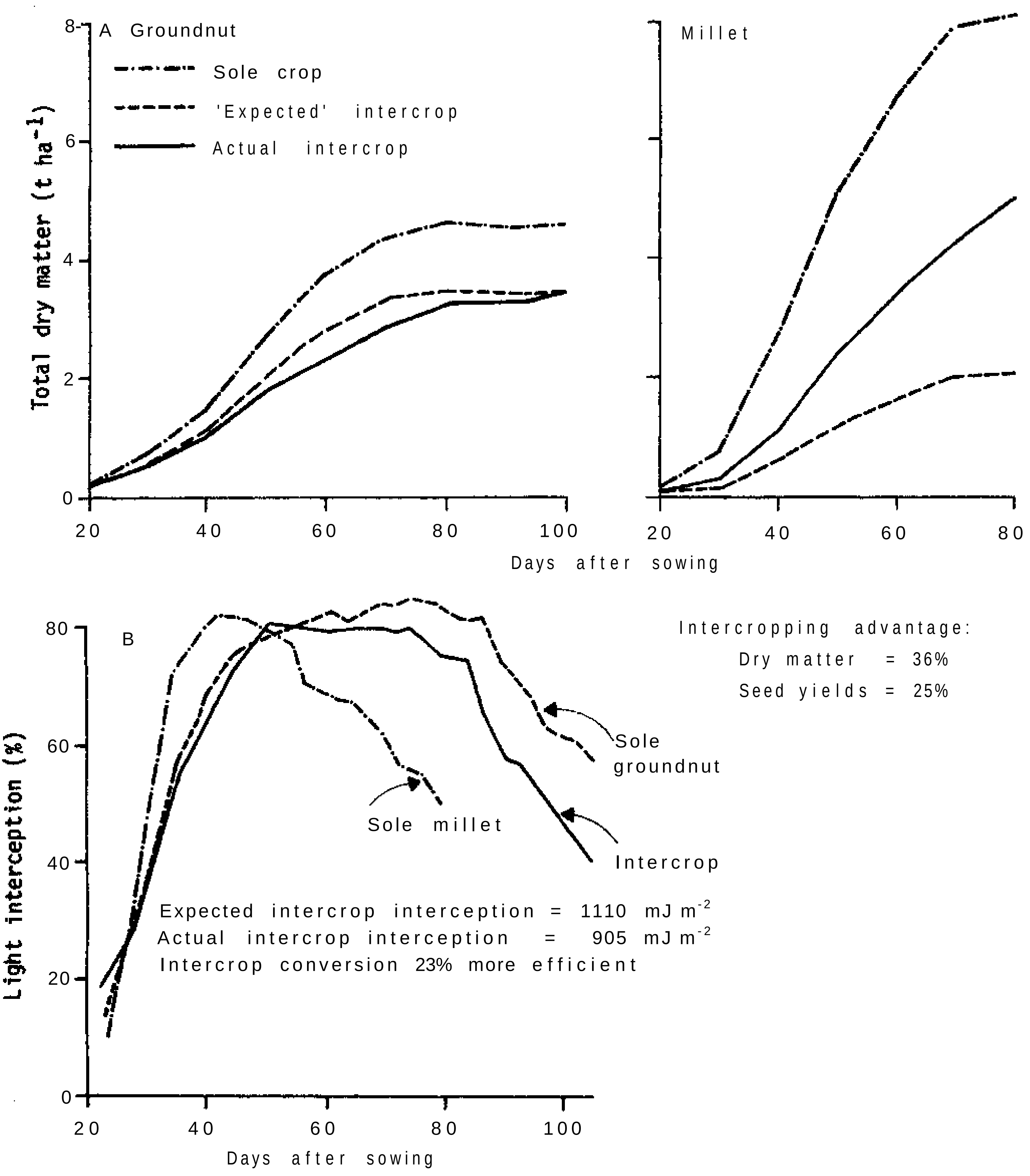


Figure 2. Dry-matter accumulation and light interception in pearl millet and groundnut as sole crops and as a 1-row millet: 3-row groundnut intercrop (means of 1978, 1979, and 1980).

accumulation of dry matter was a little less than the 75% sole-crop yield expected from the sown proportion in intercropping; thus groundnut growth was to some extent suppressed by the presence of millet. Towards the end of the season, however, when millet was senescing and was eventually harvested, the groundnut was able to recover, and its final yield was equivalent to that expected. In effect, final yield per plant was the same in intercropping as in sole cropping. In contrast, dry-matter accumulation of the millet, the more competitive crop, was more than twice its 25% sole crop expected level, and at final harvest the yield was 62% of the sole crop. Combining these dry matter yields gave an overall advantage for intercropping of 36%. For reproductive yields the advantage was a little lower (25%) because of small decreases in the harvest indices of both crops. These results are reasonably consistent with other studies that have shown intercropping advantages of up to 57% with sorghum (Evans 1960, Rao and Willey 1980, Tarhalkar and Rao 1975), and up to 54% with maize (Evans 1960, Koli 1975).

Light interception in this intercropping combination showed a pattern intermediate between the two sole crops (Fig. 2B), but intercepted energy was converted into dry matter 23% more efficiently than in sole crops. Thus, in contrast to the groundnut/pigeonpea combination, the higher yield in the intercrop was only partly due to the interception of more light, but mainly due to more efficient light conversion. In effect, therefore, this combination must have displayed some spatial complementarity between the component canopies so that overall conversion efficiency was increased. One obvious possibility is that the erect C4 millet leaves made efficient use of the high light intensities at the top of the canopy while the compact C3 groundnut canopy made efficient use of the lower light intensities in the bottom of the canopy. A detailed study that tried to separate the light use of the two crops showed that on a plant-for-plant basis, intercropped groundnut intercepted 27% less light than the sole crop, but yielded the same. It seems likely, therefore, that one of the major mechanisms in this particular situation was that shading by millet improved overall light-use efficiency (LUE) by reducing light saturation in the groundnut.

Examination of water use in these millet/groundnut experiments was not very conclusive, perhaps partly because the experiments were conducted in good rainy seasons when there was little drought stress. However, there were indications that the increased yields in the intercrop were partly because of a greater total water use, and partly because of reduced evaporation losses. The nutrient-use pattern was quite clear however, and was similar to the groundnut/pigeonpea combination in that higher yields in intercropping were associated with commensurately higher nutrient uptake. The implication of this greater nutrient uptake may be that higher intercropping yields will have to be paid for with higher fertilizer inputs. But there is the possibility that complementarity between intercrop components, perhaps because of different rooting patterns, could allow the uptake of some nutrient resources that would not otherwise be used.

Effects of Environmental Stress

These millet/groundnut studies were carried out under good conditions: the rainfall was adequate and the millet component received nitrogen equivalent to 80 kg ha^{-1} for a sole crop. Further studies examined how the relative advantages of intercropping were affected by limited supplies of water and/or nutrients, two factors of crucial importance in the rainfed SAT. These studies were also designed to determine if the importance of improved light-energy conversion observed in the earlier experiments was at least partly because other resources were not limiting. A dry-season experiment (Vorasoot 1982) on the same millet/groundnut system examined treatments of low drought stress (irrigated every 10 d) and drought stress (irrigated every 20 d) factorially combined with low nitrogen stress (80 kg N ha^{-1}) and nitrogen stress (0 kg N ha^{-1}). Table 1 indicates that compared to having a good supply of both resources, the relative yield advantage of intercropping increased slightly if there was lack of either water or nitrogen, and it increased even further if there was no evidence that improved efficiency of light-energy conversion became less important as below-ground resources became more limiting. Similarly there was no evidence that an improved water-use efficiency (WUE) was affected by the degree of drought or nitrogen stress.

One of the problems with this stress experiment, which was laid out in a conventional design, was the inability to examine a reasonable number and range of moisture regimes. Two subsequent experiments examined a range of five moisture regimes by establishing treatments at different distances from a line-source system of irrigation sprinklers. The whole experimental area was uniformly irrigated up to 25 DAE, and thereafter uniform irrigations were given

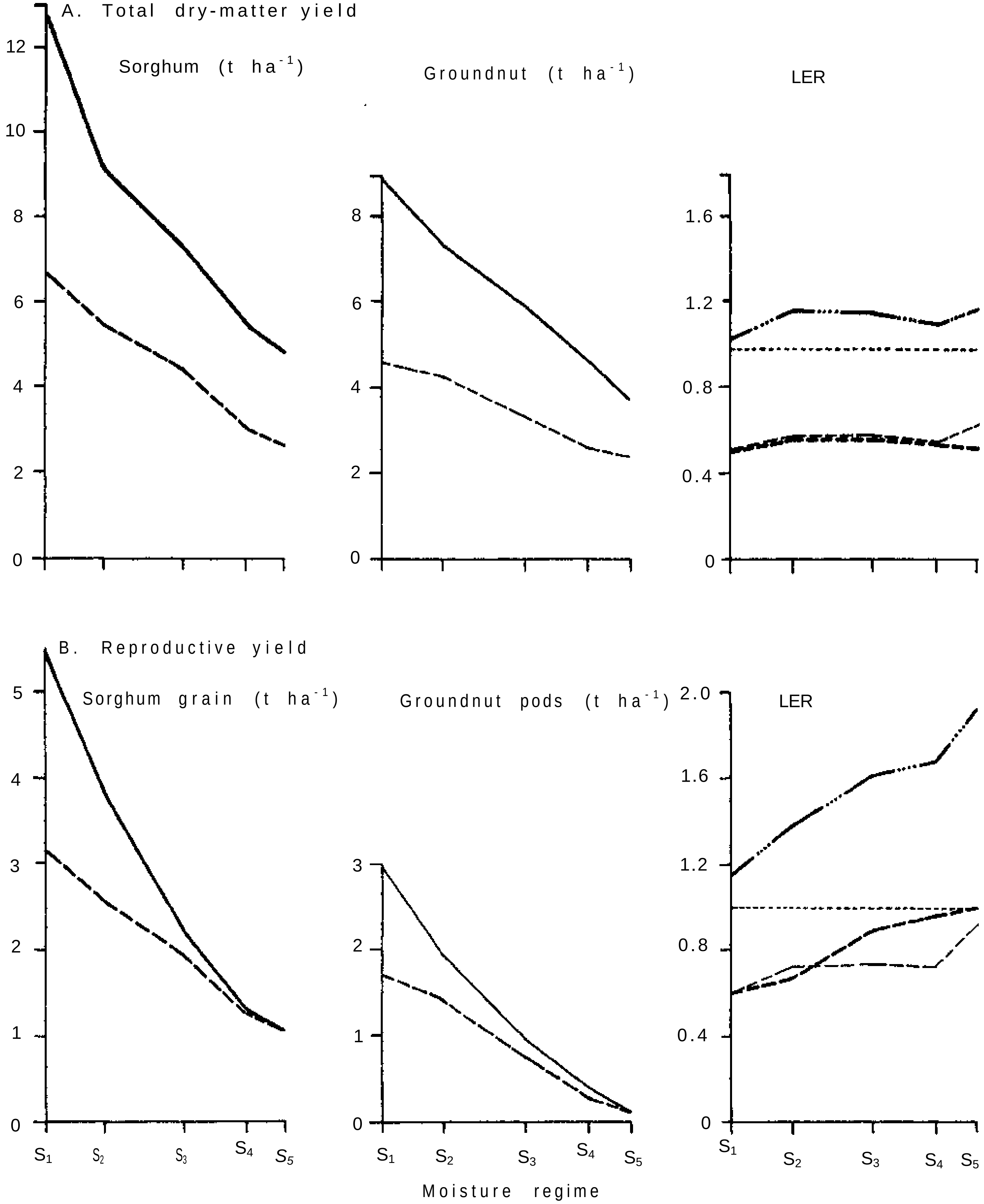


Figure 3. Effect of moisture regime on yields and LERs of a 1-row sorghum:2-row groundnut intercrop (SGG).

———'Sole sorghum, ▬ ▬ ▬ intercrop sorghum, ——— sole groundnut,

- - - - intercrop groundnut, —·····— total LER.

Table 1. Effects of drought and/or nitrogen stress on yield advantages and efficiency of resource use in a millet/groundnut intercrop compared with sole crops.

	No stress	N stress only	Drought stress only	Drought stress and N stress
LER[1]	1.21	1.27	1.29	1.39
Increase in LCE[2] (%)	+16	+33	+27	+24
Increase in WUE[3] (%)	+14	+23	+31	+24

1. LER = Land-Equivalent Ratio (e.g. a value of 1.21 represents an intercropping yield advantage of 21%).
2. LCE = Light-Conversion Efficiency (based on intercepted light).
3. WUE = Water-Use Efficiency (based on transpired water). Source: Vorasoot 1982.

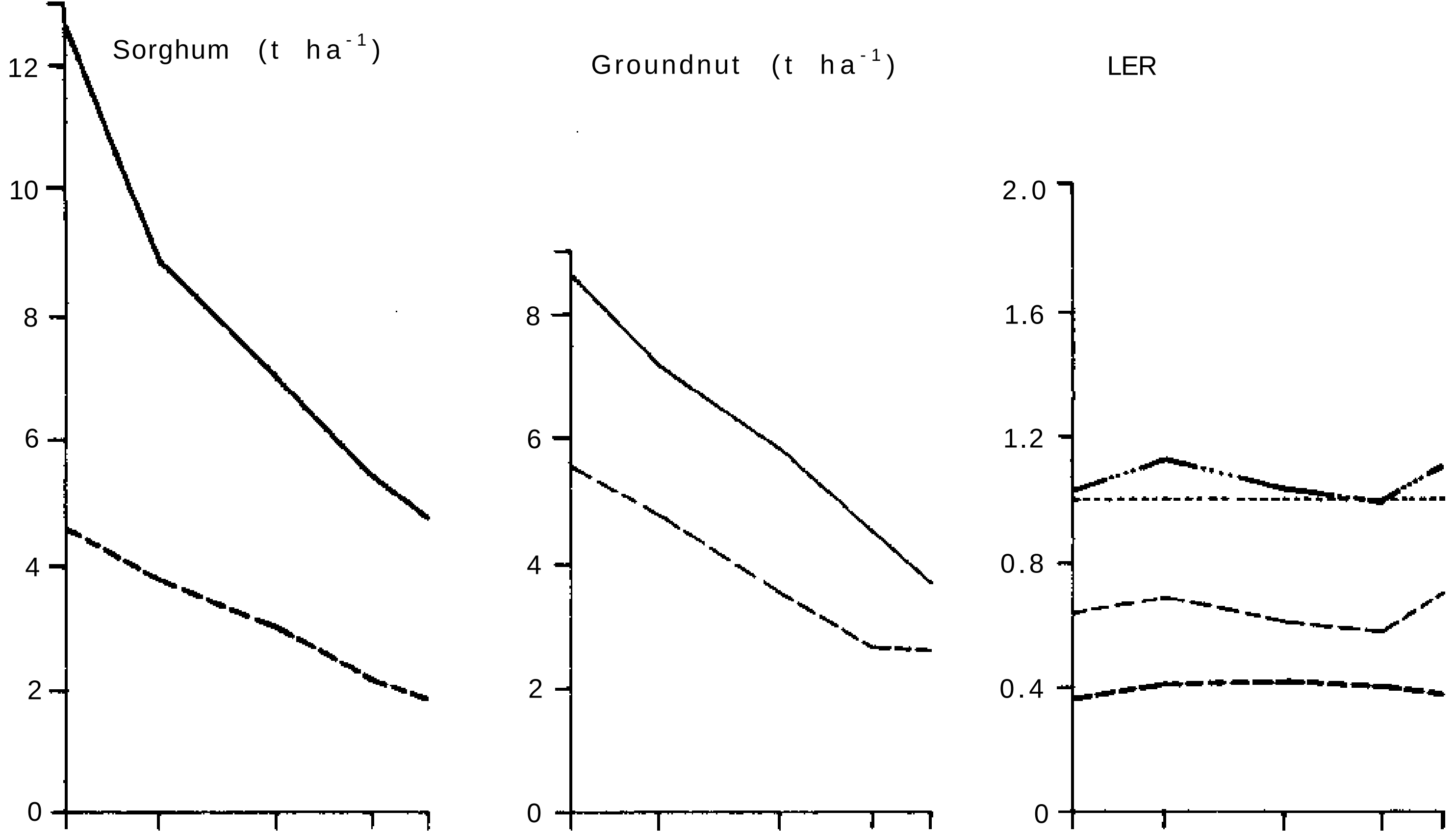
at 55 and 85 d. Moisture gradients were imposed with line source irrigations at 35, 45, 65, 76, and 95 d. Averaged over the two experiments, actual water received through uniform irrigations and rainfall was 286 mm. Water application through the line source ranged from 298 mm at the well-watered end (S1) to only 11 mm at the stress end (S5). Thus total water received ranged from 584 to 297 mm, which was equivalent to 64- 33% of open-pan evaporation.

Three combinations were studied (Natarajan and Willey, in press) but only some sorghum/groundnut and millet/groundnut treatments are presented here. There were two intercropping treatments with each cereal: 1-row sorghum or millet/2-row groundnut (SGG or MGG), and 1-row sorghum or millet/3-row groundnut (SGGG or MGGG). Results are presented as means of the two experiments. In the sorghum/groundnut combination, Figures 3 and 4 show that total dry-matter yields of the sole crop were markedly affected in both crops, ranging from very high yields at S1 to very low yields at S5. Reproductive yields were even more drastically reduced by increased drought stress because of large decreases in harvest indices; sorghum harvest index decreased from 43% at S1 to 20% at S5, while the comparable groundnut decrease was from 34% to only 3%.

Considering the SGG intercrop (Fig. 3), the total dry-matter yield of each component remained a fairly constant proportion of its sole-crop yield over the whole range of moisture regimes. Thus the intercropped dry matter advantage also remained fairly constant at about 10-20% . However, with stress increase, the harvest index of each component decreased less in the intercrop than in the sole crop particularly for the sorghum, so reproductive yields in the intercrop were equivalent to an increasing proportion of sole-crop yields. Consequently the intercropped advantage for reproductive yields increased from 14% at S1 to 93% at S5. The SGGG treatment showed a similar trend as stress increased from S1 to S3, but the maximum intercropped advantage was only 37% (at S3), and this declined under greater stress. This declining advantage in the severest stress treatments was particularly associated with a decrease in the groundnut contribution. In the millet systems (Figs. 5 and 6), the harvest index of sole millet was only slightly reduced with increased stress, and there was no evidence of any change in the intercropped millet yield relative to sole-crop yield. There was again evidence of greater relative advantages of the intercrop with increase in stress, but this was entirely due to an increase in the groundnut contribution, again attributable to a change in harvest index. In the MGGG treatment the maximum relative advantage of 78% was at S4, in MGGG there was an initial increase of up to 34% at S2 but a decline at higher stress levels.

No measurement of resource use was possible in these experiments, so the possible mechanisms responsible for different magnitudes of yield advantage with different degrees of stress can only be commented on generally. A commonly suggested advantage of intercropping is that crops may complement each other by rooting at different depths, and if this utilizes water more fully, it can be argued that this effect would be most advantageous when moisture is most limiting. There is also some indication that the presence of a shallow-root component may force a deep-root component even deeper (Natarajan and Willey 1981). The rather surprising feature of these results, however, is that increased stress did not affect total dry matter advantages of intercropping but only the reproductive yield advantages. But this could have occurred because all treatments were well watered initially, and stress only built up later in the

A. Total dry-matter yield



B. Reproductive yield

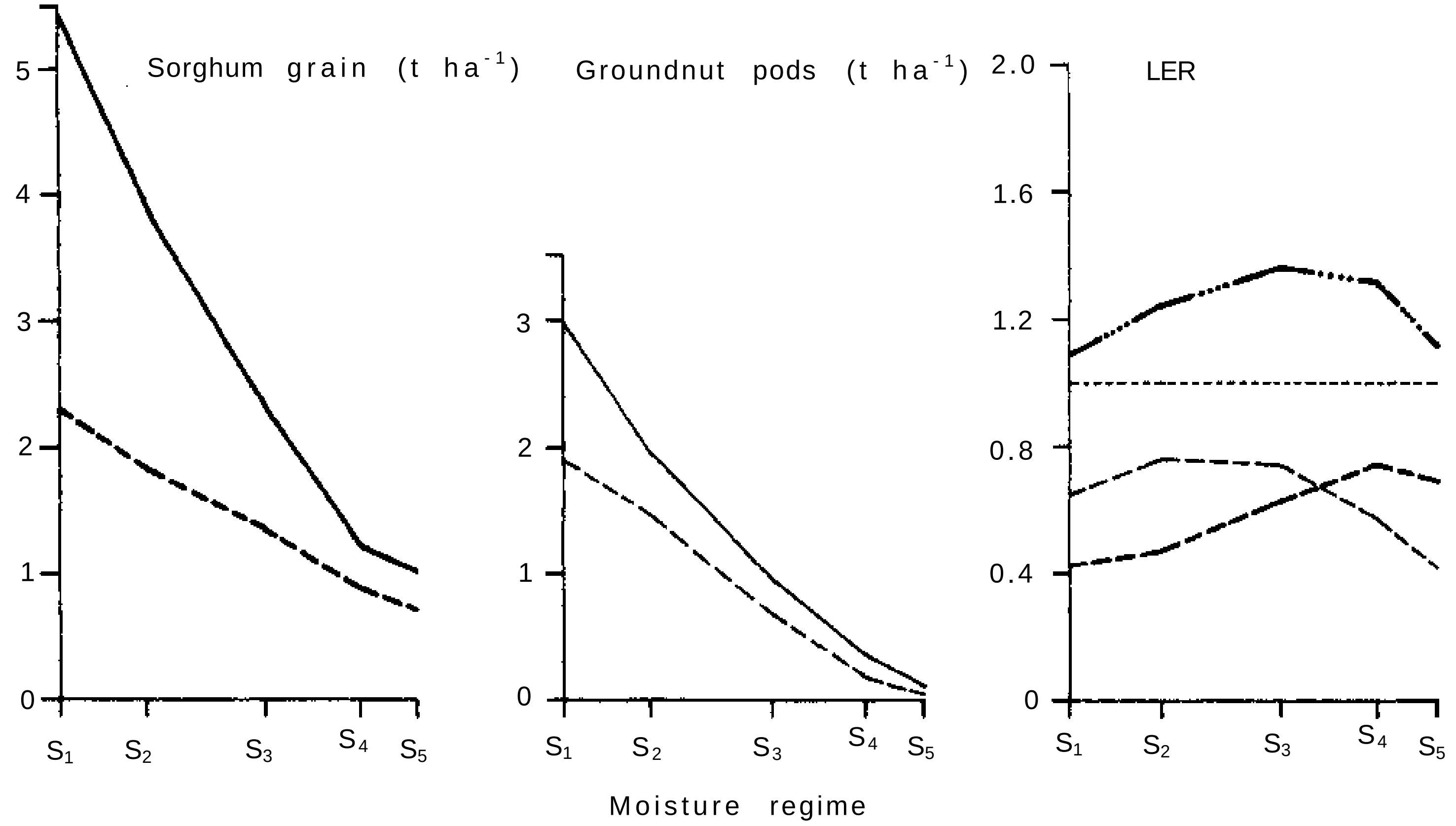


Figure 4. Effect of moisture regime on yields and LERs of a 1-row sorghum:3-row groundnut intercrop (SGGG).

━━━ sole sorghum, ▬ ▬ ▬ intercrop sorghum, ─── sole groundnut, - - - - intercrop groundnut, ━ ⋯ ━ total LER.

season when reproductive yields were being formed. This could also explain why the millet, which matured much earlier than the other crops, did not contribute to this effect.

A further possible mechanism is that the cereals provided a beneficial shading effect on the groundnut. This mechanism could help to explain the lower advantages in the SGGG and MGGG treatments, because in these treatments the shading effect was presumably less. It could also perhaps explain the drop in groundnut contribution and in reproductive yield advantage in the severest stress treatments for

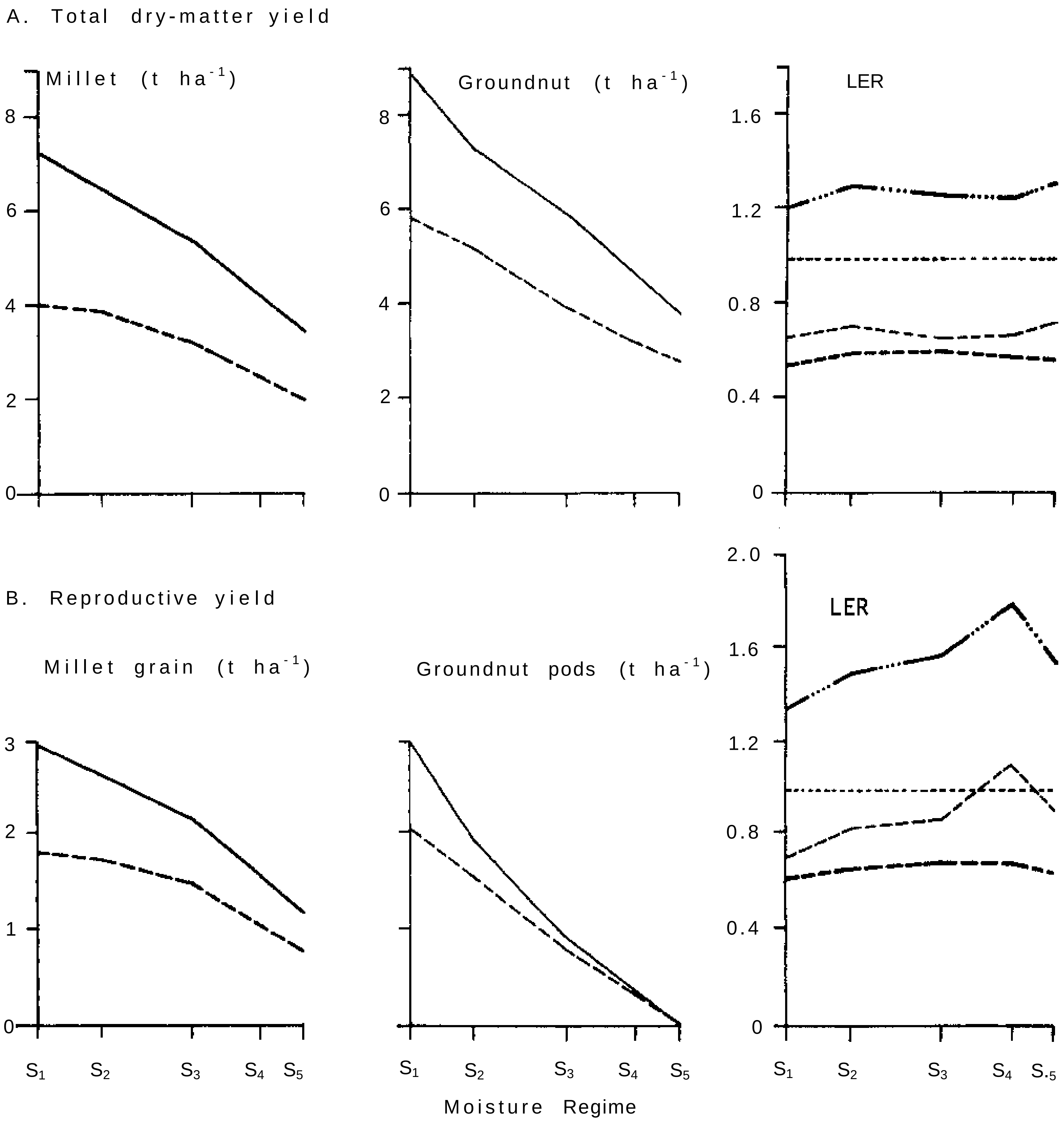


Figure 5. Effect of moisture regime on yields and LERs of a 1-row millet:2-row groundnut intercrop (MGG).

——— sole millet, ▬ ▬ ▬ intercrop millet, ——— sole groundnut,
- - - - - intercrop groundnut, —··— total LER.

SGGG and MGGG because it was in these situations that general crop growth was poorest, and thus shading was at a minimum. More recent studies (D. Harris, University of Nottingham, UK, personal communication) have supported this possibility of a beneficial shading mechanism by showing lower leaf temperatures in intercropped groundnut than in sole groundnut. But of course this mechanism cannot explain why the sorghum crop also had a higher harvest index in intercropping than in sole cropping, and if anything, this component made a somewhat greater contribution than the groundnut to the large yield advantage under stress.

The implications of these results are that although there is good evidence of some very large intercropping advantages under conditions of drought stress, these advantages may be specific to particular systems in terms of the crops they involve, and the plant populations and row arrangements at which they are grown. It must be emphasized that in the studies

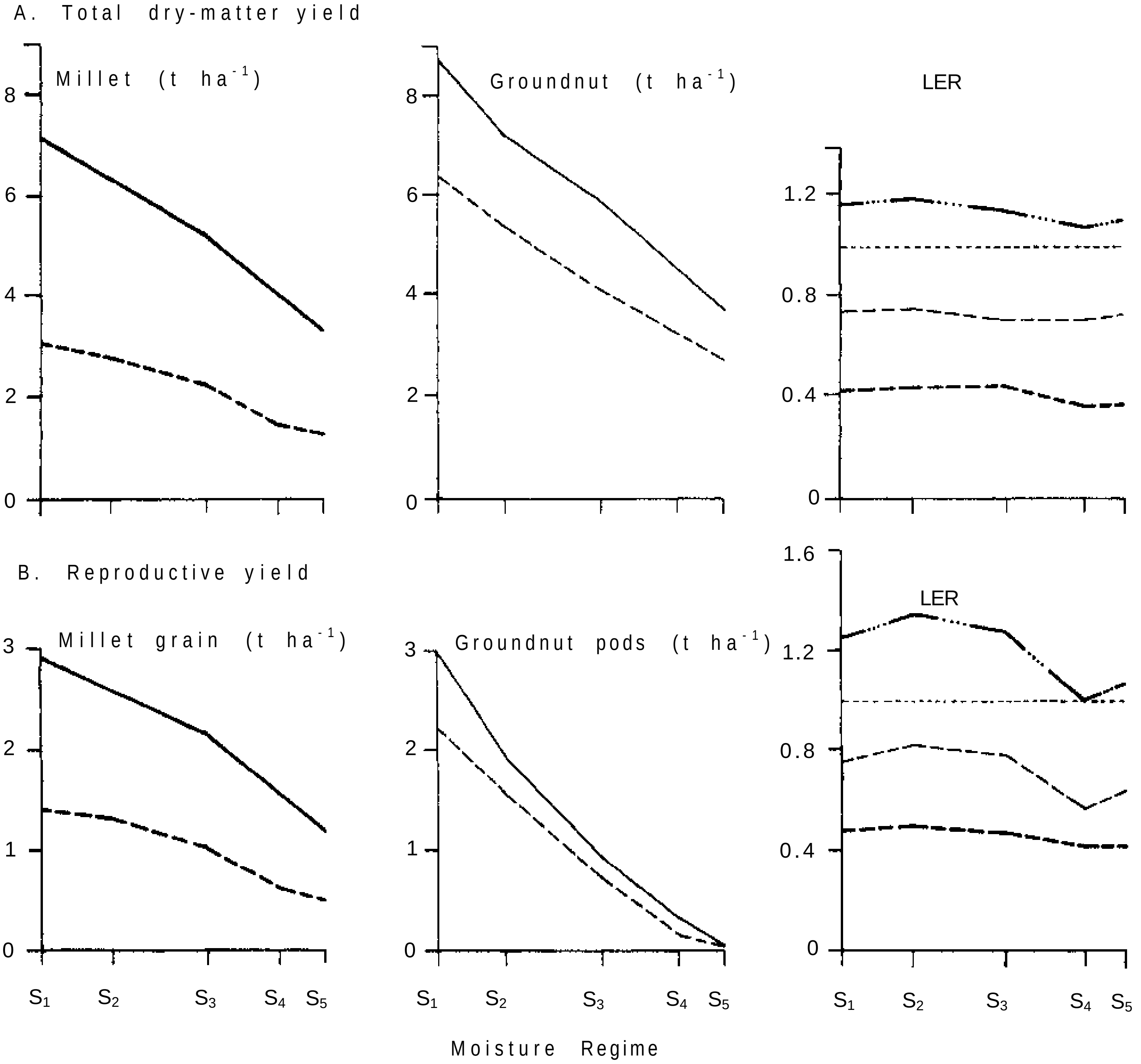


Figure 6. Effect of moisture regime on yields and LERs of a 1-row millet:3-row groundnut intercrop (MGGG).

━━ sole millet, ╍╍ intercrop millet, —— sole groundnut, - - - - intercrop groundnut, —···— total LER.

reported here, total intercrop populations were equivalent to the sole crops, and the population of each individual component was therefore only a proportion of its sole crop. In this situation there is scope for some complementarity between the crops, with a given component experiencing less competition in intercropping than in sole cropping. However, if total plant populations are greater in intercropping than in sole cropping then increased drought stress could lower yields. For example, Fisher (1977) suggested that intercropping was advantageous when the moisture supply was good but not when it was limited, but this was concluded from a maize/bean combination in which total intercrop population was higher than the sole crops.

Symbiotic Nitrogen Fixation

One of the advantages frequently claimed for intercropping combinations which include a legume is that the nitrogen economy of the system is improved because of symbiotic fixation. But there is little practical evidence for this because nitrogen effects are very often confounded with other competitive or complementary interactions between the crops. Also, fixation has seldom been measured directly, but has usually been inferred from yield responses. However, research has produced some guidelines that can help assess likely benefits.

Considering first of all the total amount of nitrogen that an intercropped legume might return to the soil, it must be remembered that as with sole crops, this depends very largely on how much of the plant is removed from the field at harvest. The removal of the seed takes off a large amount of plant nitrogen, and in the case of groundnuts the haulm is also sometimes removed for animal feed. It must also be emphasized that intercropped legumes are almost invariably partial crops and so cannot be expected to fix, or leave in the soil, as much nitrogen as a full sole crop. A further factor is that nitrogen fertilizer may well be applied to the nonlegume and it is commonly suggested that this may decrease fixation. In fact ^{15}N studies have shown that virtually no fertilizer nitrogen was taken up by a groundnut row growing only 30 cm away from a millet row to which a high level of fertilizer was applied. This was attributed to the much greater competitive ability of the millet to forage for soil nitrogen (ICRISAT 1984). However, there is considerable evidence that nitrogen application can increase growth, and the competitive ability of a nonlegume can reduce growth and presumably the amount of fixation of a legume component. An important point here is that the rate of fixation might be even more susceptible than general growth to this kind of competition. Some ICRISAT studies with maize/ groundnut showed that with an increase in the amount of applied nitrogen to the maize, the number and weight of nodules per groundnut plant decreased more rapidly than the dry-matter yield per plant. Similarly, in one of the rainy-season millet/ groundnut studies referred to earlier, the amount of fixation per groundnut plant (measured directly by acetylene reduction) was considerably less in the intercrop than in the sole crop even though dry-matter yield per plant was virtually unaffected (Nambiar et al. 1983). The most obvious cause of this decreased nodulation and fixation was lower light-energy receipts by the groundnut because of shading by the cereals, an effect that was measured in both studies. The important implication, however, is that shaded groundnut intercrops may well be fixing even less nitrogen than might be supposed from their growth.

There remains the question of how any fixed nitrogen might benefit the overall intercropping system. It is most commonly supposed that the benefit is a direct one to any nonlegume crop actually growing with the legume. But the benefit can also occur as a residual effect on subsequent crops. Studies with a range of legumes have indicated that a direct benefit is most likely to occur when the legume is the earlier maturity component and thus releases some nitrogen sufficiently early for an associated nonlegume to be able to respond. Conversely, when the legume is later-maturing, any benefit is more likely to be expressed as a residual one on following crops (Agboola and Fayemi 1972, Nair et al. 1979). Thus groundnut seems most likely to provide a direct benefit only to the kind of long-season intercrop described earlier. For example, there are reports of benefits to castor and cassava intercrop (Reddy et al. 1965, Khon Kaen University 1977). But if groundnut is intercropped with cereals, any benefit is more likely to be on following crops. This residual effect, and some of the other effects discussed above, are illustrated by a 3-year maize/groundnut study at ICRISAT Center. Sole maize was grown as two rows 75 cm apart on a 150-cm bed. This same pattern was maintained in intercropping to avoid confounding spatial arrangement or plant population effects with intercropping effects. The groundnut was added as two intervening rows. Residual effects were examined on a following sorghum crop to which four levels of nitrogen were applied to allow any benefit to be quantified in terms of an equivalent amount of applied nitrogen.

With no nitrogen added the sole maize crop was relatively poor (2.19 t ha^{-1}). Adding a groundnut intercrop gave a good yield of groundnut (1.17 t ha^{-1}) in this low-nitrogen situation, but far from giving any evidence of nitrogen transfer, there was a net competitive effect by groundnut, and maize yield was reduced by 23%. However, this good groundnut intercrop provided a benefit to the following sorghum that was estimated to be equivalent to about 20 kg ha^{-1} of applied nitrogen. When nitrogen was added to the maize the yields of maize were good but groundnut was very much suppressed (0.461 ha^{-1}). Emphasizing an earlier point, there was no evidence that this poor groundnut intercrop provided any benefit either to the maize or to the following sorghum.

Despite the lack of evidence for direct benefit to a companion nonlegume, there may still be important indirect nitrogen benefits because of the presence of a groundnut intercrop. In systems where the nonlegume intercrop is grown at a lower plant population than a sole crop, there may be a nitrogen benefit because, as emphasized earlier (ICRISAT 1984), the groundnut is less competitive for soil nitrogen. In effect, this means that the nonlegume intercrop may be able to obtain more nitrogen per plant than as a sole crop. This possibility is supported by a millet/ groundnut study in which the intermingling of millet and groundnut root systems was prevented by inserting underground partitions between the crop rows (Willey and Reddy 1981). Intercropped millet growing between partitions was paler, and presumably short of nitrogen, compared with an unpartitioned intercrop. In the unpartitioned systems millet was able to take up nitrogen from the rows examined by groundnut, confirmed more recently with ^{15}N studies (ICRISAT 1984). Thus it seems possible that a groundnut intercrop may still indirectly improve the nitrogen status of a nonlegume companion crop, even where it does not make any fixed nitrogen available. This effect could be particularly important in the many semi-arid areas where soil nitrogen is extremely low.

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Climate and Groundnut Production

Discussion

R. W. Gibbons:
As groundnut hay is an important and valuable commodity, would you care to comment on the aflatoxin content of hay?

R. E. Pettit:
There is a problem. Amadu Ba has reported considerable animal sickness as a result of consuming hay. There is very little work concerning the influence of aflatoxin in the hay. I realize that hay and grasses contain various fungi besides aflatoxin. These frequently cause disease problems in livestock of different types. Certainly this is a possibility we should consider. If the hay is dried rapidly enough, certainly it is not an ideal substrate for these fungi.

J. H. Williams:
I would like to point out that the way hay is dried is related closely to the relative humidity and temperature of the environment you are dealing with. You cited treatments indicating that we should dry groundnuts on mats, etc. In the summer environment of India, this will produce temperatures that will actually kill the seed. We measured temperatures in excess of 60℃ inside the pods put out in the sun without any black surfaces to promote temperatures.

R. E. Pettit:
I think all of us realize this would be a problem in destroying not only the viability but also the quality of the seed. How to dry groundnuts rapidly and safely in these environments is a difficult question.

B. Sarr:
Don't you think that irrigation may make the tissue more susceptible to invasion by *Aspergillus.*

R. E. Pettit:
To me the value of irrigation treatments appears to be in reducing the activity of the *Aspergillus* group and increasing the activity of the other fungi. You say that because of irrigation the tissue may be more susceptible, but I see no evidence of this.

T.H.Sanders:
a. Irrigation by itself reduces soil temperatures.
b. Regarding aflatoxin levels in the hay, we made some measurements. In the hay alone we did not find any aflatoxin. But we did find considerable amounts in the small, immature pods that are left attached to the hay. There was some work done in Australia which indicated a connection.
c. The screening methods that are generally accepted employ dried, rewetted seed which are then inoculated with the fungus *A. flavus.* I would submit that since preharvest is the greatest problem for aflatoxin, the relationship between a dried, rewetted groundnut and a pod that is developing in the soil is not good. Hence extreme care should be taken to grow resistant varieties in the field where conditions conducive to aflatoxin production are present before we make a statement that there is no aflatoxin there.

D. Smith:
a. During our survey in Senegal last year, there was a severe aphid infestation in the northern areas near Louga. That was in contrast to the situation here.
b. Very often the fungus *Leptoserolina* colonizes the necrotic tissue damage caused by leaf hopper and there is a confusion between what is known as *Leptoserolina* leaf scotch and the damage caused by leaf hopper.

R. W. Willey:
Has Dr. Lynch any evidence that intercropping with groundnuts can affect insect populations? There is good evidence that cereal intercrops can reduce insect incidence on cowpea in West Africa. Is there any comparable evidence for groundnut?

R. E. Lynch:
I am not aware of any research that has been conducted or published. In general, intercropping may increase certain insect problems while decreasing others. In certain instances, insect diversity tends to increase with intercropping and the increased diversity leads to a decrease in pests.

P. Sankara:
While you take control measures for certain insects, wouldn't it eliminate some other beneficial insects and cause a reduction in yield?

R. E. Lynch:
Yes, first of all you have to identify the insect that is actually causing damage before you can develop control measures. We are trying to conduct research along that line this year by applying insecticides at various stages of development to inhibit damage by thrips and leaf hoppers, and later by termites and millipedes. Then we will look at the yield and quality of the crop to determine what effect they are having.

A. Ba:
Frequent attacks by millipedes on groundnut have been observed in the central region of Senegal. Termites have also caused important damage on groundnut pods. Is there any method of agronomic control to reduce these attacks?

R. E. Lynch:
When he was working in Senegal, Dr. Masses looked at several control measures for termites; however, farmers will not be able to use chemical control measures either for millipedes or termites. We need to develop cultural control methods. For millipedes, we need to remove all the stumps, and all termite mounds. By this you should be able to reduce the millipede populations. We have not done any research on this, but this needs to be looked at thoroughly.

Populations of millipedes in Burkina Faso are low. However, considering the damage they cause in Senegal, this could be an important yield-reducing factor in Burkina Faso.

R. W. Gibbons:
There is some preliminary evidence that there might be varietal resistance or tolerance to pod-scarifying termites. Dr. Schilling in Cameroon also noticed differences between cultivars to millipede damage.

M. Bernardi:
We have seen a strong relationship between the climate, the crop, and the pests. IPM needs good monitoring of all weather factors, but in reality today we don't know the reaction of pests to drought. Varietal resistance can also vary because of the presence or absence of pests.

R. E. Lynch:
Insects are the most successful organisms on earth accounting for about three-fourths of the animal species. As such they have been able to exploit every niche. Certain insects thrive in humid conditions, certain others prefer dry regions. For example, termites in SAT Africa and the lesser cornstalk borer *Elasmopalpus lignosellus* in the U.S. are major groundnut pests only when the crop is under drought stress. Conversely, millipedes in SAT Africa and the southern corn root worm in the U.S. are pests only under moist conditions. In many instances, the factors that regulate the population dynamics of arthropods are not understood. This is primarily due to insufficient study of the biology and population dynamics of these arthropods. A thorough study may indicate key factors that regulate population fluctuations in one area, which in turn may be used to reduce populations in another area. Also, as you mentioned, varieties resistant to one insect must be thoroughly investigated for susceptibility to other insects over a wide area before they are released. After these factors are known, weather monitoring and forecasting are extremely important for predicting arthropod population increases and/or damage.

R. E. Lynch:
Did I understand you correctly that yield under intercropping was greater per unit area than under monocropping?

R. W. Willey:
Yes.

A. P. Ouedrago:
What is the influence of cooking temperatures on *Aflatoxin?* Does peanut butter keep well if by chance infected seeds were used?

T. H. Sanders:
a. Aflatoxin per se is not destroyed by cooking temperatures. The fungi itself is rendered relatively useless.
b. Moisture content of peanut butter is generally low enough so there is usually no problem.

M. Konate:
Do soil temperatures influence *Aflatoxin* development? If so, have you looked at the possibilities of using air temperatures for predictive purposes?

T. H. Sanders:
The work we carried out in plot studies suggests that the optimum temperatures for aflatoxin development are in the soil in which the pods develop. In our area this is 5 cm and up. Work is being developed on the lines of modeling to predict soil temperatures from air temperatures under different canopies.

A. Ba:
a. In your work you have successfully described the pod maturity of the florunner variety based on the color of the mesocarp. Do you think that your scale could work for all varieties?
b. What do you think of the usefulness of arginine index in characterizing the maturity stage of groundnut?
c. You have considered the oleic acid to linolic acid ratio, Is'nt it more advantageous to obtain a high linolic acid content in order to raise the nutritive quality of groundnut oil and get it close to other vegetable oils which are considered light?

T. H. Sanders:
a. The color of the pods simply relates to the physiological condition. In a mature state groundnut is physiologically quiescent. There is very little biochemical activity taking place. The color ranges from white to black. That color can be related to the internal color of the mesocarp. Just when groundnut begins to turn brown, the mesocarp turns brown.
b. It has been our experience that stress conditions cause a real problem for use of arginine maturity index to determine maturity.
c. The relationship of oline to linolic acid in maturity: the amount of unsaturation has generally been related to storability, the more unsaturated being less stable. Higher soil temperatures resulted in more saturated oils generally.

R. W. Gibbons:
Traditionally long-season Virginia varieties have a higher oleic to linolic acid ratio, and that oil keeps well, as Dr. Sanders just pointed out. The recent trend in West Africa is to go more towards the Spanish varieties because of early maturity. These have a low 0:L ratio, so the oil does not keep well. However, there is a variety in Senegal, 7330, a hybrid between Spanish and Virginia, that is early and dormant, has a good 0:L ratio, and it's oil keeps better than that of 55437. So I think the breeders should be aware that they ought to look at the 0:L ratio for early-maturing varieties for stability.

D. Smith:
With reference to *Puccinia arachidis,* there was a report some years ago in Phytopathology that the uredospores produce a germination self inhibitor. This has been found in other rust uredospores. So this probably bears on some of the observed discrepancies.

Session V

Applications to Groundnut Cultivation

Chairman: D. Rijks
Co-chairman: H.E. Dandaula

Rapporteur: A. Batiano

Weather-Sensitive Agricultural Operations in Groundnut Production: The Nigerian Situation

J.Y. Yayock and J.J. Owonubi[1]

Abstract

Groundnut production is currently confined largely to the Sudan and Northern Guinea Savanna zones in Nigeria, and is dependent on the availability of rain water, matching the crop-growth cycle to the length of the growing season, as well as the seasonably variable sunlight and temperature regimes. Agronomic operations and effective management practices are oriented towards the prevailing weather conditions in production areas. The recent downward trend in the total annual rainfall and the reduction in the length of the rainy season have necessitated a southward production trend. There are many implications of this shift: the need to match appropriate groundnut cultivars to the longer growing season; the use of cultivars that are resistant or at least tolerant to the major insect pests and diseases of the wetter and more humid Guinea savanna; devising ways to alleviate the inevitable problems of lifting if the crop remains unharvested up to the end of the rainy season; devising ways to efficiently dry the crop if it is lifted before cessation of rains; and the need for efficient handling of the produce in order to ensure high kernel quality devoid of contamination, especially aflatoxin.

Résumé

Opérations agricoles sensibles au climat — l'expérience du Nigeria : *Au Nigeria, la production d'arachide est concentrée dans les zones de savane soudanienne et Nord guinéenne. Elle est tributaire des précipitations, des régimes saisonniers variables d'ensoleillement et de températures, de la capacité de caler le cycle de croissance à l'intérieur de la période de croissance. Les opérations agronomiques et les pratiques de gestion efficaces sont fonction des conditions climatiques des zones de production. La tendance à la baisse de la pluviométrie annuelle totale et la réduction de la longueur de la saison des pluies a entraîné un déplacement vers le sud de la production. Ce changement a eu plusieurs conséquences: le besoin d'adapter les cultivars d'arachide appropriés à une période de croissance plus longue; l'utilisation de cultivars résistants ou tolérants aux principaux insectes et maladies de la zone plus humide de la savane guinéenne; trouver les moyens de résoudre les problèmes inévitables de l'arrachage si la culture n'est récoltée qu'à la fin de la saison des pluies et de séchage si la culture est arrachée avant la fin des pluies; le besoin d'une manipulation efficace du produit afin d'obtenir une bonne qualité de grain exempt de contamination, particulièrement l'aflatoxine.*

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT,

Introduction

Groundnut is the most important cash crop in Nigeria north of latitude 10°N. Its products, including kernels, oil, and cake, once accounted for as much as 20% of the total Nigerian export earnings while at the same time satisfying local requirements for edible nuts. The estimated groundnut-growing area annually ranges between 0.8 and 1.2 million ha, comprised largely of small farms, averaging 0.25-1.0 ha. The crop is mostly intercropped with such cereals as millet and sorghum, with invariably low populations. The annual production of groundnuts reached an all-time peak of over 1 million t of kernels in 1967/68. However, since then production has been progressively decreasing such that the current output level of 0.4-0.5 million t is inadequate to satisfy even local needs.

Several factors have contributed to declining production. Among the important causes are drought (Kowal and Kassam 1973), disease epidemics (Yayock et al. 1976, Yayock 1977), as well as suspected variability in temperature (Yayock 1978). In addition, the higher opportunity costs associated with cultivating groundnuts instead of cereals has tended to lead to an abandonment of groundnuts and other 'cash' crops.

Virtually all research effort toward finding solutions to these and other problems of groundnut production has been based at the Institute for Agricultural Research, Samara. Essentially, the thrust of our effort centers on deriving a basic understanding of the crop in relation to its environment, as well as developing appropriate agronomic technologies to improve production and productivity. In contributing the Nigerian experience to the theme of this symposium, we have attempted to focus attention on the agronomy of groundnut in the context of those management practices and operations that are constrained by adverse climatic factors.

Nigerian Climate

Nigeria lies within the tropics, between latitudes 4-14°N and longitudes 2-15°E. The climate is characterized by distinct wet and dry seasons, with most of the cropping done during the wet season. Cropping during the dry season necessarily involves the full use of irrigation water. The mean annual rainfall, potential evapotranspiration, and the length of the growing season across the country are shown in Figure 1. Each of these parameters shows a north-south gradation. The various vegetation zones are depicted in Figure 2 while their characteristics are described in Table 1. Nigeria's geographical location, the abundance of sunshine (global radiation input of 400-500 W m^{-2} averaged over 12 h), and the moderately warm temperatures (20-25°C) during the rainy season constitute assets to crop-water demand throughout the year; the amount and distribution of rainfall as well as the length of the growing season are constraints to the types of groundnut varieties that can be successfully cultivated.

Area of Production

For successful cultivation, groundnut requires well-drained soils, a relatively short wet season lasting not less than 100 d, and an abundance of sunshine. The traditional areas of production in Nigeria are mainly located within the Sudan and the northern two-thirds of the Northern Guinea savannas and

Table 1. Gross characteristics of Nigeria's ecological zones.

Vegetation zone	Approx. latitude (°N)	Annual rainfall (mm)	Length of season (days)	Soil type
Sahel	12-14	500 or less	90 or less	Arid brown, halomorphic
Sudan savanna	10-13	500-900	90-130	Non-leached, ferruginous
Northern Guinea savanna	8-11	900-1400	130-190	Leached, ferruginous
Southern Guinea savanna	6-8	1000-1650	190-250	Concretionary ferrisols
Forest	5-7	1550-2550	250	Ferrisols/Ferralitic
Coastal swamps	4-6	2300-4100	250	Juvenile

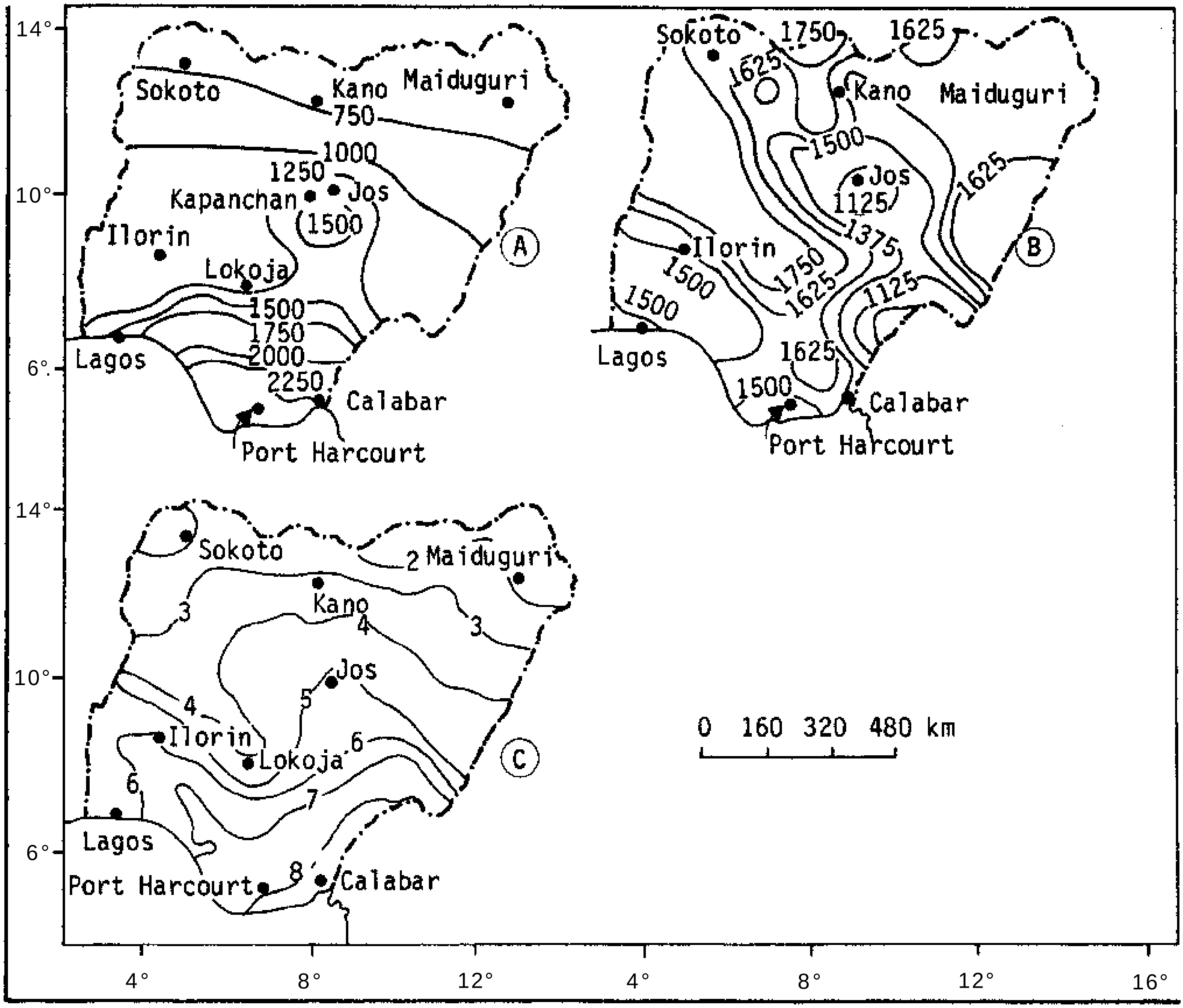

Figure 1. Nigeria: (A) mean annual rainfall (mm), (B) annual potential evapotranspiration (mm), (C) average duration of wet season (months).

bordered roughly by latitudes 9 and 13°N. Typical values of evaporation, rainfall distribution, as well as variations in temperature and relative humidity, are shown for Samaru which is located within the main producing area (Fig. 3).

Virtually no rain falls between October and May towards the northern border of the main producing area and between November and February towards its southern fringes. Benoit (1977) has demonstrated that the growing season could be assumed to begin in the main groundnut zone when accumulated rainfall in any one year totals 75 mm. Thereafter and throughout the duration of the growing season, the possibility of a dry spell lasting longer than 10 continuous days is virtually nil. This contrasts to the situation immediately south of the zone and stretching into the Southern Guinea, where there are real possibilities of dry spells in the middle of the rainy season lasting longer than 10 days (Fig. 4).

Temperatures are moderately warm and relatively stable during the cropping season at 20-25°C But once the rains end and the northeast wind prevails, the temperatures fluctuate widely on a diurnal basis. During the dry season and especially in the months of December to February, minimum temperatures often fall below 10°C. In general, the diurnal temperature variations are larger as the latitude increases,

A major characteristic of the northeast wind in the West African region generally is that of erosion and transportation of fine powdery dust during the Harmattan (dry) season. The amount of dust deposited in the area that produces the bulk of the groundnuts is estimated at a cumulative 50-230 kg ha^{-1} a^{-1}, adding as much as 0.1-0.37 kg ha^{-1} of sulphur to the soil (Bromfield 1974). The dust varies in concentration depending on location and time, and causes significant variation in daily sunlight during the dry season as demonstrated in Figure 5. Therefore, the beneficial effect of the dust deposition in terms of providing a fraction of the sulphur required by groundnut must be weighed against the disadvantages of sunlight and temperature depression if production during the dry season (under irrigation) is contemplated.

South of the traditional groundnut-producing area and especially in the southern one-third of the Northern Guinea and the whole of the Southern Guinea savanna, rainfall is higher, the rainy season is longer, temperatures are moderate, and the soil is deep and well-drained. This area holds much promise as an alternative major production zone in light of the progressively worsening rainfall situation, particularly in the Sahel and Sudan ecological zones. The relative disadvantages in this southward extension of the groundnut belt are largely in relation to:

- the poorer handling properties of the soil which are relatively heavier to work;
- the need to balance the growth cycle of the crop in relation to occurrences of dry spells;
- the higher potential for insect pest and disease infestation under the wetter and more humid atmosphere; and
- the problem of drying and contamination of the

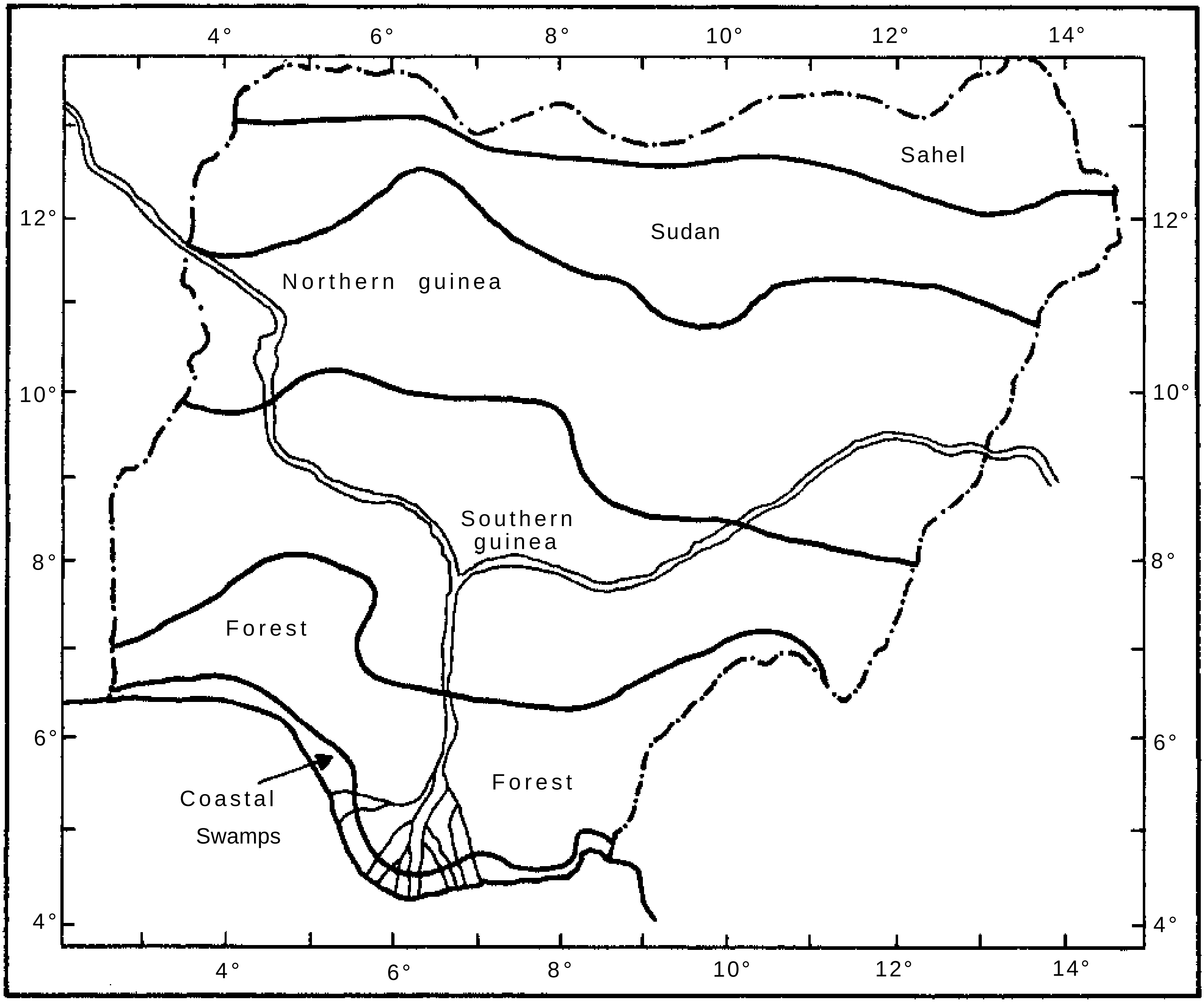

Figure 2. Major vegetation zones of Nigeria.

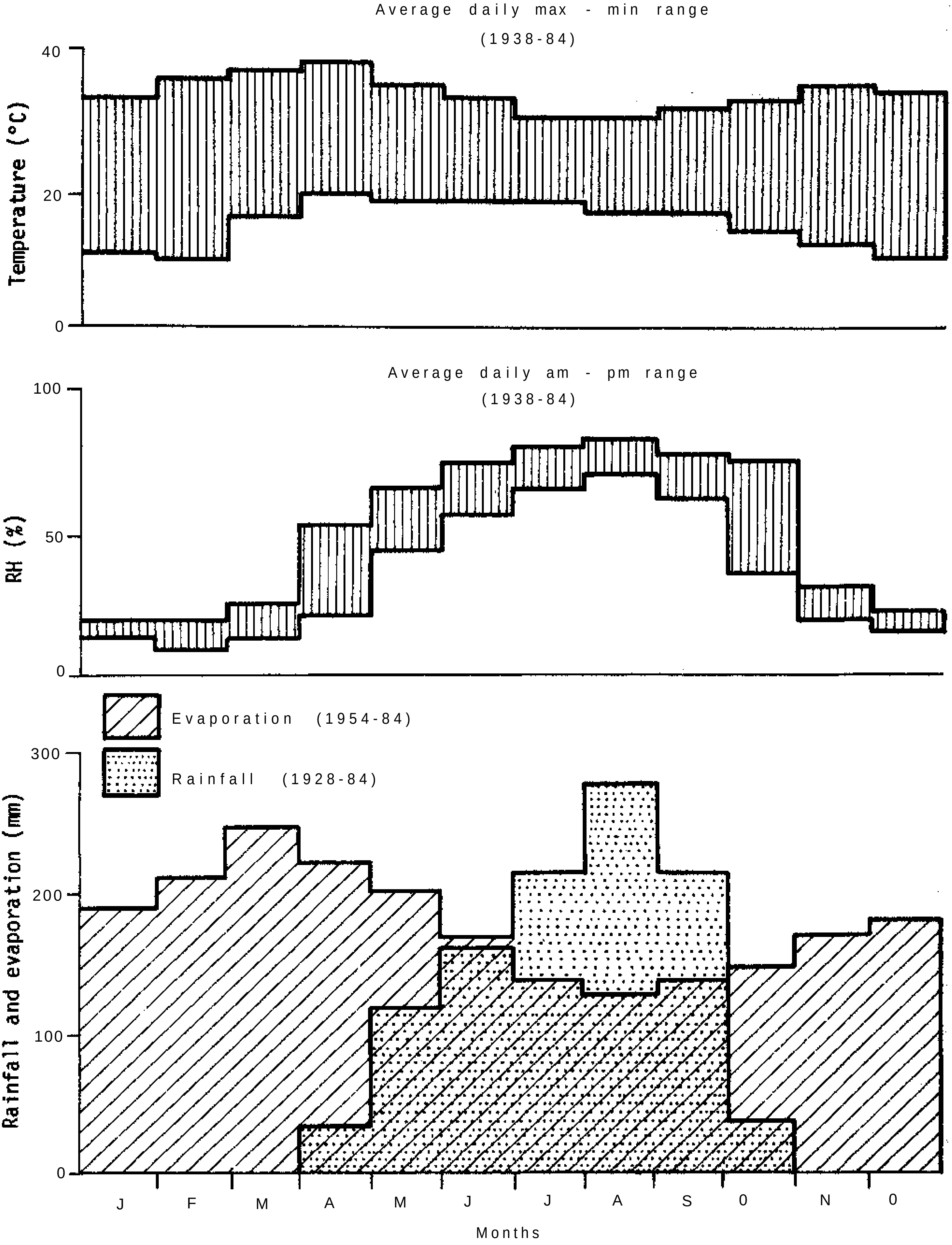

Figure 3. Rainfall, evaporation, temperature, and humidity characteristics of Samara (11°11'N, 7°38'E) located within the main groundnut-producing zone of Nigeria.

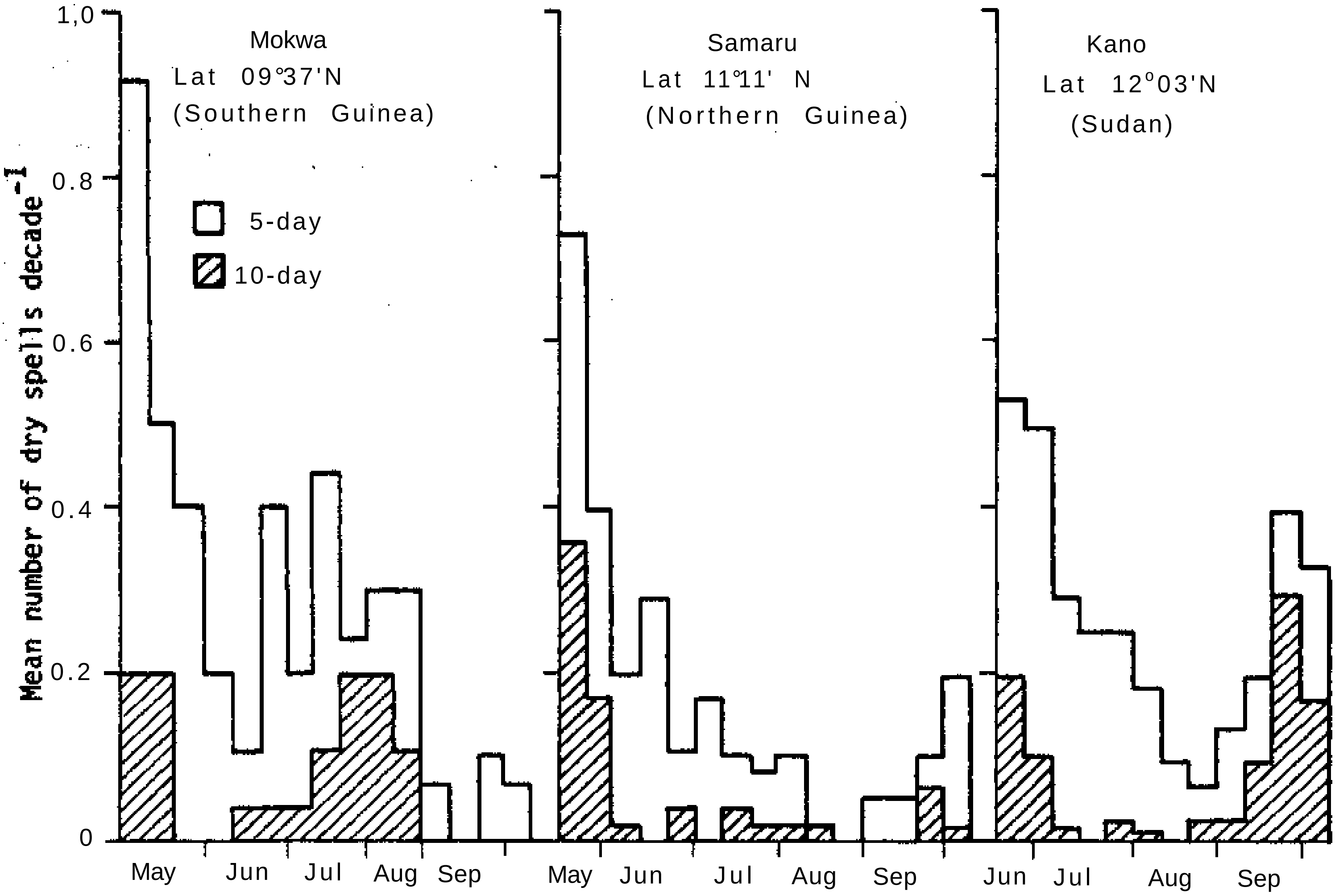

Figure 4. Frequency of dry spells during the rainy season at selected locations in Nigeria.

produce if the crop is lifted before cessation of rains.

Weather-Sensitive Elements of Production

Effective husbandry operations are generally derived from an integration of the optimal crop requirements in the context of the environment of a particular site. Groundnut management practices conditioned by weather factors are briefly discussed below.

Choice of Variety

The choice of a groundnut variety for any particular area depends primarily on matching the variety with the length of the growing season. The beginning and end of the rains and, therefore, the length of the growing season, are a function of latitude (Fig. 6). Ordinarily, the estimated season length and the possibility of rainfall to meet the consumptive water requirements of a particular variety identify an appropriate zone in which it could be grown (Fig. 7). However, because of the progressive decline in the amount (Fig. 8) and spread (Fig. 9) of rainfall in the last three decades, a continuous review of this desirable match becomes necessary.

Groundnut varieties whose growth cycle is longer than the duration of the growing season at a particular location either fail to mature or do so at a time when the soil is too hard for easy and efficient lifting. Premature harvesting of groundnut invariably leads to substantial yield losses as demonstrated in Figure 10.

Land Preparation

Because conditions in the Nigerian savanna readily support the formation of soil-surface crusts (Kowal 1972), it is essential to till the soil to enhance groundnut pod formation and to ease harvesting.

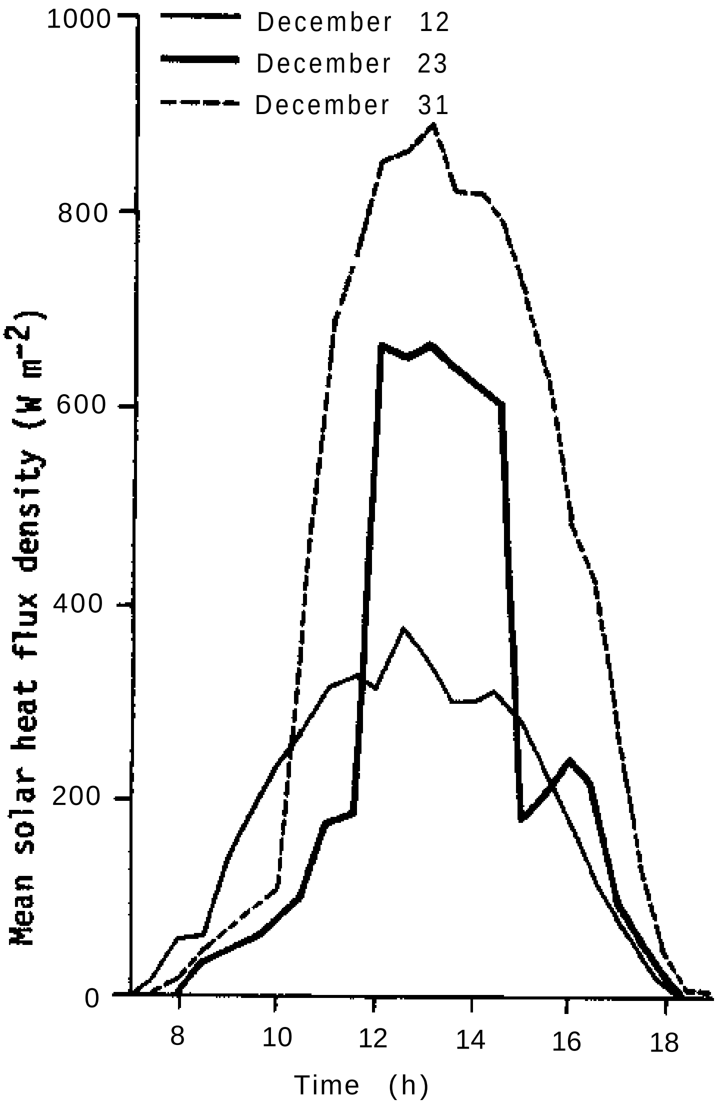

Figure 5. Depletion of sunlight by dust in the atmosphere recorded in 1980 for Samara, Nigeria.

Whether or not to ridge largely depends on the soil conditions, the need for water conservation, as well as possible dangers posed by erosion at the particular site.

The atmospheric water demand, especially in the main groundnut-producing areas, is less than the amount of rainfall measured in the middle of the growing season (Fig. 3). The distribution of rains is such that precipitation significantly exceeds potential evapotranspiration for at least 2 months during the growing season. Therefore, to avoid possible waterlogging and at the same time conserve soil moisture, groundnuts are invariably grown on ridges. Whether the ridges are open or tied depends upon moisture-conservation needs.

Time of Sowing

Because groundnut is essentially a cash crop in a predominantly subsistence setting, the sowing time has traditionally been late, and occurs only after food crops such as cereal grains have been sown. The crop has an optimum temperature range of between 25 and 30℃ while minimum air temperature during the growing season often falls below 17℃. Studies at Samaru indicate that a mean night temperature of 15℃, especially if it persists for as long as 10 days during early flowering, markedly decreases the rate of dry-matter accumulation, flower production, as well as the number of pegs formed (Owonubi unpublished data). Such effects are probably responsible for the low productivity of groundnuts observed in this zone in 1978 (Yayock 1978).

When sown with early rains, the crop invariably takes advantage of the higher insolation and warmer temperatures to become well established, such that the period of flower and pod formation coincides with the cooler midrainy season. According to Kowal and Knabe (1972), the optimum time to begin cropping with little or no drought risk may be defined in terms of latitude (X) and expressed by the equation:

$$Y = 1.43\ X - 1.31,$$

where Y represents days in decades.

The relative advantage of matching cropping to both water availability and seasonal temperature patterns is demonstrated in Figure 11, The relatively cool temperatures between December and February result from the position of the earth in relation to the sun, as well as the prevalent high concentration of Harmattan dust in the atmosphere at this time. If cultivation of irrigated groundnut in this area is to be successful, sowing must be completed between September and November (Kumar et al. In press). In practice, the period mid-October to mid-November is ideal to allow time for the preparation of the land following the wet-season cropping.

Timely groundnut sowing is especially crucial, since dry spells soon after sowing may often seriously enhance the incidence and spread of insect pests and diseases. For example, the aphid *Aphis craccivora,* which spreads rosette disease virus, normally requires high humidity for survival and is, as a result, mainly confined to the Southern Guinea zone. In years with prolonged dry spells after groundnut emergence, the winged adult aphids migrate with the southwest winds to the Northern Guinea and Sudan savannas, spread the virus (rosette) disease and cause serious damage to the crop. The unprecedented disease which caused devastating damage to groundnuts in

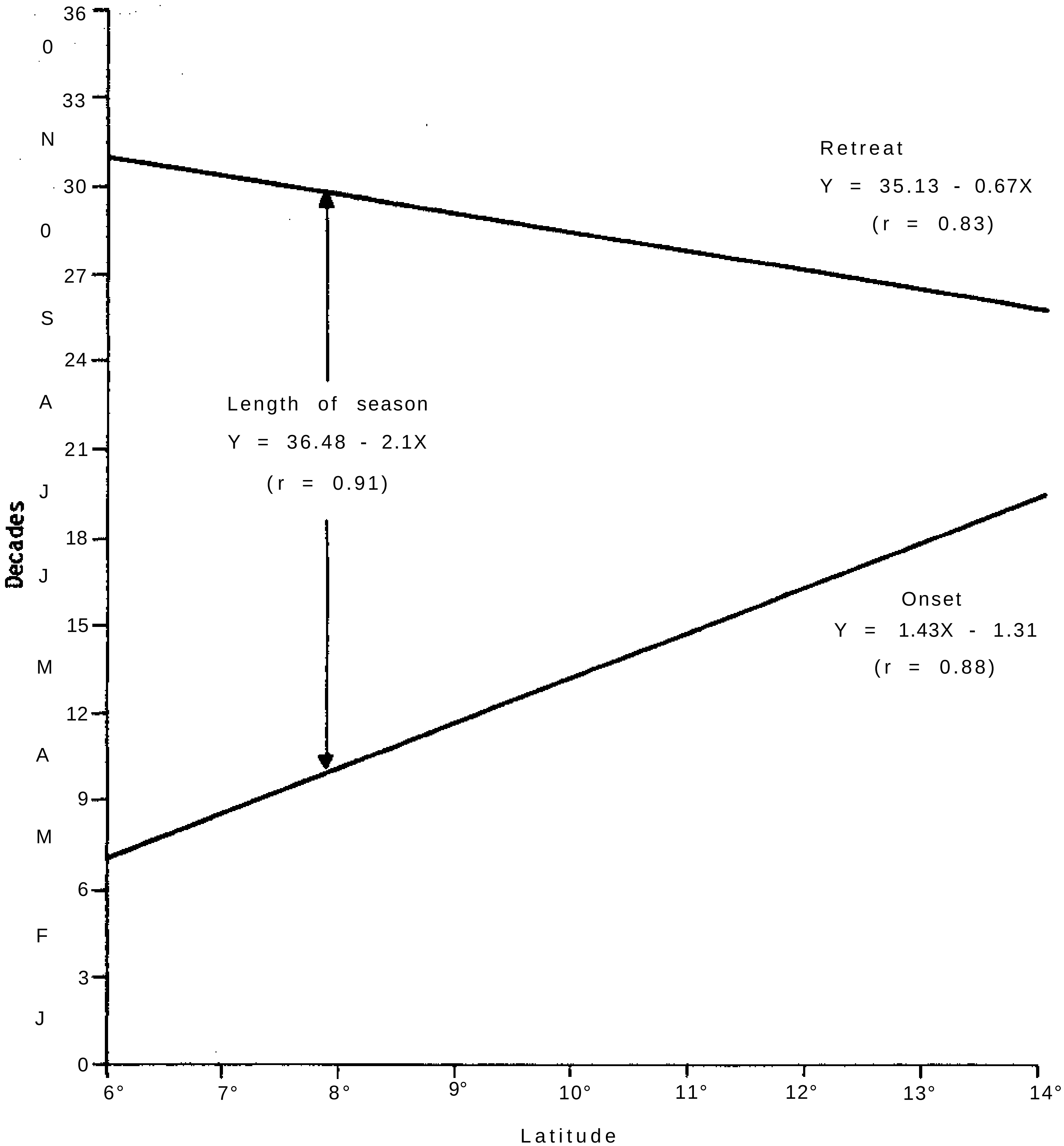

Figure 6. Relationship of time of onset and retreat of rainfall and the length of the growing season to latitude in Nigeria.

1975 is believed to have originated in this way (Yayock et al. 1976).

Plant Density

Current recommendations for the cultivation of sole groundnut in Nigeria call for sowing 23 cm apart on 91-cm ridges, thus giving populations of 47000 plants ha^{-1}. Grown in mixtures with other crops, the population of groundnut is invariably much lower, at 28 000 plants ha^{-1}. At such relatively low populations, the plants do not provide a dense canopy, and the crop thus fails to fully utilize available soil moisture and/or solar radiation, even at peak leaf area index (LAI). In investigations on the effect of plant density on vegetative growth, development, and dry-matter production in five cultivars of groundnut, Yayock (1979a) found that even though growth and branching of individual plants were reduced at high populations (Fig. 12), more dry matter was produced per unit of land area. At high populations, individual plants tend to be faster in developing a larger leaf area earlier in the season and, as the canopy closes, there is an increased opportunity to make better use of sunlight.

An analysis of data from across the main groundnut-producing area of Nigeria indicates that the cur-

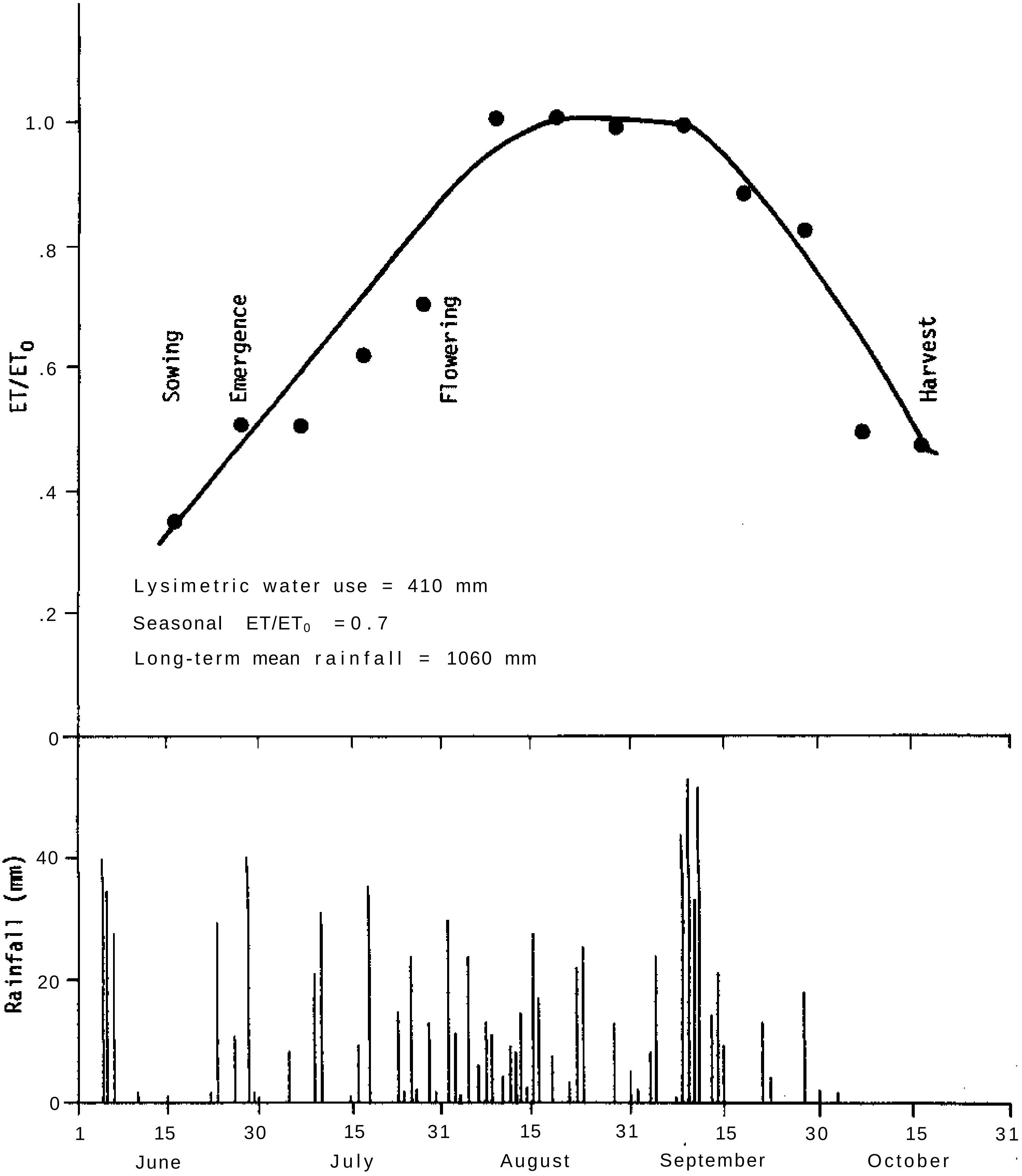

Figure 7. Relative evapotranspiration (ET/ET$_0$) in a groundnut canopy at Samaru, Nigeria, 1973.

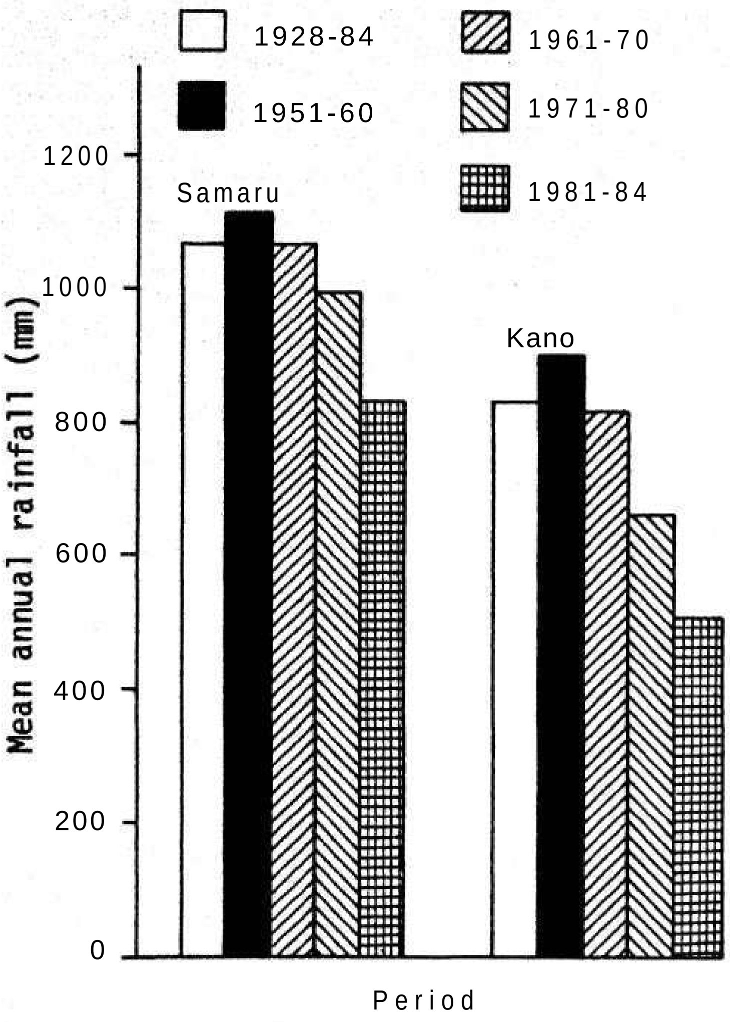

Figure 8. Progressive decline in total annual rainfall at Kano and Samaru (Nigeria) for the 30-year period 1955-84.

rently advised cropping density of 47 000 plants ha^{-1} can be increased substantially with benefits (Yayock 1979b, Yayock and Owonubi 1983). Generally, pod yield and haulm production as well as shelling percentage are enhanced as population is increased up to 172 000 plants ha^{-1}. However when restricted to cropping on 91-cm ridges, the economically optimal population density is estimated at 86000 plants ha^{-1}.

Crop Nutrition

The nutrient requirements of groundnut are primarily a function of the variety, soil-nutrient content, available soil moisture, as well as the level of crop husbandry. In general, groundnut production in Nigeria is relatively less sensitive to fertilizer application than most other field crops. Because groundnut is quite efficient in obtaining nutrients from the soil, it is able to exploit residual fertilizers from previous applications.

Currently, only phosphorus and, at specific locations, potassium fertilizers are recommended for groundnut. Specifically, 54 kg of P_2O_5 and 25 of K_2O are recommended per hectare for all soils in the Sudan, Northern, and Southern Guinea savanna zones. Phosphorus, which is the main nutrient required by groundnut, is relatively immobile so that no benefit is generally derived from split-applying this nutrient in any one year.

Recent observations show that low soil nitrogen produces light green plants with reduced yields. However, it has been demonstrated that while under savanna conditions a "starter" dose of nitrogen fertilizer increases haulm yield, its routine application is uneconomical for pod production (Balasubramanian et al. 1979, Lombin et al. In press). However, as the cropping intensity increases, nitrogen nutrition to groundnuts, either through fertilizer use or by inoculation, may need to be reevaluated, more so if production is extended into the wetter Guinea savanna.

Mention has been made earlier of the contribution of sulphur to the soil from Harmattan dust deposited during the dry season. While the level of sulphur from the dust contributes to the total amount available in the soil, mineral fertilizers are necessary for successful production, particularly where cultivation is intensive. Presently, single superphosphate is the major source of sulphur for groundnut, in addition to the phosphorus. This implies that any change from single superphosphate as a source of phosphorus must also provide sulphur.

In certain isolated areas, particularly in the Sudan zone, blindnut problems have been observed. The data currently available suggest that the problem of blindnut is caused by low moisture, which is a constraint to the mineralization of applied nutrients, as well as the availability of calcium and, to a lesser degree, magnesium (Balasubramanian and Yayock 1981). In other words, the application of calcium-supplying fertilizers alone without first correcting a moisture deficit is unlikely to alleviate problems of groundnut pod development and pod fill.

Insect Pest and Disease Control

Wet and humid conditions generally encourage the development of such sporulating diseases as leaf spots and rust on groundnuts. The spread of aphids and, hence, the incidence of rosette disease tends to be suppressed with frequent rains. To benefit from high plant populations, it is advised that the crop be

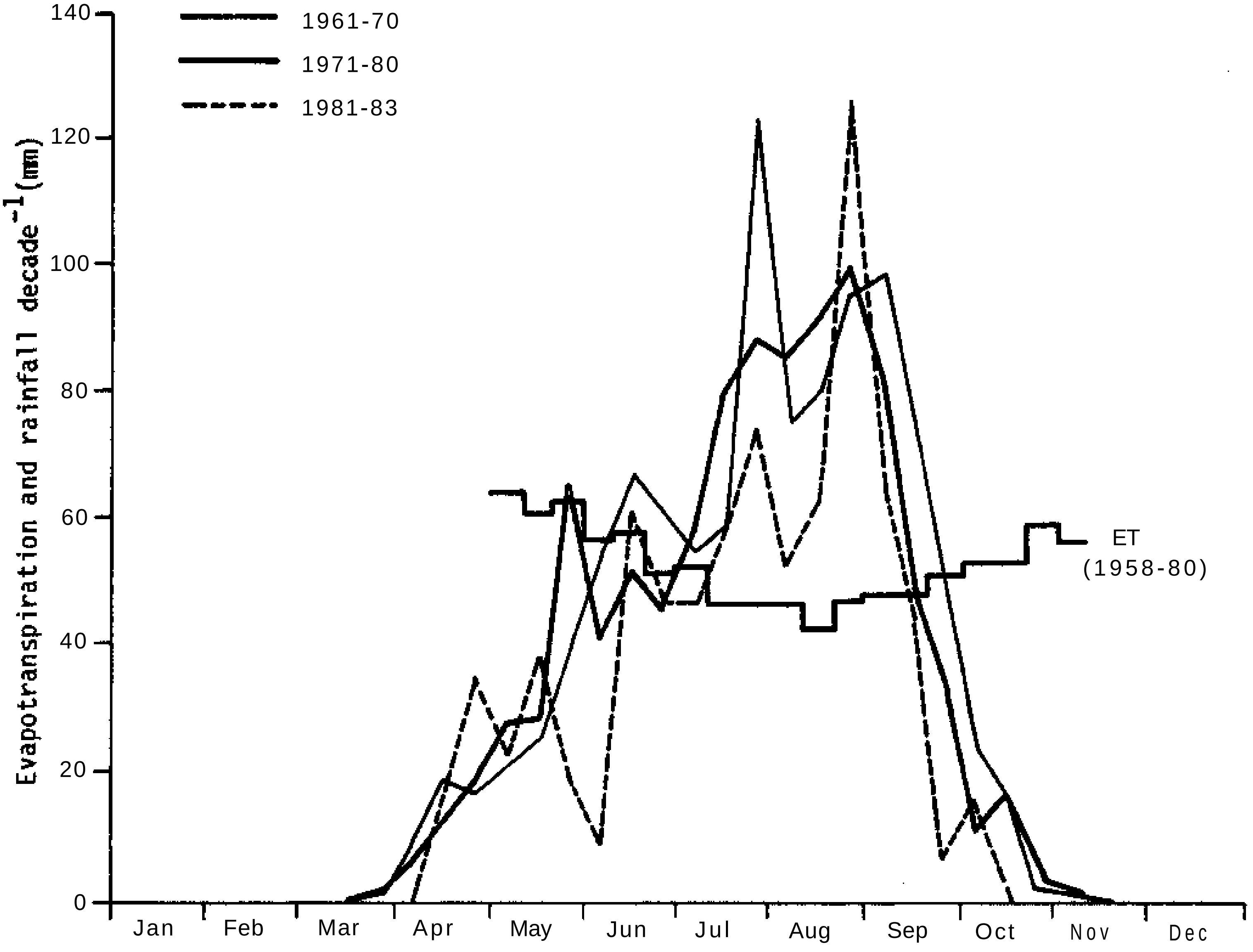

Figure 9. Distribution pattern of rainfall at Samaru, Nigeria, for the 22-year period 1961-83.

sprayed with a fungicide (e.g., Dithane M-45) to protect it from leaf spot disease. Groundnut cultivated during the dry season under full irrigation is relatively free from leaf spots and rust disease. However, production in the dry season is generally discouraged because of the risk that such irrigated crops may serve as reservoirs for aphids and sources of rosette virus which would infect the main crop in the following (rainy) season. The use of cultivars that are resistant to rosette and/or enforcement of a closed season between the irrigated crop and the start of the rainy season would pave the way for the cultivation of groundnut both under full irrigation in the dry season and as a rainfed crop.

Harvesting

The earlier mention of the length of the rainy season relative to the choice of groundnut varieties has highlighted the need to lift the crop when the soil is moist and workable. Equally important to ensure high quality, especially in terms of aflatoxin contamination (by the fungus *Aspergillus flaws),* is the relative humidity at harvest. The fungus reportedly thrives best under humid conditions when the crop dries slowly.

In the major production areas of the Sudan and Northern Guinea zones, the crop is invariably left in the field after lifting, roots up, for as long as the pods require to dry. In normal years when there is no rain after lifting, this air-drying ensures good seed quality. But where it becomes necessary to lift and pick the crop before the rains stop, the use of alternative methods of drying is imperative. Thus, any shift of the groundnut zone toward the southern third of the Northern Guinea and into the Southern Guinea must deal with drying, since groundnuts would invariably need to be lifted before the end of the rains. Lifting well after the rains might be a gigantic task

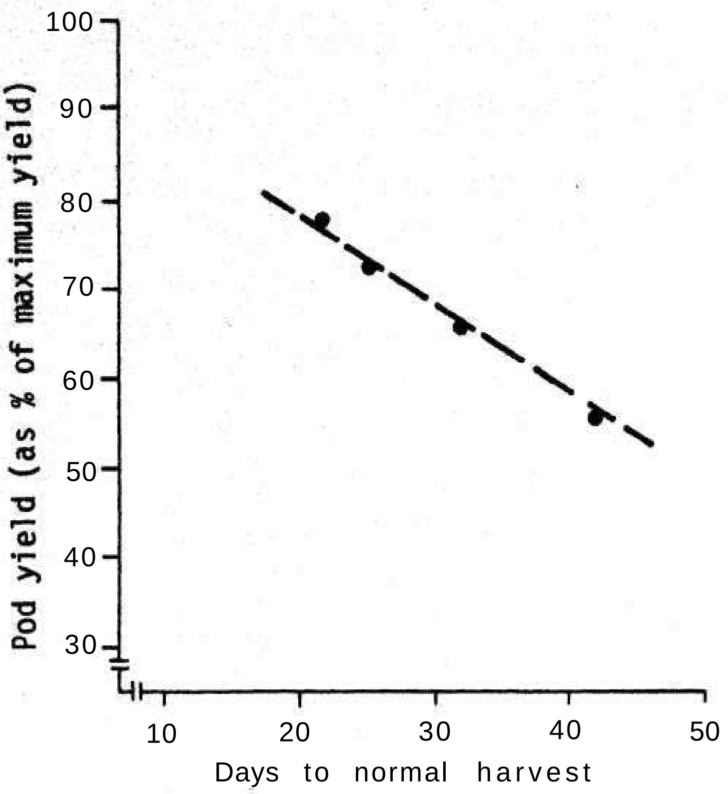

Figure 10. Relationship between pod yield and days to normal harvest for a 120-day groundnut cultivar.

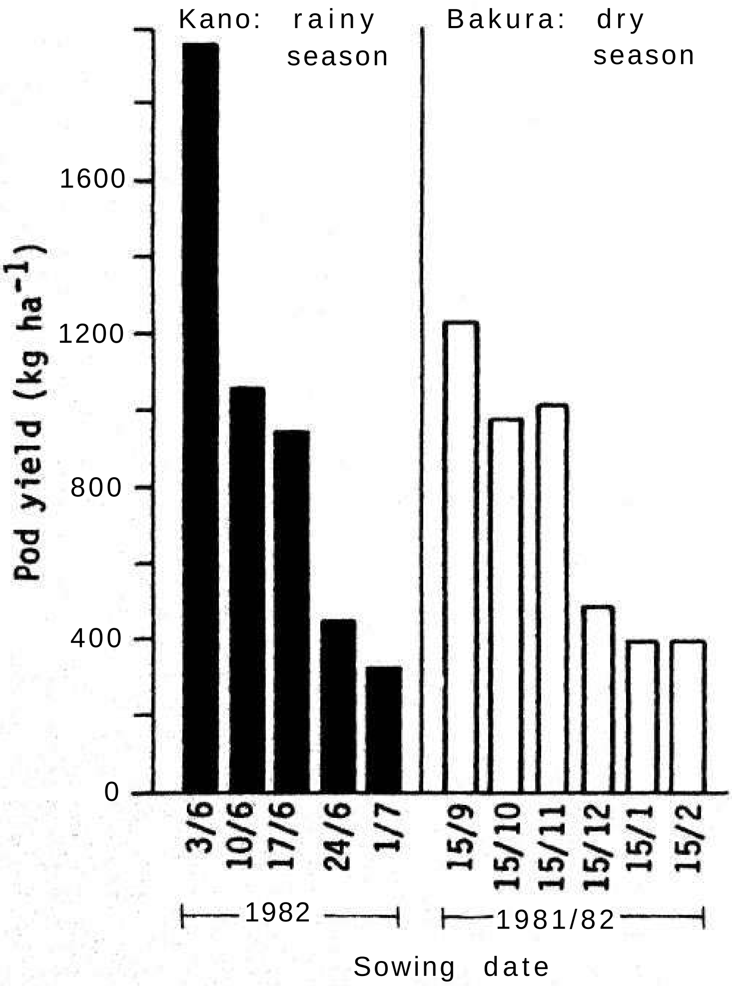

Figure 11. Effect of sowing time on groundnut yields in the Sudan savanna zone of Nigeria.

resulting in large pod losses, especially since the heavier soils of the Guinea zone easily harden and become difficult to work.

Intercropping

As in most other developing countries, agricultural production in Nigeria remains primarily at the subsistence level The issue of food security in the face of heightened agricultural risks means that intercropping will continue to be practiced for quite some time. This contention is further supported by the relative economic advantage of intercropping over monoculture on a unit land basis (Andrews and Kassam 1976). The implication is that while most research into the agronomy of groundnuts has concentrated on monoculture, the search for the scientific basis for the age-old practice of intercropping remains relatively new and only sparingly tackled.

The fact that most groundnuts are cultivated with other crops implies a mutual sharing of growth resources, including light, moisture, and nutrients. Relative to other crops, research into the intercropping aspects of groundnut is not common, probably because of its complexities as well as the generally held view that major improvements in its cultivation are possible only under a system of monoculture.

The only investigation so far undertaken in Nigeria on the environmental relationship of intercropped groundnuts was designed to evaluate the response of the crop to an artificial reduction of sunlight (Owonubi and Yusuf. In press). According to these workers, as much as 30% shading during the main vegetative phase did not affect pod yield, even though flower production was significantly reduced. Application of the shade after the vegetative phase had been completed caused a reduction in pod development, but with no detectable effect on flowering. Valid as these and similar observations may be, their usefulness towards improving groundnut production in the context of crop mixtures can be realized only when research is deliberately focused on understanding this subsistence system of farming.

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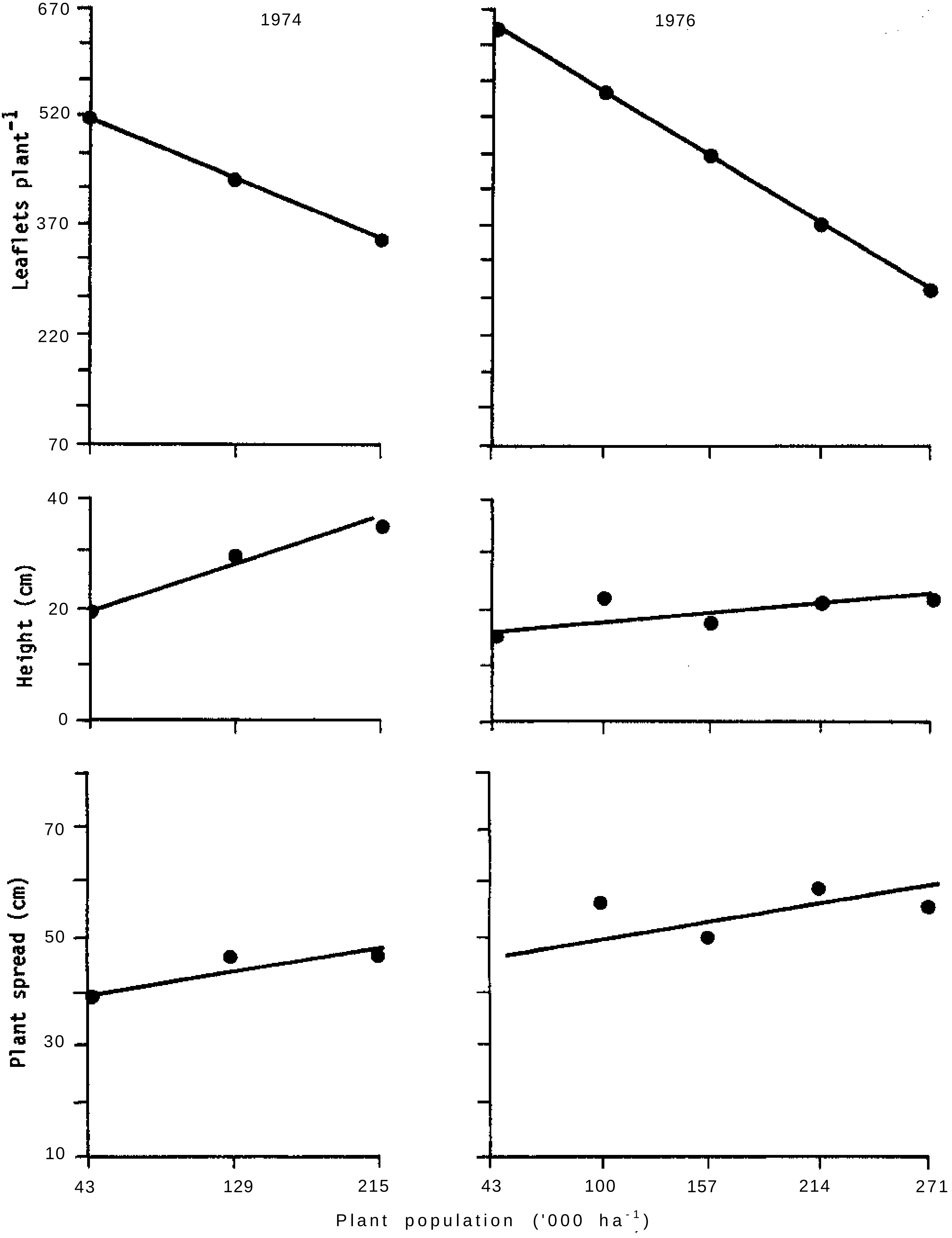

Figure 12. Groundnut population in relation to the number of leaflets plant^{-1}, plant height, and plant spread.

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Le suivi agrométéorologique opérationnel des cultures pour la prévision des récoltes

M. Frère[1]

Résumé

L'Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO) a conçu un modèle agrométéorologique, à des fins de suivi et de prévision, fondé sur un bilan hydrique cumulé sur un pas de 7 ou 10 jours. Ce bilan donne à un moment donné du cycle de croissance de la plante un indice (%) exprimant le degré de satisfaction de ses besoins en eau. Il y a une forte corrélation entre cet indice et le rendement donnant ainsi une très bonne idée, du moins qualitative, du rendement à escompter.

Si, pour la région considérée, on dispose de longues séries statistiques sur le rendement, l'indice obtenu sur un certain nombre d'années a aussi une valeur quantitative. La méthode a été appliquée avec succès dans les pays semi-arides de l'Afrique tropicale.

Abstract

Operational Agrometeorological Monitoring of Crops for Harvest Prospects: *The Food and Agriculture Organization (FAO) has designed an agrometeorological model for crop monitoring and forecasting based on a cumulative 7-day or 10-day crop water balance, which shows at a given stage of the growing cycle of the crop an index (%) expressing the degree of satisfaction of the crop water requirements. This index is strongly correlated with the yield and gives a very good idea, at least qualitatively, of the yield to be expected. If the area has a long record of statistical yield information, the index obtained over a number of years has also a quantitative value. The method has been successfully utilized in the semi-arid countries of tropical Africa.*

Les fluctuations des valeurs moyennes du climat à l'échelle de temps annuelle ou mensuelle montrent en général des courbes régulières faisant ressortir des maxima et des minima de température de l'air, des fluctuations monomodales ou bimodales des précipitations, suivant que l'on se trouvera dans les tropiques ou en région équatoriale. Ces courbes et en particulier celles qui illustrent la distribution des précipitations sont en réalité très trompeuses, car elles masquent complètement les variations dans la distribution actuelle des pluies dans le temps que ce soit à l'échelle mensuelle, décadaire ou journalière.

La courbe (Fig. 1) montre la distribution moyenne des précipitations à Maradi, Niger, au cours des différents mois de l'année. Cette courbe montre aussi la valeur moyenne des dates de début et de fin de la saison de pluie.

Or, si l'on examine de près et une à une un certain nombre d'années, comme nous l'avons fait pour Niamey pour les années 1980, 1983 et 1984, on constate

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[1] Division de la production et de la protection des cultures, FAO, Rome, Italie.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT.

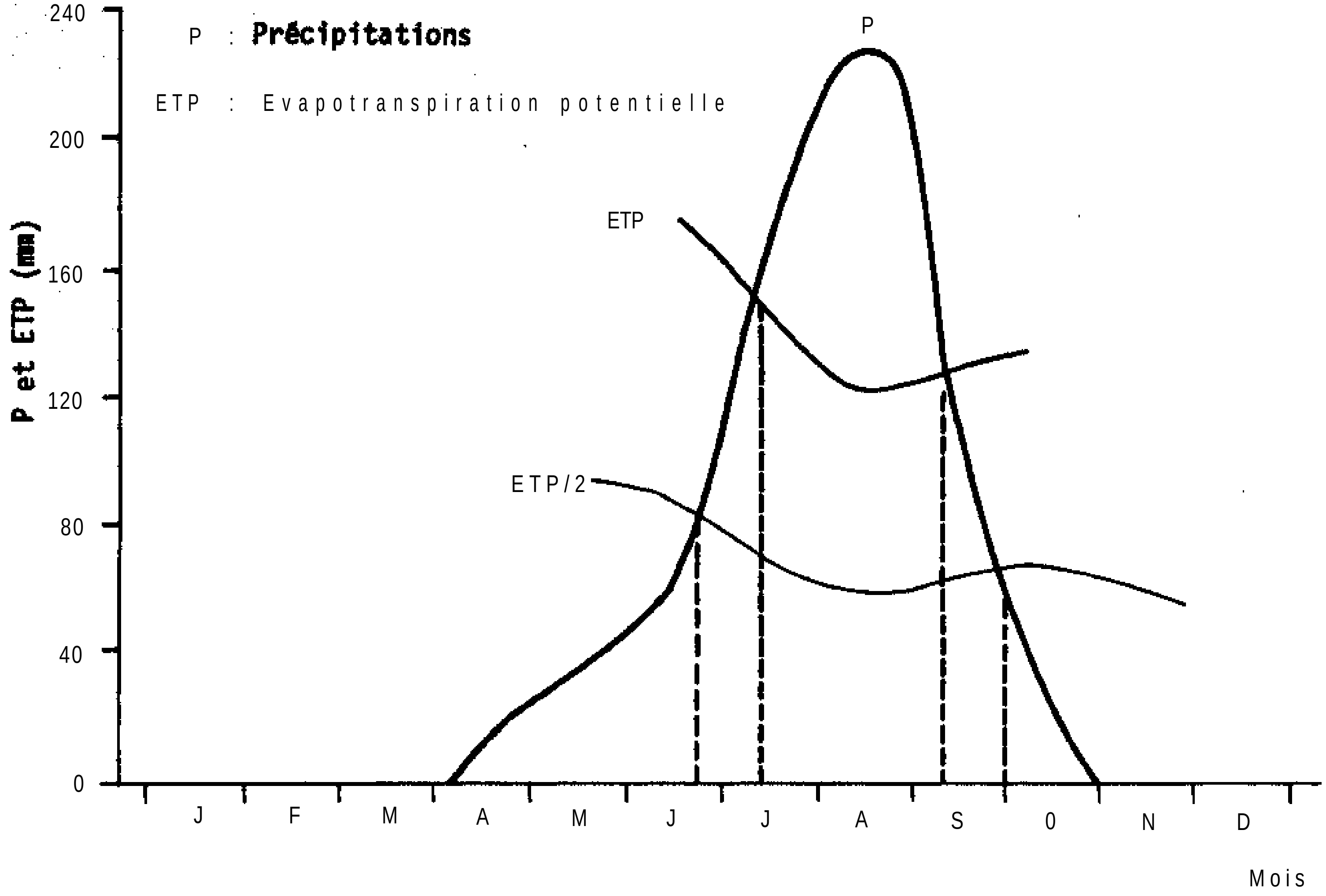

Figure 1. Distribution moyenne des précipitations à Maradi, Niger.

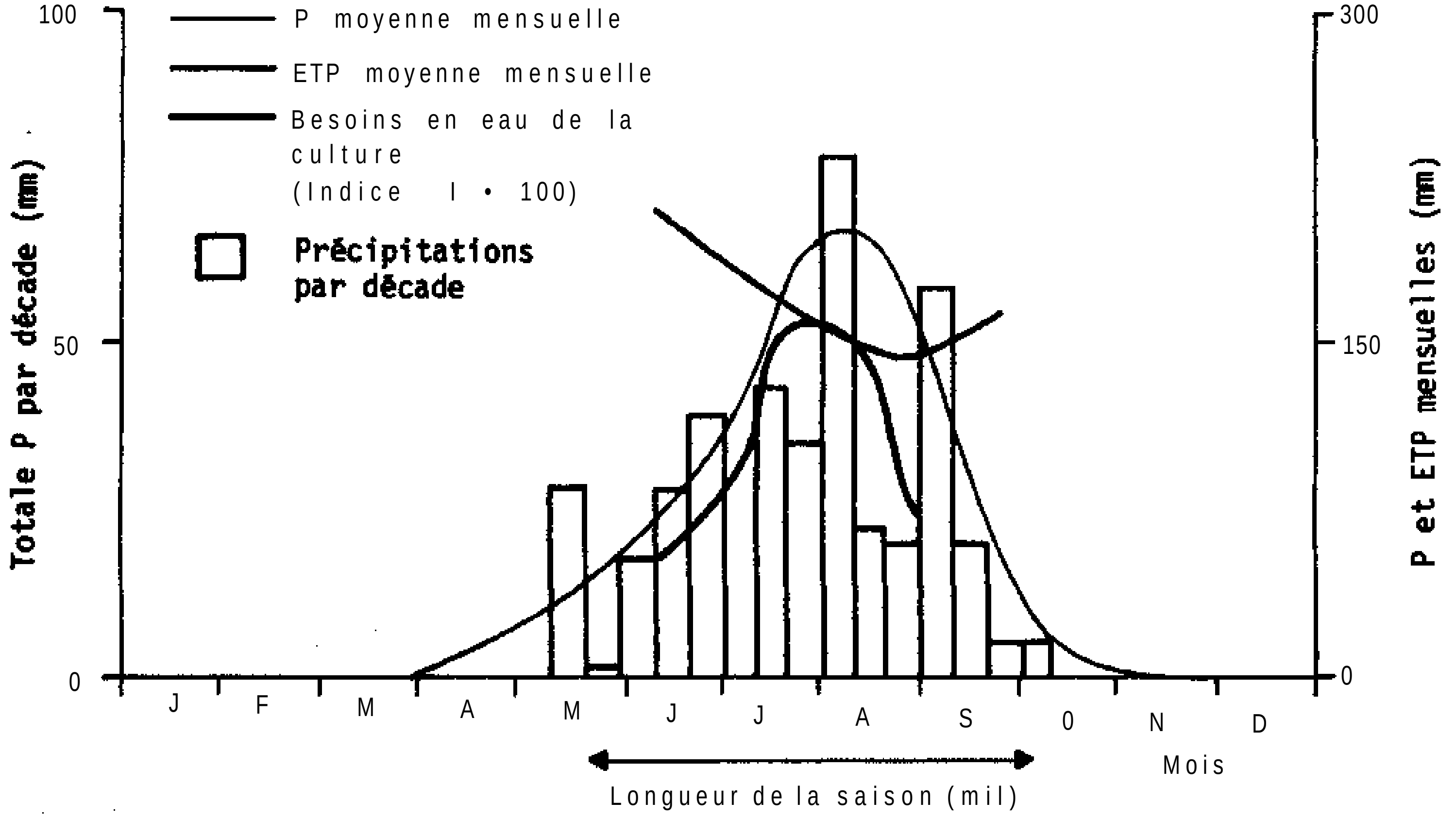

Figure 2. Distribution des précipitations par décade à Niamey, Niger 1980.

qu'à côté de la courbe moyenne, la répartition des pluies mesurées à l'échelle décadaire (période de 10 jours) varie considérablement d'une année à l'autre. Alors que 1980 nous montre une année proche de la normale (Fig. 2), l'année 1983 (Fig. 3) nous montre une année complètement déphasée en avance sur l'année moyenne et des pluies extrêmement irrégulières quoique abondantes, ayant entraîné une avance généralisée de la saison agricole par rapport aux calendriers agricoles moyens.

L'année 1984 (Fig. 4) nous montre par contre un démarrage hâtif de la saison suivi d'une période complètement déficitaire qui s'est d'ailleurs soldée par des déficits agricoles désastreux dans plus de 20 pays africains (Fig. 5).

De ce qui précède, il apparaît clairement qu'un système de suivi agrométéorologique ne pourra pas être basé sur une démarche découlant d'une étude statistique des données pluviométriques collectées sur un intervalle de temps plus ou moins long, mais devra suivre les précipitations telles qu'elles se présentent au cours d'une saison donnée avec toutes ses variations aussi bien spatiales que temporelles.

Un second élément très important pour un suivi à objectifs opérationnels est l'échelle de temps adoptée. Alors que l'échelle de temps communément adoptée par les climatologistes est le mois, ceci est complètement insuffisant pour un suivi agrométéorologique car cette échelle cache des périodes de sécheresse de l'ordre d'une ou deux semaines, qui en milieu tropical peuvent avoir un effet désastreux sur la croissance des cultures. Par ailleurs une échelle journalière pour les besoins opérationnels impose la transmission et le traitement d'un grand nombre de données, ce qui pose une impossibilité technique pour beaucoup de pays où les moyens de transmission et de traitement des données sont encore insuffisants.

Compte tenu de ces contraintes, la FAO a mis au point en 1976 et a continuellement amélioré depuis un système de suivi agrométéorologique opérationnel simple qui a été expérimenté dans plus de 30 pays et qui est adopté, entre autres, au sein du programme Centre régional de formation et d'application en agrométéorologie et hydrologie opérationnelle (AGRHYMET) au Niger (Fig. 6).

Ce système, basé sur l'établissement d'un bilan d'eau cumulatif des cultures, a deux caractéristiques importantes qui le rendent facile à utiliser même sans disposer de puissants moyens de traitement des données.

Premièrement, le pas de temps de ce modèle est la décade ou la semaine dans certains pays anglophones. Deuxièmement, ce modèle est hybride dans le sens qu'il utilise d'une part les données cumulatives déca-

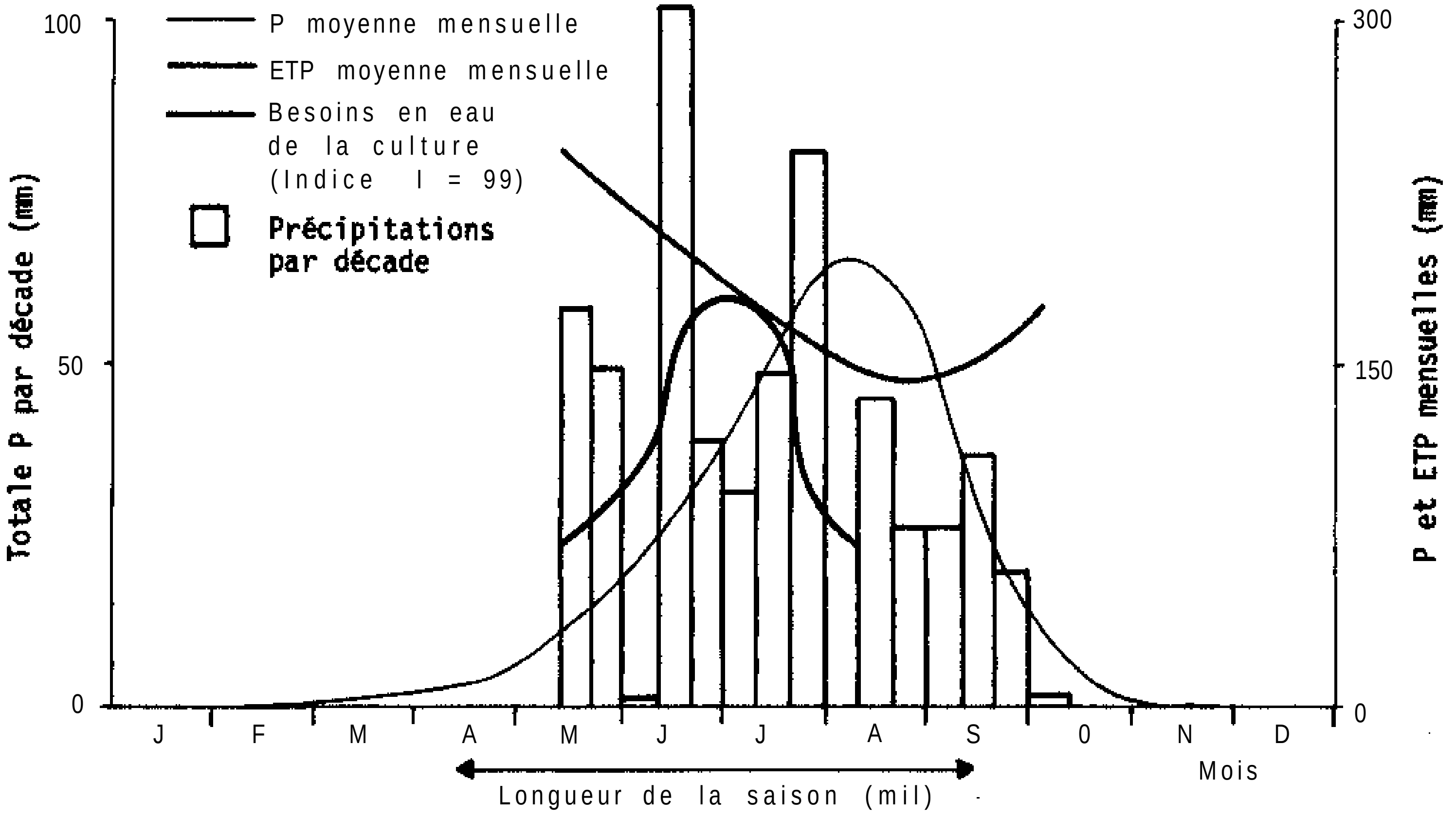

Figure 3. Distribution des précipitations par décade à Niamey, Niger 1983.

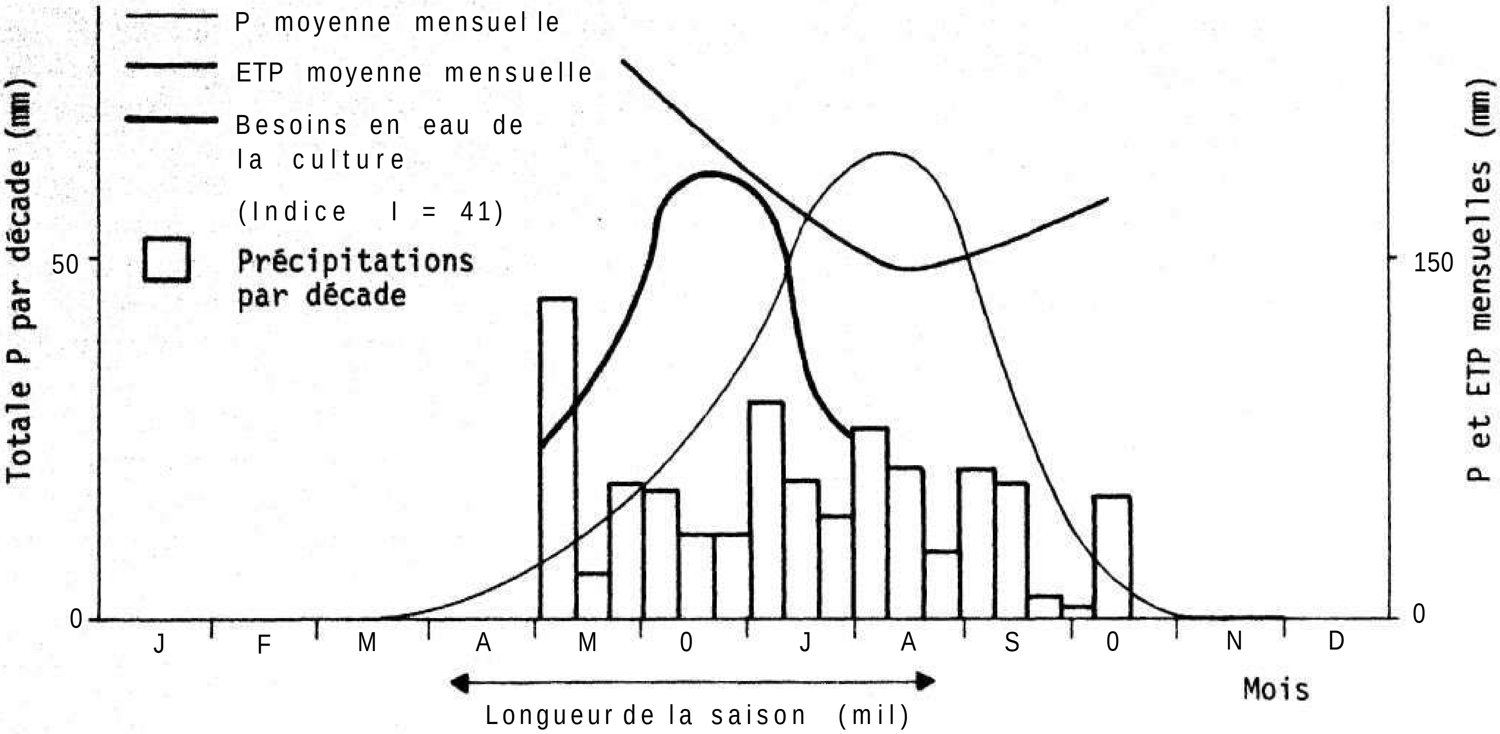

Figure 4. Distribution des précipitations par décade à Niamey, Niger 1984.

daires de précipitations telles qu'observées dans les stations et que d'autre part la composante évapotranspiration utilisée dans le bilan d'eau cumulatif provient des données climatologiques de cette station. Cette simplification est rendue possible parce que :

- au cours de la saison végétative, les paramètres conditionnant l'évaporation sont généralement assez stables pour un lieu (station) et une époque (décade) donnés;
- cette stabilité des paramètres est augmentée par l'amortissement des fluctuations journalières dès que l'on se place à l'échelle de la décade.

Les résultats de ce qui précède est que les seules données d'observations nécessaires en temps semi-réel pour le fonctionnement du modèle sont les précipitations et les informations réelles concernant le développement de la culture qui, en fait, ne font que confirmer les décisions estimées sur les dates de semis ou des différents stades phénologiques de la culture. La plupart de ces données en effet résultent de l'analyse en dehors du temps réel, ou si l'on préfère, dans la phase préparatoire du suivi, des éléments d'information sur les caractéristiques de la culture (variété, durée de végétation, phases de développement, rendements moyens, etc.) et de son environnement pour une station ou une région donnée.

Le caractère hybride des données utilisées dans le modèle FAO de bilan hydrique permet aussi dans des régions à topographie assez régulière comme le Sahel d'utiliser en plus des observations provenant de stations météorologiques complètes, celles qui sont fournies par de simples stations pluviométriques, pourvu que celles-ci disposent de moyens rapides de transmission de données (radio, téléphone, courriers, etc.) Dans ce cas les données d'évapotranspiration climato-

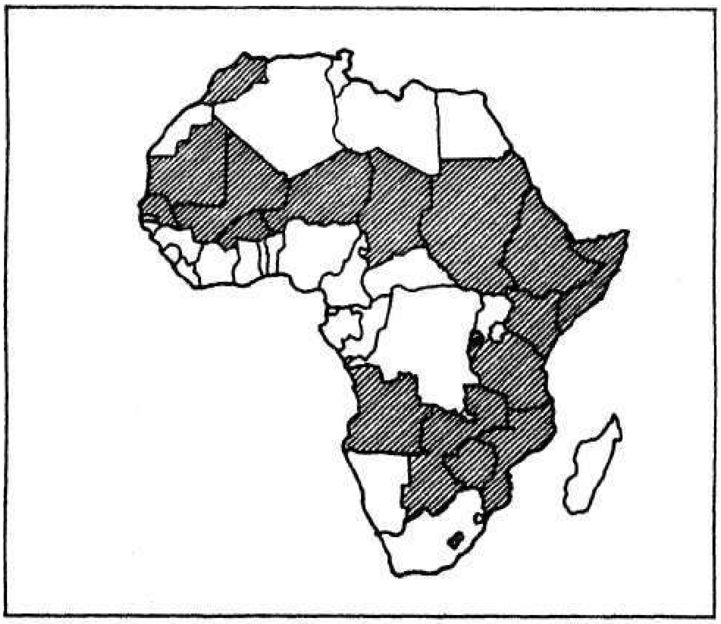

Figure 5. Les pays africains affectés par des déficits agricoles désastreux (Source : Food Situation in African Countries Affected by Emergencies, Special Report, FAO, May 1985).

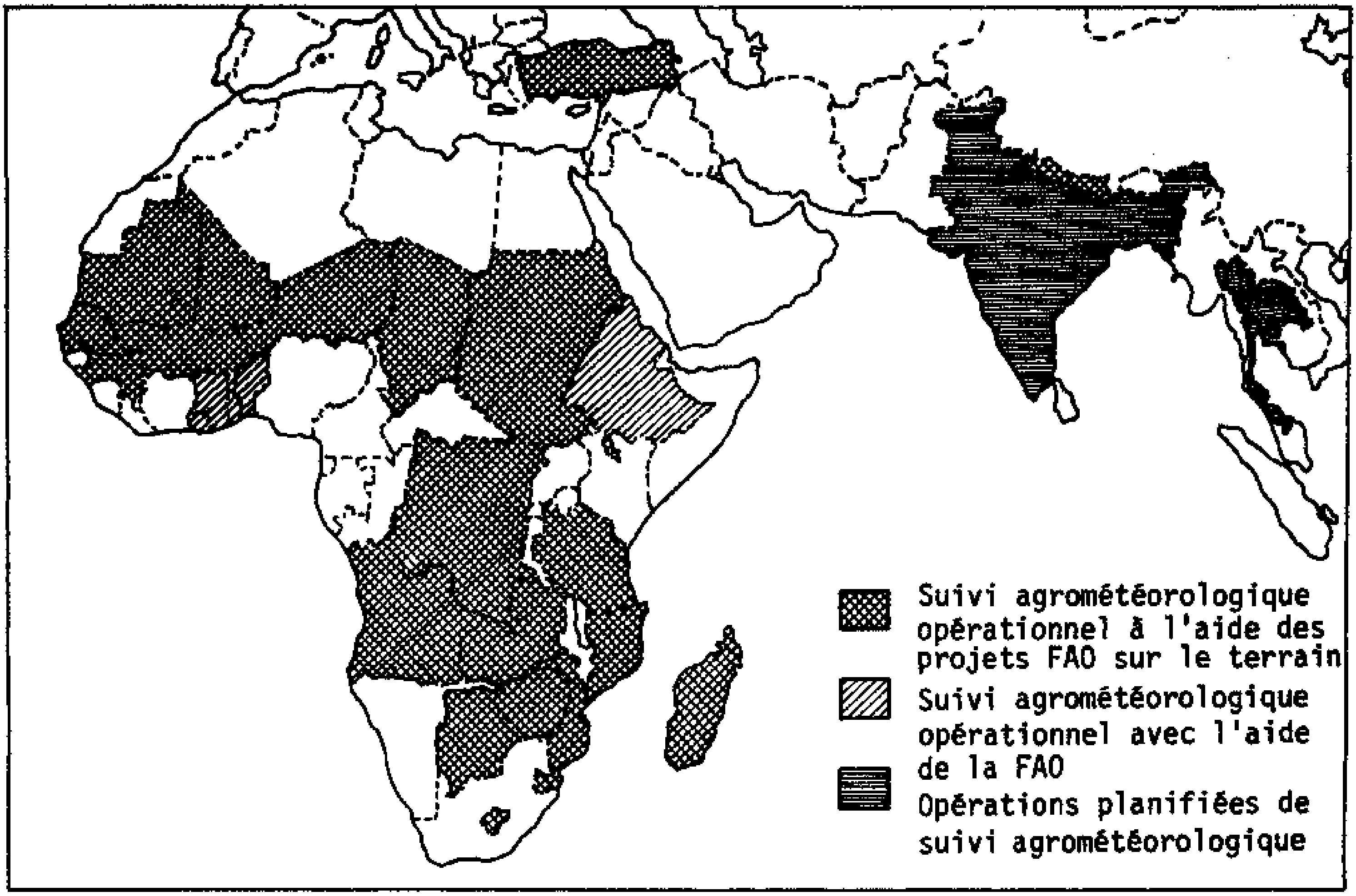

Figure 6. Suivi agrométéorologique FAO.

logiques pourront éventuellement être interpolées à partir des données mesurées dans des stations plus importantes, ceci permettant, en définitive, d'utiliser les données d'un réseau beaucoup plus dense (Fig. 7).

Au Niger, par exemple, compte tenu des stations gérées par l'Institut national de recherches agronomiques du Niger (INRAN) et par le Ministère de l'Intérieur et qui disposent de moyens de radio-télécommunication, on devrait pouvoir exercer un suivi utilisant quelque 50 stations à la place des 10 stations synoptiques utilisées actuellement.

Dans la pratique, le modèle est utilisé de la façon suivante (les exemples choisis se réfèrent à la culture de l'arachide au Sénégal). Le modèle utilise à la base une feuille de calcul où les données sont inscrites ligne après ligne, chaque ligne correspondant à une décade. Les données observées ou calculées figurent dans les colonnes appropriées.

Cette présentation, qui est l'inverse de celle figurant dans des publications antérieures sur le sujet, a été choisie car elle correspond mieux aux documents obtenus par ordinateur et la comparaison entre documents est donc plus facile (Tab. 1 et 2).

Dans les pays caractérisés par une longue saison sèche, on suppose qu'au début de la saison, la réserve du sol en eau est nulle. Le bilan d'eau sera démarré lorsqu'une précipitation de l'ordre de 25-30 mm aura été reçue au cours d'une décade. L'expérience montre en effet que cette intensité de pluie correspond en général à un démarrage effectif de la saison pluvieuse alors que précédemment des précipitations plus faibles peuvent déjà avoir eu lieu. Celles-ci cependant ne permettent pas une alimentation hydrique suffisante des jeunes plantes.

Les colonnes 1, 2 et 3 montrent respectivement le numéro d'ordre de la décade, son emplacement et d'une manière facultative la précipitation moyenne qui la caractérise.

Les colonnes 4 et 5 montrent respectivement la précipitation observée et le nombre de jours de pluie durant la décade en question. Le nombre de jours de pluie donne une valeur indicative et sert à donner une information sur l'intensité et l'efficacité des précipitations, une précipitation de 140 mm répartie sur 7 jours étant probablement plus efficace que 90 mm reçus en deux jours.

Dans la colonne 6, on inscrit les données d'évapotranspiration potentielle décadaire telle que calculée par méthode de Penman (Frère et Popov 1979) ou obtenues à partir de la publication FAO sur les données agroclimatologiques de l'Afrique (FAO 1984).

Il sera également possible de suivre le bilan hydrique pour des simples stations pluviométriques pourvu que la régularité du relief et l'absence de différences importantes dans les paramètres conditionnant l'évapotranspiration permettent d'interpoler ces données à partir des stations plus importantes.

La colonne 7 permet d'insérer les coefficients culturaux de chaque décade. Le coefficient cultural est le rapport entre l'évapotranspiration maximum (ETM) de la culture à un stade donné et l'évapotranspiration potentielle (ETP) déjà définie : Kc=ETM/ETP. Ces coefficients culturaux varieront de 0,3 au moment du semis à 1,0 et plus au moment de la floraison, pour diminuer ensuite jusqu'à 0,5 au moment de la maturité (Fig. 8). Dans l'exemple de la culture arachidière pratiquée au Sénégal avec des variétés à 12 décades, l'on a les coefficients suivants :

Décade n°	1	2	3	4	5	6	7	8	9	10	11	12
Kc	0,3	0,4	0,7	0,8	0,9	1,0	1,0	1,0	0,9	0,8	0,6	0,5

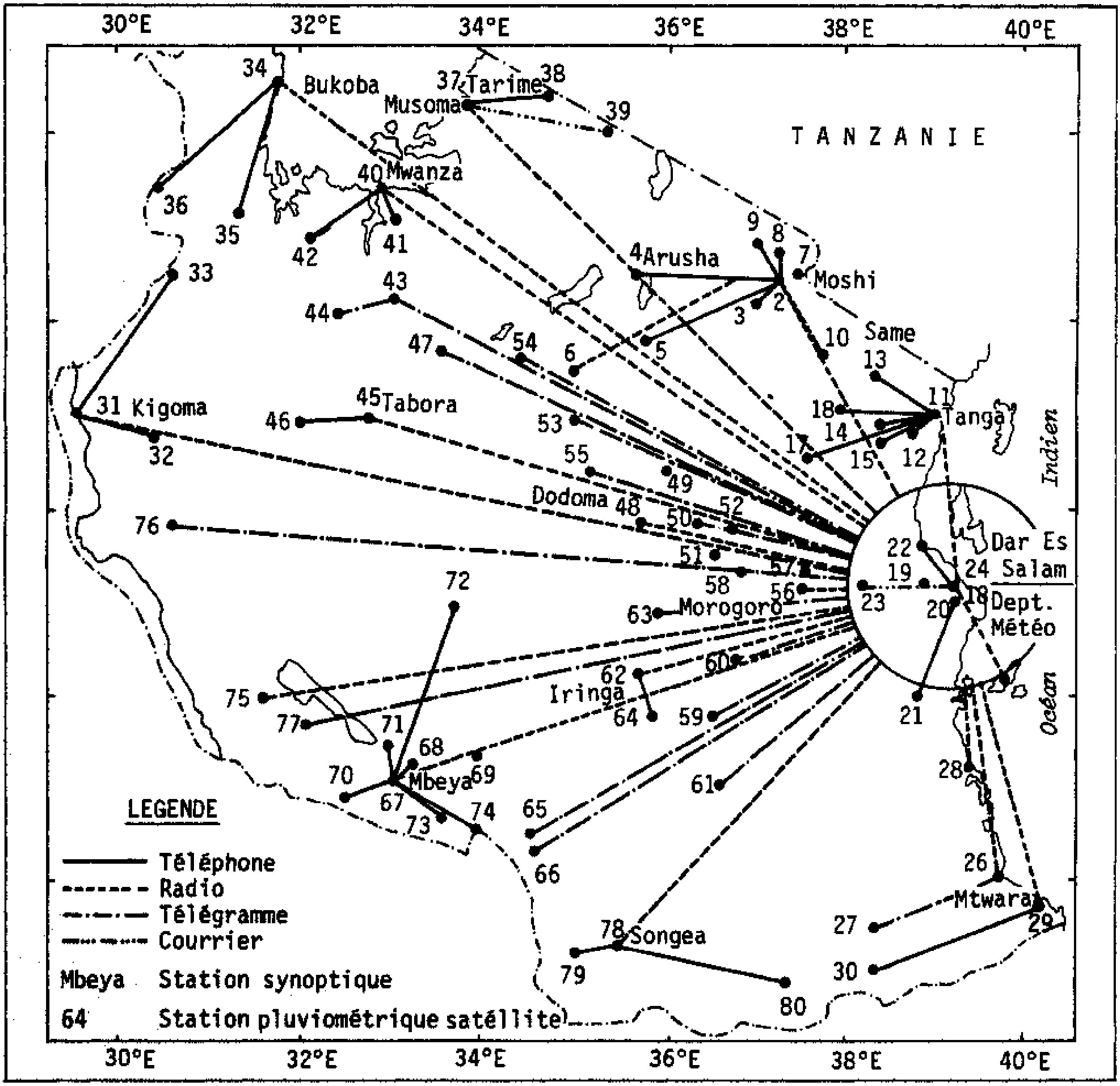

Figure 7. Réseau d'observations et de télécommunications en Tanzanie.

Tableaux 1 et 2. Exemples d'utilisation de la méthode FAO de suivi agrométéorologique.

FAO AGROMETEOROLOGICAL RAINFED CROPS MONITORING . SHEET I

STATION BAMBEY COUNTRY SENEGAL SEASON 1949

LAT. 14.42 LONG. -16.28 ALT. 17 m Crop/Cultivar ARACHIDE

LGS (no. of days) 120

SOIL WATER RETENTION CAPACITY: 60 mm TOTAL WATER REQUIREMENTS: 404 mm

No	DEKAD/ MONTH	P_N	P_a	d_a	PET	K_c	WR	P-WR	R_a	S/D	I %	NOTES
1	2	3	4	5	6	7	8	9	10	11	12	13
	1/6		0	0								
	2/6		1	1								
	3/6		0	0								
1	1/7		73	4	56	0.3	17	+56	56		100	
2	2/7		24	4	52	0.4	21	+ 3	59		100	
3	3/7		22	6	50	0.7	35	-13	46		100	
4	1/8		65	1	47	0.8	38	+27	60	+13	100	
5	2/8		107	5	45	0.9	40	+67	60	+67	100	
6	3/8		67	6	44	1.0	44	+23	60	+23	100	
7	1/9		12	2	41	1.0	41	-29	31		100	
8	2/9		20	1	41	1.0	41	-21	10		100	
9	3/9		15	2	43	0.9	39	-24	0	-14	97	
10	1/10		2	1	45	0.8	36	-34	0	-34	89	
11	2/10		0	0	47	0.6	28	-28	0	-28	82	
12	3/10		52	3	48	0.5	24	+28	28		82	

FAO AGROMETEOROLOGICAL RAINFED CROPS MONITORING . SHEET I

STATION BAMBEY COUNTRY SENEGAL SEASON 1963

LAT. 14.42 LONG. -16.28 ALT. 17 m Crop/Cultivar ARACHIDE

LGS (no. of days) 120

SOIL WATER RETENTION CAPACITY: 60 mm TOTAL WATER REQUIREMENTS: 404 mm

No	DEKAD/ MONTH	P_N	P_a	d_a	PET	K_c	WR	P-WR	R_a	S/D	I %	NOTES
1	2	3	4	5	6	7	8	9	10	11	12	13
	1/6		0		67							
	2/6		1	1	62							
	3/6		20	2	59							
1	1/7		61	3	56	0.3	17	+44	44		100	
2	2/7		52	1	52	0.4	21	+31	60	+15	100	
3	3/7		23	4	50	0.7	35	-12	48		100	
4	1/8		93	6	47	0.8	38	+55	60	+43	100	
5	2/8		12	3	45	0.9	40	-28	32		100	
6	3/8		70	4	44	1.0	44	+26	58		100	
7	1/9		133	6	41	1.0	41	+92	60	+90	100	
8	2/9		42	5	41	1.0	41	-1	59		100	
9	3/9		0	0	43	0.9	39	-39	20		100	
10	1/10		42	5	45	0.8	36	+ 6	26		100	
11	2/10		46	3	47	0.6	28	+18	44		100	
12	3/10		0	0	48	0.5	24	-24	20		100	

La colonne 8 indique les besoins en eau de la culture obtenue en multipliant ETP par Kc. Cette opération montre un accroissement de ces besoins du semis à la floraison et une décroissance vers la maturité. De même nous voyons que la phase de développement entourant la floraison se caractérise par les plus grands besoins d'eau. Il en résulte que cette phase sera la plus sensible aux déficits d'eau pouvant se manifester au cours de la saison.

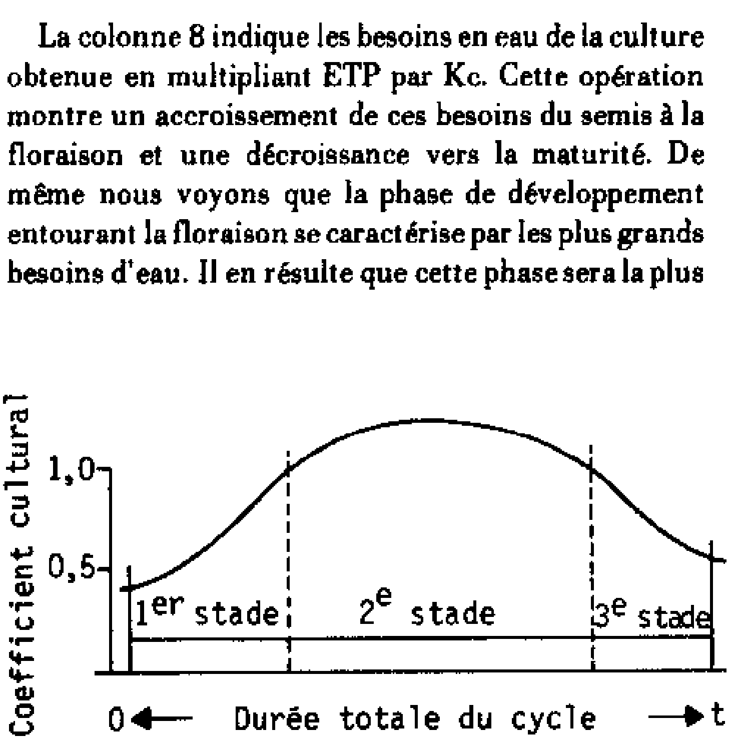

Figure 8. Variation saisonnière du coefficient cultural.

Dans le modèle FAO, une fois fixée la date du semis, il est donc possible de calculer les besoins d'eau pour chaque décade (Kc et ETP climatologiques) et, en conséquence, les besoins totaux pour l'ensemble de la saison WR. Ce paramètre sera très important dans la suite.

Dans la colonne 9 figure la différence entre précipitation et besoins d'eau (RS), montrant jusqu'à quel point ces besoins d'eau sont satisfaits par les précipitations.

La colonne 10 exprime la réserve en eau utile du sol pour une culture donnée et compte tenu du bilan d'eau. Cette réserve sera influencée non seulement par le type du sol mais également par le niveau atteint par les poils absorbants des racines de la plante (Fig. 9). Dans un cas extrême comme le riz de montagne, le développement des racines atteint difficilement 30 cm et la réserve sera au maximum de 20 mm. Par contre, dans le cas du sorgho, cette réserve en eau utile pourra atteindre sur un même sol un maximum de quelque 70-80 mm d'eau, compte tenu du développement beaucoup plus important du système radiculaire de cette culture.

Aussi longtemps que le terme RS restera positif, on n'aura pas de déficit d'eau (colonne 11) ni d'excès, tant que la réserve maximum n'a pas été atteinte.

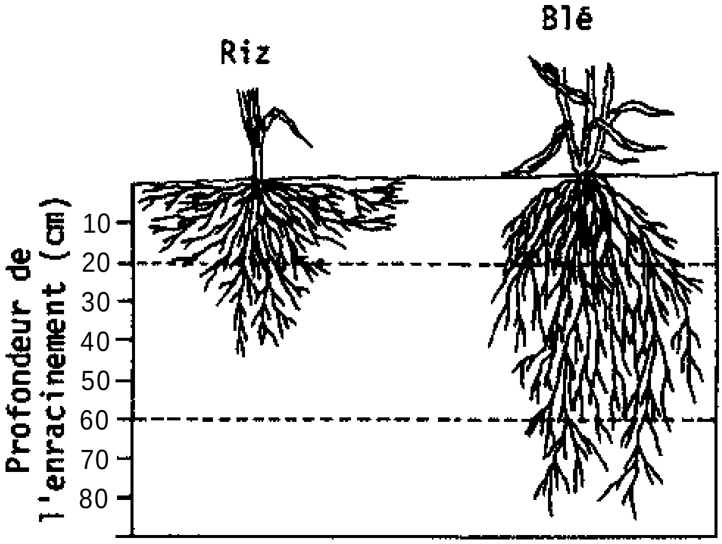

Figure 9. Divers types de systèmes radiculaires.

Si cette différence devient négative, on aura un déficit qui correspondra aux besoins d'eau non satisfaits par la réserve exprimés en mm.

La colonne 12 exprimera ce déficit d'eau cumulé par un index de satisfaction des besoins en eau, I ou ISBE. Il se calculera en soustrayant de 100 (100% des besoins en eau satisfaits au départ), une expression du quotient entre le déficit d'eau de la décade sous étude et la somme des besoins en eau (WR). Par exemple, si nous trouvons en colonne 11 un déficit de 20 mm et que nous le comparons à la somme des besoins en eau (colonne 8, WR) de 400 mm, nous trouvons 5% et donc l'index passera de 100 à 95. Cet index restera sur cette valeur pour autant qu'il ne se manifeste aucun autre déficit sur la saison. Autrement sa valeur diminuera encore, comme sur les autres exemples illustrés.

L'index est pour la plupart des cultures céréalières étroitement lié au rendement (Fig. 10). Toutefois étant donné que les rendements absolus des cultures ne dépendent pas seulement du bilan d'eau, mais encore de l'alimentation minérale de la plante et des

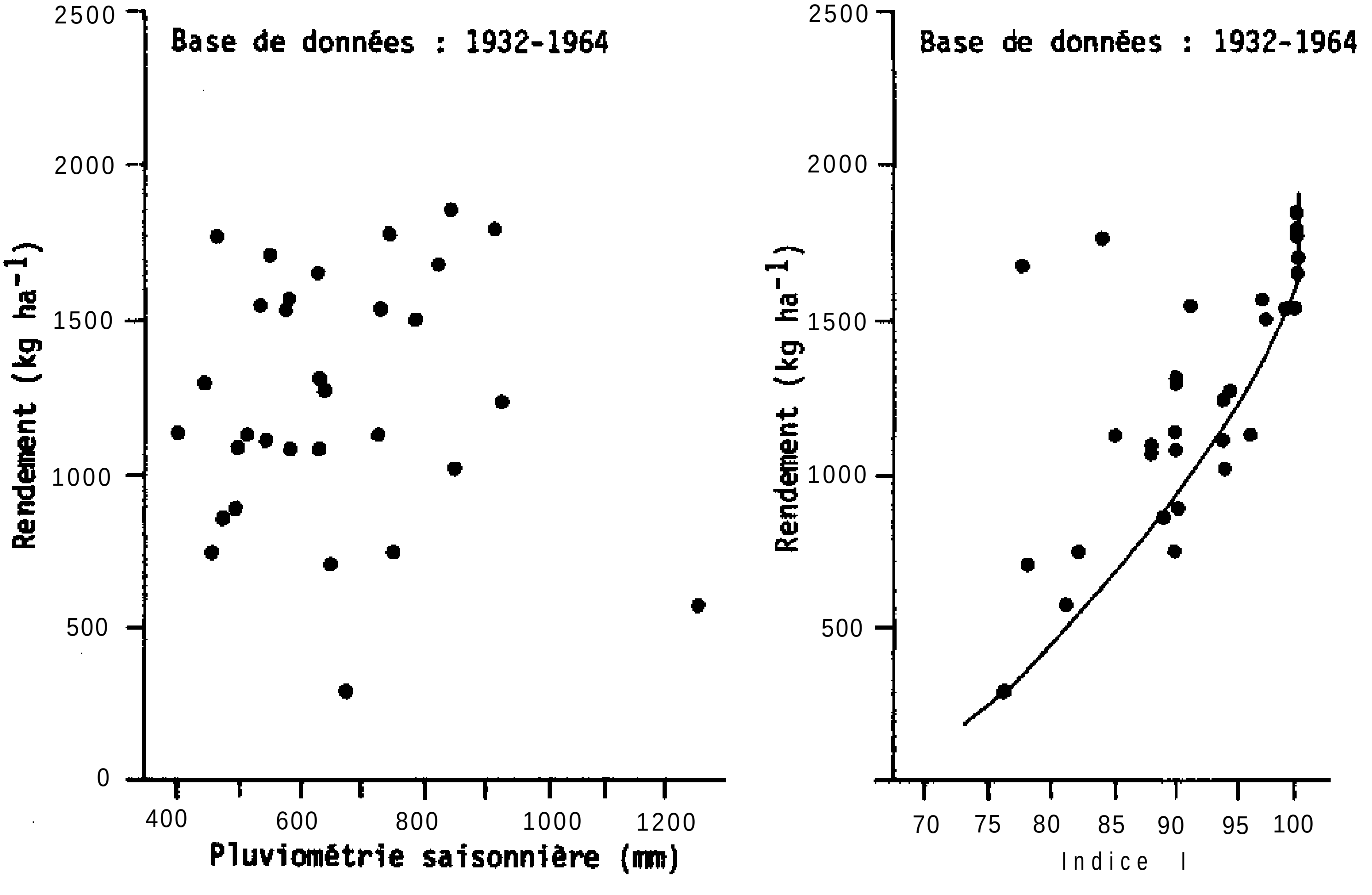

Figure 10. Application du modèle FAO de suivi agrométéorologique sur des arachides (variétés 24-11/24-48) à Bambey, Sénégal.

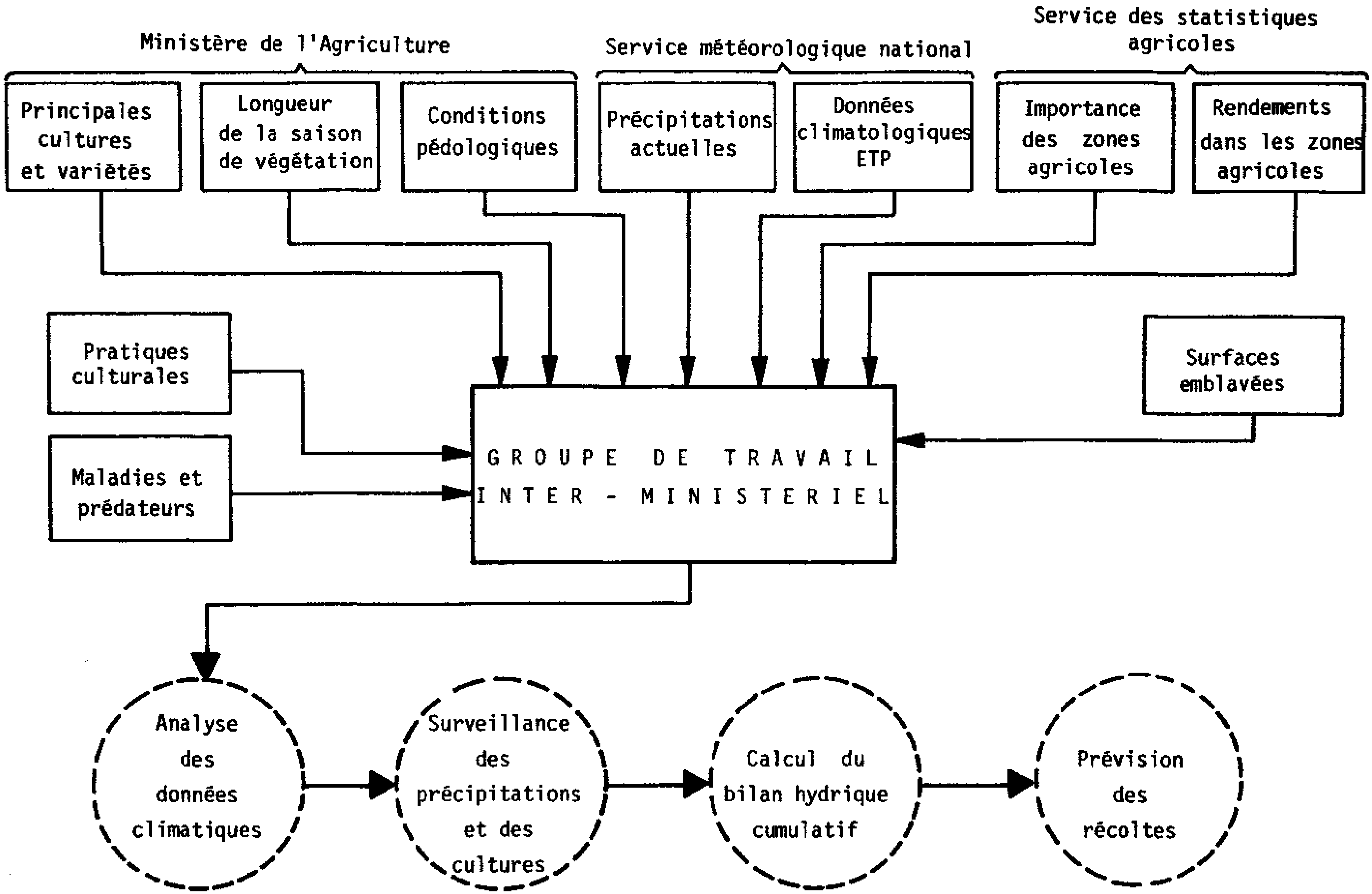

Figure 11. Schéma des diverses contributions techniques au suivi agrométéorologique FAO.

mesures de protection en usage contre les maladies et parasites, il est souvent avantageux de comparer l'index examiné plus haut à un index de rendement exprimé comme le quotient entre le rendement actuel exprimé en kg ha^{-1} et la moyenne des rendements en kg ha^{-1} des trois meilleures années sur une période d'une dizaine d'années. De cette façon on arrive à une relation entre Index de satisfaction des besoins en eau et Index des rendements.

La méthode de suivi agrométéorologique proposée par la FAO a l'avantage d'une grande simplicité d'emploi et donne des résultats exploitables sous forme de prévisions au moins qualitatives à un stade précoce de la saison culturale. En fait, sur 10 ans d'expérience la méthode a démontré un parfait accord avec les prévisions d'ordre statistique.

Son avantage toutefois est qu'étant basée sur les causes d'une sécheresse, elle donne des résultats quelque deux mois avant les méthodes statistiques basées sur des échantillons montrant les effets d'une sécheresse. Cet avantage temporel est extrêmement important pour l'organisation du système d'alerte rapide (early warning) et des opérations de secours d'urgence.

Le modèle décrit ci-dessus et utilisé à des fins de prévision des récoltes s'intègre en fait dans la collecte et l'analyse d'un ensemble d'information physiques, biologiques et aussi économiques dont l'ensemble concourt à la détermination exacte de la situation alimentaire d'une région ou d'un pays (Fig. 11).

Il est très important qu'une structure adéquate coordonne les activités des divers ministères, départements et services concernés par la sécurité alimentaire à l'échelon régional ou national, de façon à obtenir en temps opérationnel une information synthétique, complète et détaillée couvrant l'ensemble des provinces et du territoire national (Fig. 12).

Cette organisation existe déjà dans un ensemble de

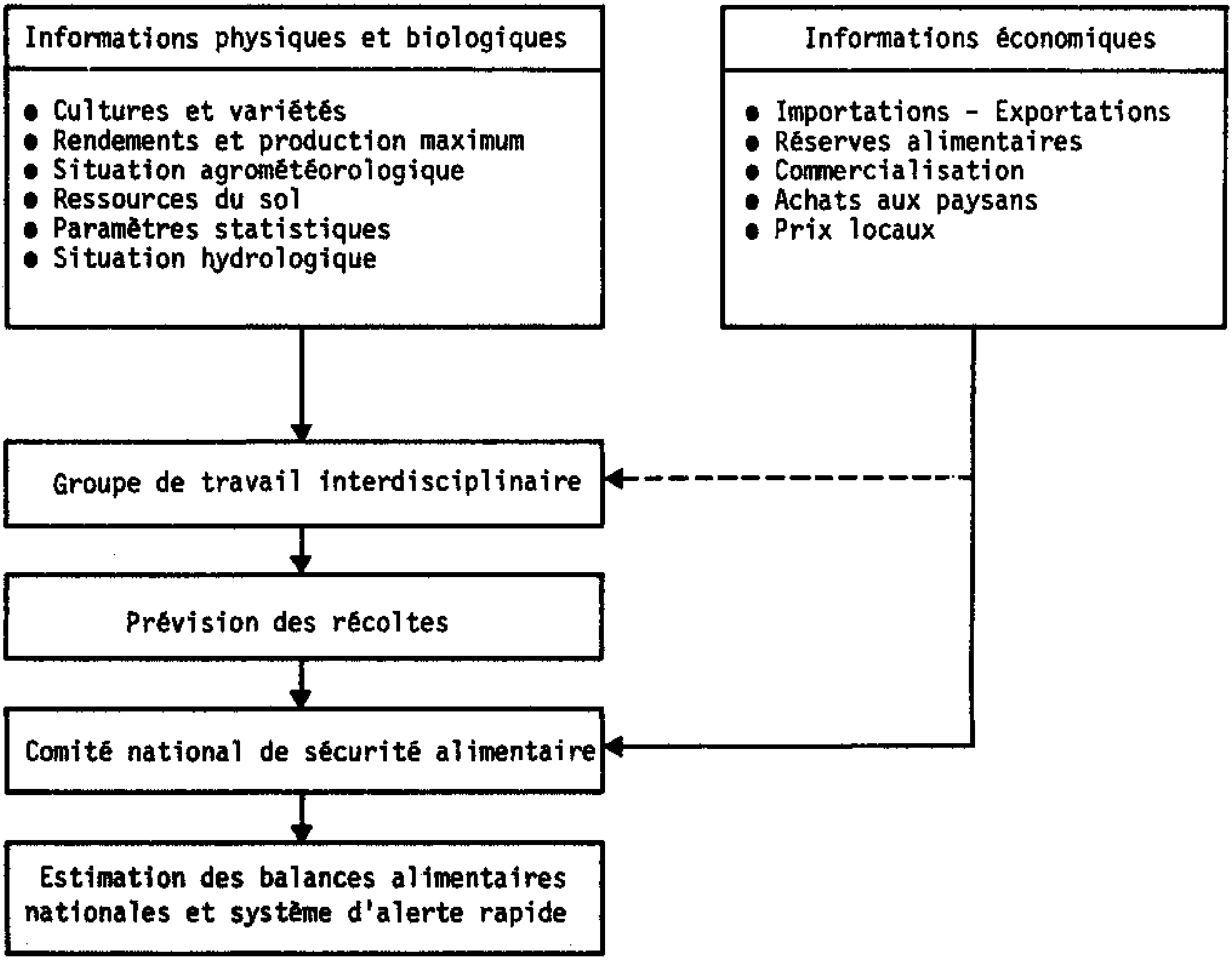

Figure 12. Structure d'ensemble d'un système national de sécurité alimentaire.

pays bien qu'à des stades divers, et a démontré sa valeur en termes d'information, de prévision et d'organisation de la production et éventuellement des aides d'urgence. Grâce à ces actions, il a été possible de mieux prévoir les balances alimentaires nationales et régionales et d'avoir de moins en moins recours à des procédures d'urgence qui dans tous les cas se révèlent toujours plus dispendieuses que les procédures normales.

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Disease-Forecasting Method for Groundnut Leaf Spot Diseases

D.H.Smith[1]

Abstract

A disease-forecasting method for groundnut leaf spot diseases was developed in Georgia in 1966. The system is based on the effects of daily minimum air temperature and duration of relative humidity equal to or greater than 95% on development of leaf spot epidemics. The system was computerized and daily spray advisories were issued to groundnut growers in the southeastern United States beginning in 1971. However, because of the availability of inexpensive fungicides that provided satisfactory control of leaf spots when applied at intervals of 14 days, the system was not widely accepted by growers in the United States. Currently there is a renewed interest in the system because of increased costs of fungicides, application costs, and the deleterious nontarget effects of some fungicides. In Virginia field trials from 1979 to 1982, the total number of fungicide applications based on the leaf spot advisory program averaged 4.25 fewer applications per season than did the number of applications on a 14-day schedule.

Résumé

Une méthode de prévision des maladies des feuilles de l'arachide : ***Une méthode de prévision de maladies des feuilles de l'arachide a été développée en Georgie en 1966. La méthode est basée sur les effets de la température et de la durée d'humidité relative supérieure ou égale à 95% sur le développement des maladies des feuilles. Elle a été informatisée et des avertissements journaliers sont fournis aux planteurs, dans le Sud des Etats-Unis depuis 1971. Cependant à cause de l'existence de fongicides bon marché qui permettent un contrôle satisfaisant de la maladie, quand ils sont appliqués à des intervalles de 14 jours, la méthode n'a pas reçu, auprès des planteurs, une large audience. Il existe actuellement un regain d'intérêt pour la méthode à cause des coûts croissants des fongicides. des traitements et de l'effet nuisible de certains fongicides. Au cours d'expériences en Virginie, de 1979 à 1982, le nombre total de traitements basés sur le programme d'avertissement à été en moyenne 4,25 fois plus faible que celui aurait résulté de traitements bimensuels.***

Introduction

Early and late leaf spot, caused by *Cercospora arachidicola* Hori and *Cercosporidium personatum* (Berk and Curt.) Deighton commonly contribute to decreased productivity of groundnuts (Porter et al. 1982.) In addition to pod yield losses, reduced yield and quality of haulms is also attributable to epidemics of early and late leaf spot (Cummins and Smith 1973). Early and late leaf spot occur either alone or

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT.

together in the same field. In some areas early leaf spot, late leaf spot, rust, and web blotch occur in the same field.

Currently groundnut foliar diseases can be managed with multiple applications of fungicides. The initial fungicide application is usually made at 30-40 days after sowing (DAS). Subsequent application is usually made at intervals of 10-14 d until 2 or 3 weeks prior to the anticipated harvest time. In the United States, fungicides are applied with tractor-propelled sprayers, fixed-wing aircraft, controlled-droplet application equipment, sprinkler-irrigation systems, and helicopters. A partial list of fungicides that have been or are currently used for management of groundnut foliar diseases in the United States is included in Table 1. The fungicides approved for management of groundnut foliar diseases in the USA have been available to growers for 15 years or longer. Several experimental compounds have been extensively evaluated in the USA. Therefore, it is probable that new fungicides will soon be approved for use in the USA.

Forecasting Method

Jensen and Boyle (1965) studied the influence of temperature, relative humidity, and precipitation on progress of leaf spot epidemics. Although it was not stated in their paper, early leaf spot was the predominant disease at that time. Since their investigations in the 1960s, late leaf spot has become the predominant foliar disease in Georgia, Florida, and Alabama (Smith and Littrel 1980). The disease-forecasting system described by Jensen and Boyle (1966) was based on the duration of relative humidity at 95% or greater and the minimum air temperature during the high-humidity periods.

The graph developed by Jensen and Boyle is presented in Figure 1. Spray or no-spray advisories are made on the basis of these temperature and relative humidity conditions. For example, when the relative humidity is equal to or greater than 95% for 10 h, and the minimum temperature is 21℃ or higher for 48 h, growers are advised to apply a fungicide if a period of at least 7 d elapsed since the application of a fungicide to the groundnut foliage. The existing system is actually based on application of a fungicide after a period of time when weather conditions are favorable for disease development. With improved weather-forecasting technology, it may be possible to apply a fungicide to the foliage prior to the occurrence of weather conditions that are favorable for disease development.

The influence of temperature and leaf wetness on spore germination, penetration, colonization, lesion development, sporulation, spore release, and dispersal of C. *arachidicola* and *C. personatum* conidia has not been fully explained. In spite of these gaps in the knowledge about the epidemiology of early and late leaf spots, the Jensen and Boyle forecasting method has been successfully tested in Georgia, Virginia, North Carolina, and Texas. Home et al. (1976) prepared a good extension publication describing the use of the Jensen and Boyle disease-forecasting system in Texas.

Table 1. Partial list of fungicides that have been or are being used for management of foliar diseases of groundnut in the United States.

Common name	Chemical name
Benomyl	methyl 1-(butylcarbamoyl)-2-benzimidazolecarmate
Captafol	cis-N [(1, 1, 2, 2,-tetrachloroethyl)thio] -4- cyclohexene-l,2-discarboximide
Chlorothalonil	tetrachloroisophthalonitrite
Copper ammonium carbonate	copper ammonium carbonate
Copper hydroxide	copper hydroxide
Fentin hydroxide	triphenyltin hydroxide
Mancozeb	zinc ion and manganese cthylenebisdithiocarbamate 80%, a coordination product of manganese 16%, zinc 2%, and ethylenebisdithiocarbamate 62%
Maneb	manganese ethylenebisdithiocarbamate
Sulfur	elemental sulfur

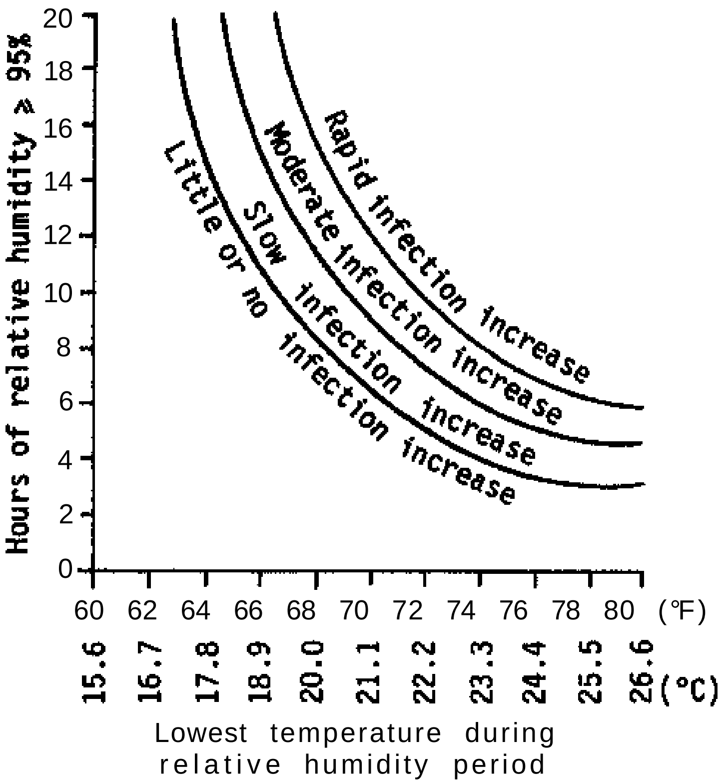

Figure 1. Classification of infection using daily meteorological observations.

In 1966 the forecasting system was first used to develop daily advisories for growers in the southeastern United States. During the growing season, daily advisories were issued on a teletype network and transmitted to growers by radio and television. The Jensen and Boyle method was evaluated in replicated field plot tests at Plains, Georgia, during 1969, 1970, and 1971 (Smith et al. 1974). During these three growing seasons, the interval between applications ranged from 7-19 d, depending on temperature and relative humidity conditions at the test site. The number of applications per season ranged from seven to eight over three growing seasons. A minimum fungicide-application interval of 7 d was used because of assumed adequate crop protection for a period of at least 7 d.

Parvin et al. (1974) developed a computer program for producing a worded daily groundnut leaf spot spray advisory in 1971. The computerized advisory was compared with advisories issued by a National Weather Service agricultural meteorologist over three growing seasons. With the exception of a few marginal situations, the computer-produced advisories were identical to those prepared by an agricultural meteorologist.

In 1976 an agroenvironmental monitoring system (AEMS) was established in Virginia (Phipps and Powell 1984). This computerized system consisted of electronic sensors and microprocessors for data acquisition. This approach for preparation of leaf spot advisories eliminated the problems associated with the use of hygrothermographs and the time-consuming clerical work required for processing data obtained from a hygrothermograph. Bailey and Matyac (In Press) recently developed a portable electronic weather station for deployment of a groundnut leaf spot spray advisory in North Carolina.

In Virginia the value of groundnut leaf spot advisories generated by a computerized agroenvironmental monitoring system was determined in field tests conducted in 1979, 1980, and 1982. In this time period 4.2S fewer fungicide applications per season were made on the basis of the advisory schedule as compared with the usual schedule, i.e., fungicide applications at 14-day intervals. Although leaf spot incidence was greater in plots sprayed in accordance with the advisory method than in plots sprayed on a 14-day schedule, pod yields were not significantly different (Phipps and Powell 1984). As a result of these tests, Virginia growers are now using the advisories as a basis for scheduling fungicide applications.

In some areas where groundnuts follow groundnuts in the crop-production system, onset of disease occurs earlier and the probability of substantial crop loss is higher because crop rotation is not part of the crop-management system. When cultivars with resistance to early and/or late leaf spot become available to growers, it may be necessary to modify the existing advisory program. As new fungicides become available to growers, it will also be important to monitor the development of fungicide-tolerant strains so that appropriate crop-management decisions can be made to prevent crop losses attributable to these strains. In areas where both irrigated and rainfed crops are produced, it will be necessary to monitor environmental conditions within fields.

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Modeling Growth and Yield of Groundnut

K. J. Boote, J.W. Jones, J. W. Mishoe, and G.G. Wilkerson[1]

Abstract

*Modeling growth and development of groundnut (*Arachis hypogaea *L.) offers considerable potential to assist with agrotechnology transfer, crop management decision-making, research guidance, and understanding and synthesizing results of past and present research projects. For these reasons, we have developed a groundnut crop-growth simulation model, (PNUTGRO), patterned after our soyabean crop-growth simulation model, (SOYGRO).*

Our approach was to develop a physiologically-based model which dynamically responds to daily weather inputs (temperature, rainfall, and radiation) and to pest and soil-water deficit stresses. PNUTGRO is a physiologically-based crop model which considers crop-carbon balance, nitrogen balance, and water balance at the process level. For example, crop-carbon balance includes daily inputs from photosynthesis, conversion, and condensation to crop tissue, carbon losses due to abscised parts, and carbon loss due to respiration associated with growth and maintenance. Crop-nitrogen balance considers daily input from N assimilation, internal remobilization to seeds, and N loss in abscised parts. Crop-water balance includes infiltration of rainfall and irrigation, root uptake of water, and crop transpiration.

Résumé

Modélisation de la croissance et des rendements de l'arachide : *La modélisation de la croissance et du développement de l'arachide (*Arachis hypogaea *L.) offre un potentiel considérable en facilitant le transfert de l'agrotechnologie, les décisions relatives à la gestion des cultures, l'orientation de la recherche et en permettant de mieux comprendre et de faire la synthèse des projets de recherche actuels et passés. Nous avons mis au point un modèle de croissance de l'arachide (PNUTGRO) en adaptant un simulateur éprouvé de la croissance du soya (SOYGRO).*

Notre approche visait à développer un modèle dynamique répondant aux données journalières sur le temps (température, pluviométrie, rayonnement) et aux stress causés par les insectes et le manque d'eau. PNUTGRO est un modèle physiologique qui tient compte de l'équilibre du carbone, de l'équilibre de l'azote et de l'équilibre hydrique au niveau du processus. Par exemple, l'équilibre du carbone inclut des données journalières portant sur la photosynthèse, la conversion et la condensation aux tissus des plantes, les pertes de carbone dus aux parties "abscisées" et les pertes de carbone dues à la respiration associée à la croissance et la conservation. L'équilibre de l'azote tient compte des données journalières sur l'assimilation de N, la remobilisation interne aux semences et la perte de N dans les parties "abscisées." L'équilibre hydrique inclut l'infiltration de l'eau de pluie et l'irrigation, la consommation d'eau par les racines et la transpiration.

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Introduction

There are several existing models that simulate groundnut growth and yield. W.G. Duncan has an unpublished model (PENUTZ) cited in Duncan et al. (1978). A strong point of his model is that it considers individual fruit-growth rate and duration (to limits of shell size), and adds cohorts of new fruits each day. A limitation is that his model usually considers no pest or soil-water limitations (although it has a simple soil-water balance). Young et al. (1979) published a groundnut growth and development model based on photosynthesis, growth, and respiration in response to daily environment. Their model was developed from single-plant phytotron data, and certain factors were later calibrated to field data. Their model does not consider pests nor does it have a soil-water balance (it requires soil-moisture tension as input).

Our reasons for starting with the SOYGRO model and converting it for groundnut are that SOYGRO has user-friendly interfaces, user-friendly graphics output, it is in FORTRAN on the IBM-PC, its structure considers pest stresses, and it has a transportable, generic soil-water balance subroutine. The other two groundnut simulators lack these features. Another personal reason was simply our familiarity with SOYGRO and because we had previously adapted SOYGRO Version 4.2 to simulate groundnut (Boote et al. 1983). SOYGRO has a modular structure which makes it easy to change one module at a time. It also has two input files of crop-specific and cultivar-specific traits which are easily changed. The conversion was also facilitated by crop similarities. Groundnut and soybean are both legumes, and have similar vegetative-N concentrations, similar crop-growth stages, similar plant parts (we used leaf, stem, root, shell, and seed), and their partitioning can be simulated as a function of the crop-growth stage.

Methods and Materials

Our approach was to use as much of the SOYGRO Version 5.0 code as possible, and to change only those parameters that are species or variety specific. The majority of our changes were made to two input files which pertain to species and variety characteristics. Few code changes were made; where made, these are explained in the text.

PNUTGRO uses the same differential equations as SOYGRO to describe crop growth. (See Wilkerson et al. 1983 for SOYGRO Version 4.2, and Wilkerson et al. 1985 for SOYGRO Version 5.0). Processes considered to be important included photosynthesis, synthesis and maintenance respiration, partitioning, N remobilization, pod addition, and senescence.

Data collected at Gainesville, Florida, in 1981 (Boote, unpublished) were used to calibrate PNUTGRO and estimate parameters not available from the literature. This data set consisted of periodic dry-matter samples from an irrigated crop of cultivar Florunner sown 1 Apr 1981. Row spacing was 0.762 m and plant spacing in the row 0.102 m.

Daily weather information (daily photosynthetically-active radiation, maximum temperature, minimum temperature, and rainfall) were available from the agronomy farm weather station. The actual irrigation record was also used, because we subsequently discovered that our irrigation frequency had caused low-level unintentional drought stress during early growth and a short interval of stress during pod fill.

Model Description

Photosynthesis

Daily canopy photosynthesis rate is represented as a multiplicative function similar to SOYGRO.

$$PG = PGMULT * PTSMAX * f_L * f_O * f_N * f_T$$

PTSMAX is a function of daily radiation influx at optimal values of L (leaf area index), T (temperature), N (nitrogen concentration of leaves), and fraction available-soil water. The f-terms represent functions that vary from 0.0 to 1.0 to reduce PTSMAX when L, T, N, and soil water are not optimal as illustrated in Figure 1. Due to lack of data on groundnut canopy photosynthesis response to these factors, we assumed that the equations for soybean applied to groundnut. SOYGRO's crop-photosynthesis response to photosynthetically active radiation came from data of Ingram et al. (1981). It is interesting to note that to simulate the 1981 Gainesville groundnut dry-matter accumulation rate, the PTSMAX term was increased 24% above the values computed from the data of Ingram et al. (i.e., PGMULT=1.24). This is consistent with groundnut's greater crop-growth rate (Duncan et al. 1978) and greater single-leaf photosynthesis rate (Pallas and Samish 1974).

In this version, canopy light interception was assumed to vary with leaf area index (LAI), row spacing, and plant spacing in the row. The more evenly spaced the plants, the more light will be intercepted by a given LAI due to less interplant competition for light. For evenly-spaced plants, a table of normalized-fraction light capture versus normalized LAI was developed from data of Shibles and Weber (1965). For evenly-spaced plants, an LAI of 1.5 is needed to intercept 63% of the daily light. Wilkerson et al. (1985) developed a function from the ratio of plant spacing to row spacing to compute the LAI

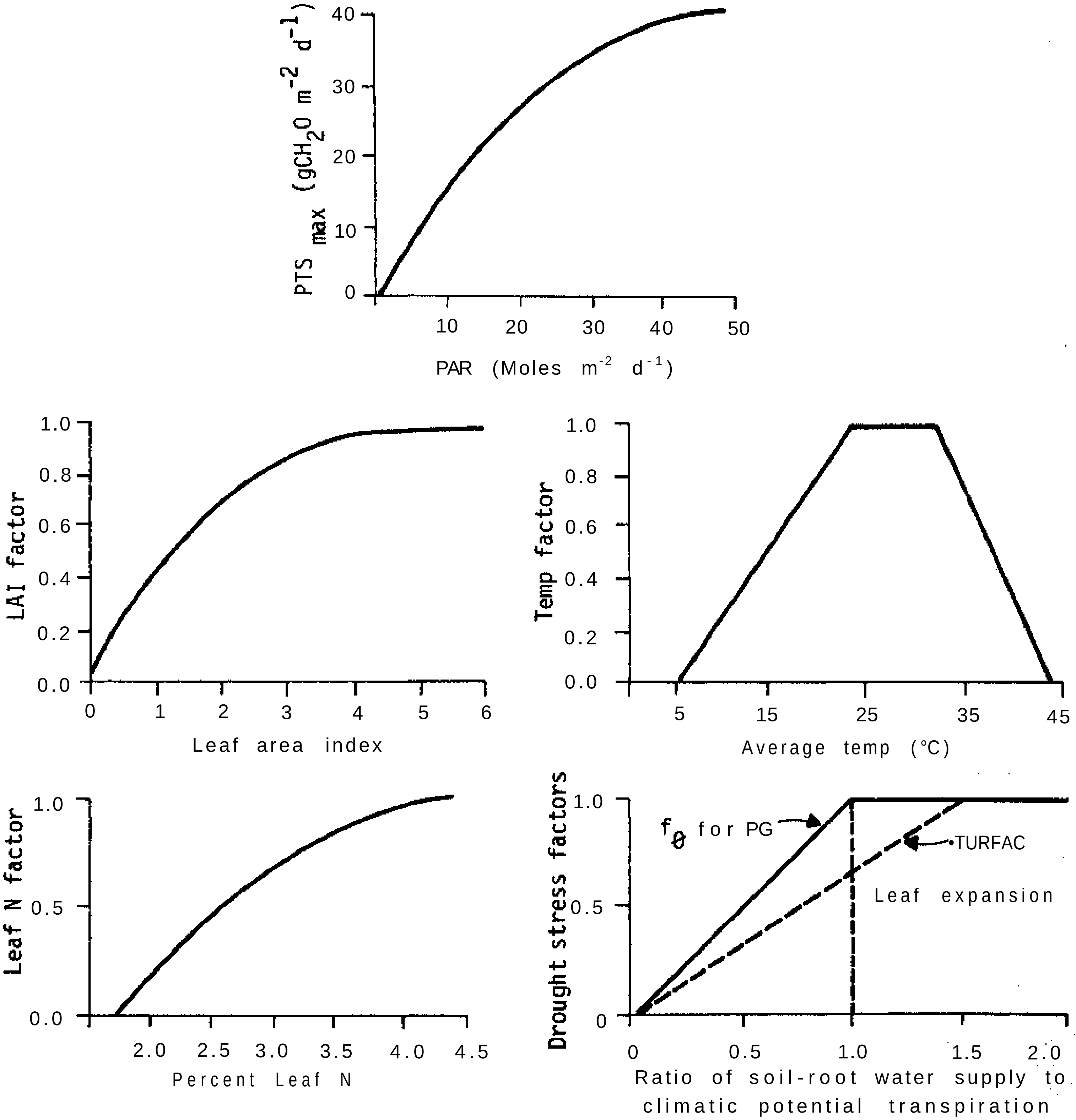

Figure 1. Functional relationships of crop photosynthesis (P_G) to (a) solar radiation, (b) leaf area index, (c) temperature, (d) leaf nitrogen, and (e) ratio of soil-root water supply to climatic potential plant transpiration.

needed to capture 63% of the light for nonequidistant spacings. Fraction light capture was computed with this normalization.

The equation for photosynthetic reduction due to N remobilization from leaves was derived from an equation developed by Boote et al. (1978) for single leaves of soybean during seedfill. We assumed that the effect of N loss on whole-canopy photosynthesis is the same as the effect on single leaves.

The temperature effect on canopy photosynthesis is a relative value of 1.0 between 24-34°C daytime mean temperature with linear reductions below 24℃ down to 5℃ and with linear reductions above 34℃ up to 45℃. This agrees with data of Cox (1979) showing that dry weight accumulation of Florigiant during the middle of its growth cycle was not different for day temperatures of 26, 30, and 34℃, but was slightly reduced (10%) by a day/night temperature of 22/18℃. Young et al (1979), based on calibrations of field data to their groundnut model, reported calibrated optimum temperatures for total growth ranging from 25.5 to 31.3℃ with a mean of 28.2℃.

Respiration and Cost of Tissue Synthesis

Maintenance respiration depends on temperature, crop photosynthesis rate, and on current crop biomass (less oil and protein stored in the seed). We assume that seed storage components do not require energy for maintenance (protein turnover, ion concentration gradients, and DNA-RNA turnover). Maintenance respiration is represented as:

$$R_m = R_o \times R_m + R_a \times R_p$$

The exact coefficients R_o and R_a were derived for soybean by calibration of SOYGRO. The shape of temperature sensitivity for these coefficients was derived from the quadratic temperature function of McCree(1974).

Growth respiration and the efficiency of conversion of glucose to plant tissue, was computed using the approach of Penning de Vries and van Laar (1982, pp. 123-125), assuming that approximate tissue composition is known. Their approach considers the glucose loss due to growth respiration for various synthetic pathways, and considers the glucose-energy equivalent stored in the compounds due to changes in molecular structures of each tissue. Groundnut and soybean tissue were assumed to have similar proportions of protein, lipid, lignin, carbohydrate, organic acids, and minerals, except as noted in Table 1. Protein concentrations of vegetative tissues were values measured prior to active pod fill when most of the vegetative tissue had been produced, but before protein mobilization had started. Protein concentrations (g g^{-1} tissue dry weight) in leaf (0.281), stem (0.115), shell (0.188), and root (0.137) are from unpublished data (Boote) on Florunner, and agree with leaf, stem, and shell values on cultivar Egret (Williams 1979), and with leaf values on Virginia bunch (Shiffmann and Lobel 1973). Groundnut stems were assumed lower in lignin than soybean (0.07 versus 0.18). Cobb and Johnson

Table 1. Approximate composition and resulting glucose cost to synthesize various groundnut plant tissue.

	Approximate composition						Synthesis cost[2] (g glucose perg tissue)
Tissue	Protein	Lipid	Lignin	Organic acid	Mineral	Cellulose carbohydrate	
	(g component/g tissue dry weight)						
Leaf	.281[1]	.025	.07	.05	.094	.4803[3]	1.60
Stem	.115[1]	.020	.07	.05	.046	.699[3]	1.42
Root	.137[1]	.020	.07	.05	.057	.666[3]	1.44
Shell	.188[1]	.020	.28[1]	.04	.030'	.442[3]	1.74
Seed	.280[1]	.510[1]	.02	.04	.025'	.1253	2.54
Seed (using mobilized amide)							2.09

1. Values estimated from the literature cited in the text; values without superscript 1 are best guesses.
2. Cost of synthesis computed according to Penning de Vries and van Laar (1982, pp. 123-125). Glucose Cost = Protein * 1.704 + Lipid * 3.106 + Lignin * 2.174 + Organic acid * 0.929 + Mineral * 0.05 + Cellulose-Carbohydrate * 1.242.
3. The amount of cellulose-carbohydrate is the difference between 1.0 and the sum of the other components.

(1973) cited a value of 0.28 for fraction lignin in groundnut shells which is greater than the value (0.07) used for soybean shells. Values for Florunner seed-lipid fraction (0.51) are from Norden et al. (1983) and those for seed protein (0.28), carbohydrate (0.13), and ash (0.025) come from Cobb and Johnson (1973). Organic acid in seed was assumed to be 0.04 and lignin 0.02.

The estimated cost to synthesize groundnut seed is 2.54 g glucose g^{-1} of seed including N assimilation, and 2.09 g glucose g^{-1} of seed where amides are available from protein mobilization (Table 1). Respective costs for soybean were 2.08 and 1.45 g glucose g^{-1} of seed. Groundnut seed is more costly to make than soybean because it is higher in lipid (0.51 versus 0.197) and because 3.11 g glucose are required per g of lipid produced.

Phenology

Vegetative and reproductive crop-growth stages were defined for groundnut by Boote (1982a) to have a similar meaning to those for soybean. This facilitated the adaptation of SOYGRO to groundnut because changes in partitioning and the start, end, and rate of pod addition are keyed in the model to crop-growth stage progression. Groundnut phenological development responds primarily to heat unit accumulation. The relative rate of node progression and rate of progression toward reproductive stages are assumed to have a linear response to temperature, beginning at zero at 13.5℃ and increasing to 1.0 at 30°C average temperature and, declining linearly from 1.0 to 0.0 between 30 and 45℃. Two papers reporting on heat units to flowering for groundnut have suggested a base temperature of 13-14℃, below which reproductive development stops (Emery et al. 1969, Mills 1964).

Bolhuis and de Groot (1959) studied the time to flowering of three cultivars under constant-temperature conditions. From their data, the rate of progression to flowering was most rapid at temperatures between 29.4 and 33.3℃. Cox and Martin (1974) reported optimum maximum daily temperatures between 30-31.5℃, Based on these papers, we used 30℃ as the optimum temperature.

Rate of early leaf-area development in groundnut was assumed to be limited by temperature and by number and size of early leaves up to stage V7.5. We assumed a temperature-limited rate of leaf appearance and that possible feedback inhibition of photosynthesis can occur in groundnut up to V7.5 stage. This can occur especially if node (V stage) progression is slow because of low temperature. After stage V7.5 and the start of branching, vegetative growth rate is assumed unlimiting and thus uses all assimilates produced by photosynthesis. (At this point the model becomes completely photosynthetically driven until after pods are set.)

Vegetative Growth and Partitioning

Vegetative growth consists of leaf, stem plus petiole, and root growth from emergence through to maturity. Partitioning of assimilate to these tissues depends on the stage growth but also varies with drought stress. New growth of leaves, stem, and roots are calculated by the equation

where X_i represents partitioning factors for leaves, stems, and roots, E is the conversion efficiency for photosynthate (g dry matter g^{-1} glucose), P is gross photosynthesis rate (g CH_2O day^{-1} m^{-2}), and R_m is the maintenance respiration rate. The X_i values for partitioning to vegetative tissues are computed from the proportion of growth that goes to vegetative tissue (1-XPOD) multiplied by the proportion of vegetative tissue which is to go to leaves (FRLF), stems (FRSTM), and roots (FRRT). For early growth through stage V7.5, values for FRLF, FRSTM, and FRRT are input as a function of stage V. Values used here came from a 1984 potted-plant study (C. E. Maliro, University of Florida, unpublished). After stage V7.5, partitioning among vegetative tissue changes linearly until reaching the end of the pod addition (NDSET). Thereafter, the relative partitioning among vegetative tissue is constant to maturity.

Until podset, all assimilate goes to vegetation. As pods (and seeds) add, they have first priority for assimilate and progressively reduce the fraction of growth going to vegetative components. Unlike the determinate soybean, groundnut continues some vegetative growth even after a full pod load is added. To mimic Florunner growth, it was necessary to limit assimilate partitioning to seed plus shell to a maximum of 0.83 at which point no further pods were added. From prior experience (Duncan et al. 1978), we know that this maximum value of partitioning to fruits (XFRUIT) varies considerably among groundnut cultivars. Code changes were necessary to implement the concept of maximum partitioning to fruits (XFRUIT) and to allow leaf-area growth during seedfill. PNUTGRO allows addition of new leaf area after podset is complete, whereas SOYGRO only allows thickening of existing leaves after a stage called NDLEAF.

Effects of Drought Stress on Leaf Expansion and Partitioning

Partitioning between roots and tops (leaves and stems), and leaf expansion is affected by drought stress. A turgor factor for leaf expansion (TURFAC) is computed from the soil-water balance. TURFAC changes from 1.0 to 0.0 as the ratio of root water supply to climatic potential transpiration declines from 1.5 to 0.0 (Fig. 1e). As the TURFAC drops below 1.0, a certain fraction (ATOP) of the assimilate normally partitioned to leaves and stems is diverted to roots. We presently assume that ATOP can be up to 0.50 of the leaf and stem growth if TURFAC drops to zero.

In addition to altered partitioning to root and shoot, TURFAC additionally acts to reduce relative leaf expansion from 1.0 to 0.0 as the ratio of root supply to climatic potential transpiration goes from 1.5 to 0. The effect is to allow leaves to grow in dry weight but not as much in area. Thus the leaves thicken and specific leaf area decreases.

Changes in Specific Leaf Area during the Season

Specific leaf area (SLA) is the ratio of leaf area to leaf mass. SLA of newly-produced leaves is primarily a function of phenological stage and secondarily dependent on TURFAC. Because groundnut leaves are much thicker (lower SLA) than soybean, new parameters were needed to define the initial SLA after emergence and the change in SLA during the groundnut life cycle.

Pod Addition, Reproductive Growth, and Partitioning

Pod (shell) addition is simulated to begin at phenological stage R4 (first full pod) for groundnut (Boote 1982). Early dry weight accumulation in flowers and pegs is considered insignificant. The rate of pod addition depends on several factors. PODMAX is defined as the maximum rate of pod addition for days when photosynthesis is maximum per unit land area (PHTMAX) and when temperature is optimum. The actual number of pods added on a given day depends on PODMAX times the ratio of actual PG to PHTMAX and the heat units accrued on that day(ACCDAY).

$$SH(0,t) = \min \begin{matrix} PODMAX \times (PG/PHTMAX) \times ACCDAY \\ PGLEFT/(GRRATI \times AGRSH) \end{matrix}$$

PGLEFT is the CH_20 remaining after existing seeds and pods grow, after vegetative tissue grows its minimum (1.-XFRUIT), and after maintenance respiration is subtracted. The GRRATI is the temperature-limited maximum growth rate per shell per day and AGRSH is the glucose required to make a gram of shell. When partitioning to existing seeds and shells (XPOD) exceeds XFRUIT (here, 0.83), new shell addition is stopped.

The shells added each day are grown and aged as separate groups. Shells formed on a given day grow for LNGSH days (12 d) during which they add weight as limited by GRRATI, temperature, and available CH_20 after supplying seeds and maintenance respiration. After shells have grown LAGSD days (5 d), a decision is made to start seeds or abort some or all of the shells in a given age class, depending on assimilate supply. A running average of the ratio of shell growth to potential shell growth is calculated to determine seed set in shells at age LAGSD. If the ratio exceeds SETMAX (presently 0.60), then seeds are set in this group of pods at the rate of SDPERP (seeds per pod). If the ratio is less than SETMAX, only a fraction of shells set seeds and the rest are aborted.

Seed Growth

Once seeds are set, they are not aborted unless by pest damage. Seed growth rate is a function of available assimilate supply (multiplied by XFRUIT = 0.83 for cv Florunner), temperature (TMPFAC), and cultivar-specific individual seed-growth rates. Cultivar-specific seed and shell maximum growth rates (SDMAXR and SHMAXR) are inputs to the model. The SDMAXR and SHMAXR are multiplied by a temperature factor (TMPFAC) to determine the potential growth rates for seeds and shells. The TMPFAC varies from 0-1 where the "normalized" shape of the temperature function was derived from seed growth-rate data of Egli and Wardlaw

(1980). They reported that soybean optimum seed-growth temperature is 23.2℃ which is virtually identical to the optimum temperature of 23.5℃ reported by Cox (1979) for growth rate per pod (plus seed) of Florigiant groundnut. The Cox study was a phytotron study where a 26/22 day/night treatment produced 23.5℃.

If sufficient assimilate is available, seeds will grow at their potential rate per seed as set by TMPFAC. In computing assimilate requirement, we need to consider whether seeds use new or remobilized N because the CH_2O cost for seed synthesis is less if amides are available from mobilized protein. Seed growth can be supplied by either remobilized protein or newly-fixed protein.

Different from SOYGRO, protein remobilization from vegetative tissue is simulated to begin as soon as seeds are formed. Mobilized protein is assumed to be used first, in preference to sending CH_2O to nodules to fix new N. To the extent that mobilized protein is available, assimilate is first used to grow seed with an energy-conversion cost of AGRSD2, which accounts for condensation and respiration for seeds using mined protein.

After using a certain amount of assimilate to synthesize seed from remobilized protein, the remainder of the assimilate (if any is left) is used to synthesize seed using AGRSD1 conversion cost, which accounts for costs of N assimilation as well as condensation and growth respiration to make seed. This additional seed growth would be limited to PGLEFT/AGRSD1, also within the constraints of XFRUIT, SDMAXR, and TMPFAC.

After computing seed growth using these two sources of N, any remaining assimilate (multiplied by XFRUIT = 0.83) is used to grow shells for those shells still in their active growth phase (LNGSH). Then, any remaining assimilate is used to add shells if all reproductive growth is using less than XFRUIT of the total daily available photosynthate.

Crop Maturation

Seed growth continues until either of two events occur. Seed growth ceases when the ratio of seed weight to shell plus seed reaches a maximum shelling fraction (THRESH = 0.78). This is a cultivar-specific trait; however, the same value applies for Florunner (Norden et at 1983) as for Bragg soybean. Secondly, seed growth can also be terminated by the loss of photosynthetic capacity. Such an event is presently approached slowly in the model as the result of protein mobilization which reduces canopy photosynthesis. Disease, insects, severe drought, and frost can cause more rapid termination.

Senescence

Leaf senescence is caused by crop aging, drought stress, and protein remobilization. Prior to beginning of seed growth, senescence is based on a table of cumulative percent senesced leaf weight as a function of stage-V for fully-irrigated plants. This feature is similar to SOYGRO in that normal leaf senescence starts at V-5 and increases linearly to 12% of cumulative leaf weight grown (WLPOS) by V-14, and 16% by V-30. If drought stress occurs, leaf senescence may exceed that described above. The maximum limit on leaf senescence due to drought stress (SENMAX) begins at 0.0 at V-3, reaches 0.20 at V-5, increases linearly to 0.60 by V-10, and can be 0.60 after V-10 to maturity. The variable SENDAY determines the maximum fraction of existing leaf weight to senesce on a severe drought-stress day when TURFAC is low. Actual senescence is delayed by 4 d from the time of drought stress (lag of 4 d) because leaves take time to die and abscise. Experience with a drought period on 1981 Florunner groundnut suggests that groundnut leaf-senescence response to a given drought is less drastic than that of soybean. Either SENMAX or SENDAY could be reduced. We chose to reduce SENDAY from 0.05 to 0.03.

Groundnut lacks the grand senescence phase common to soybean, thus we disabled the grand senescence that is triggered at stage R7 in soybean. This feature allows renewed fruiting and vegetative growth when existing pods have matured. The realism of this feature is subject to question, but renewed vegetative growth and new fruiting may be possible if disease, insects, and weather conditions allow. PNUTGRO can presently be run either with determinate fruiting or with indeterminate fruiting triggered by XPOD dropping below XFRUIT.

Protein Mobilization

Protein remobilization and leaf senescence linked to it begin in PNUTGRO as soon as seed growth begins (NPODϕ+LAGSD). (SOYGRO only begins mining after NDSET). Mining increases for several weeks while seed number increases, and thereby increases the total seed-growth capacity to use the available amides. Thereafter, mobilization continues at a constant rate controlled by growing degree days per day and by the ratio of mineable protein pool divided by the physiological time from NPODϕ to maturity. For 40 days or more vegetative growth continues to add new protein to the protein pool even while protein is being mined from existing leaves. The net effect is to reduce the vegetative protein composition even while vegetative dry weight is increasing. Data of Boote (1976 unpublished) and Williams (1979) show that protein composition of leaf, stem, and shell begin to decline shortly after beginning of pod addition. For each g of protein mined from leaves SENRTE g of leaves are abscised, in addition to the protein weight lost. SENRTE value is presently 1.0. If leaves senesce prior to start of protein mobilization, or abscise due to drought stress, the mineable protein in those leaves is also abscised and lost from the available protein pool.

The amount of protein available to mobilize from leaf, stem, shell, and root is computed using initial and minimum protein fractions reported for groundnut. Initial composition is the same as in Table 1; final protein composition is 0.178, 0.071,0.094, and 0.069 g protein g^{-1} tissue dry weight for leaf, stem, root, and shell, respectively. These values represent a consensus of results of Boote (1976 unpublished), Williams (1979), and Schiffmann and Lobel (1973).

Soil-Water Balance and Root System

The soil-water model in PNUTGRO was adapted from the soil-water balance of Ritchie (In press) as described by Wilkerson et al. (1985). The soil is divided into up to 10 layers. Each layer- zone contains soil water and root density which change with time. Water content in each zone varies between a lower limit (LL(J)) and a saturated upper limit (SAT(J)). If water content is above a drained upper limit (DUL(J)), then drainage occurs.

Plant transpiration is based on root length and soil-water distribution in each zone, and on a potential plant transpiration rate determined by weather and LAI. Temperature and radiation are used to compute the Priestley and Taylor equilibrium evapotranspiration (EP1) which is multiplied by an exponential function of LAI to give climatic potential plant transpiration. The water-supplying capability of the soil-root system is calculated and compared with the potential plant transpiration. Actual plant transpiration and water extraction by roots is the minimum of the two rates. Drought stress occurs if the capability of the soil-root system to supply water is less than the climatic potential transpiration. Crop PG is reduced in direct proportion to the ratio of soil-root water-supply rate to climatic potential. Turgor is assumed to be reduced as the ratio declines below 1.5, thus reducing leaf-area expansion and altering shoot / root partitioning before PG is reduced.

Root growth is similarly handled in SOYGRO and PNUTGRO. Total root length is determined by the carbohydrate partitioned to roots and a length-to-weight parameter (RFACl). Partitioning was changed for groundnut, but the same RFACl of 9500 cm root length g^{-1} was used. The distribution of roots in the soil zones depends on current root depth (RTDEP), soil water in each zone, and an empirical weighting function (WR(L)) that represents the probability distribution of roots growing in each zone later in the season if well-watered. This function accounts for horizon effects on root growth as well as genetic differences. The rate of root-depth increase (RFAC2 = 0.249 cm/℃-day) continues until reaching a maximum depth (DEPMAX) which is soil- and crop-limited. The root length weighting function (WR(L)) was changed for groundnut based on data of Robertson et al. (1980) as reported by Boote (1982b). For simulating groundnut, we increased the probability of root-length distribution in the 90-120, 120-150, 150-180, and 180-210 cm depths. This change also helped to minimize a simulated severe water deficit which the 1981 experimental data showed to be less severe than the model simulated when a soybean root distribution was used. This substantiates an opinion we have had for several years, that groundnut's deep-rooting traits make it less drought-susceptible than soybean.

The proportion of roots to grow in each zone is the total growth multiplied by the SWDF(L) x WR(L) for that zone and divided by the sum of the SWDF(L) x WR(L) over the active root zone (RTDEP). The SWDF(L) reduces root growth in a zone if water content in that zone is less than 25% of the extractable water. Also, when this soil-water level is reached in a given zone, root senescence begins at a rate of 1% of root in the layer per day.

Results and Discussion

Model Calibration Versus 1981 Field Data

A systematic procedure was followed to calibrate the PNUTGRO model to simulate the 1981 field data for Florunner groundnut. Before running any simulations, the cost of tissue synthesis for each plant was estimated as described in the methods. The approximate tissue composition and resulting cost for synthesis is shown in Table 1. Likewise, parameters associated with protein mobilization, initial and final fraction protein in vegetative tissues were defined.

The second step was to simulate phenological development using the model, the 1981 weather, and the observed dates for groundnut crop-growth stages for 1981. The physiological day accumulator in the model used base and optimum temperatures of 13.5 and 30°C as described earlier. Running the model in this mode allowed computing the cumulative physiological days necessary to emergence, V1, R1, R4, and R8 harvest maturity. These parameters were then used as setpoints in the model. Maximum rate of main-stem node development was computed to be 0.423 trifoliates per physiological day after V1.

The next step was to include early partitioning and early temperature-limited leaf-area development per plant as a function of stage V up to V7.5. This information is placed in an 'input' table in the data file of cultivar-specific traits. Data for this came from a potted-plant study (C. E. Maliro, University of Florida, Gainesville) which gave leaf area per plant and dry-matter partitioning to leaf, stem, and root as a function of stage V up to V7.5. This information also established the initial weights per plant at emergence, initial fraction leaf, stem, and root and the initial specific leaf area.

Because of the importance of correctly simulated LAI to photosynthesis, we next changed the specific leaf area (SLA) function to better simulate groundnut. Groundnut leaves are much thicker (lower SLA) than soybean. The changes in SLA with the groundnut life cycle were different from soybean and required some code changes. The SLA of both crops begins low, then increases as the canopy develops; however, groundnut SLA then remains high whereas that of soybean begins to decline (leaves thicken) when leaf expansion is terminated at the R4 growth stage.

Parameters and relationships developed to this point are assumed to be cultivar-specific traits which should hold true in other cropping years and locations.

Using the above developed parameters, we now begin simulations with actual weather, irrigation record, row, and plant spacings. During the first simulations, we adjusted a PGMULT factor, response of photosynthesis to solar radiation, to give the approximately correct slope to total dry-matter accumulation, up to 80 or 90 d (Fig. 2). At this point, late-season partitioning, pod addition, and growth rates of shells and seed were not yet correct.

The next step was to calibrate pod-addition rate, growth rates and durations per shell and per seed. These parameters also affect maturity. Based upon previous field studies, we estimated maximum Shetl- and seed-growth rates (SHMAXR and SDMAXR), seeds per pod (SDPDVR), maximum seed shell-out (THRESH), pod-addition rate (PODVAR), length of shell growth (LNGSH), and length of shell growth at which seeds start (LAGSD). The PODVAR parameter was adjusted to give the proper slope to pod number versus time as shown in Figure 3. These data points define full-sized pods and full-sized pods with developing seeds, respectively. Parameters SHMAXR, LNGSH, SDMAXR, THRESH, and SDPDVR are interrelated and must be carefully adjusted because together they define the pod filling-period, seed size, and weight per pod. Procedurally, one should run the model once to integrate the daily temperature and weather effects on seed and shell growth, then adjust SHMAXR and LNGSH to give the correct average weight per shell at maturity. Then, adjust SDMAXR to give the correct average weight per seed at maturity and to observe that shelling percentage progresses over time as field data show (Fig. 4). Notice carefully that if SDMAXR or

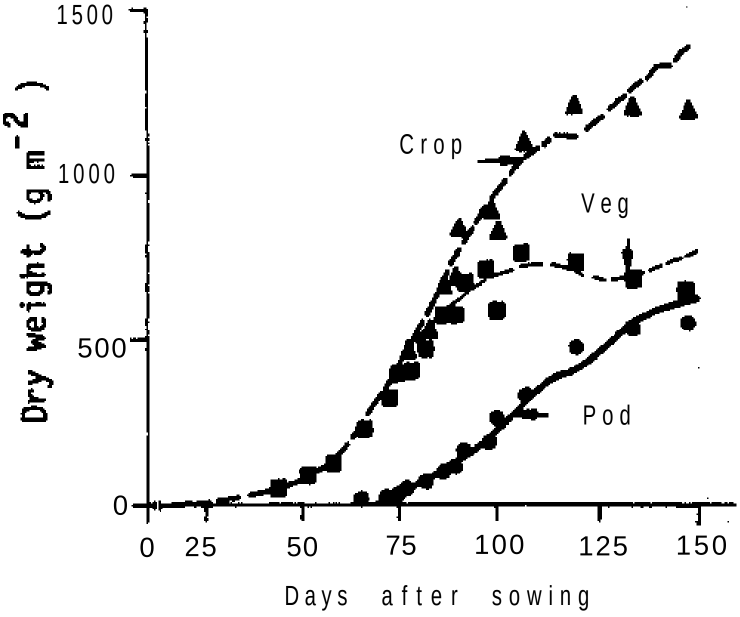

Figure 2. Simulated and field-measured vegetative dry weight, reproductive (pod) dry weight, and total above-ground crop dry weight for Florunner groundnut sown 1 April 1981 at Gainesville, Florida.

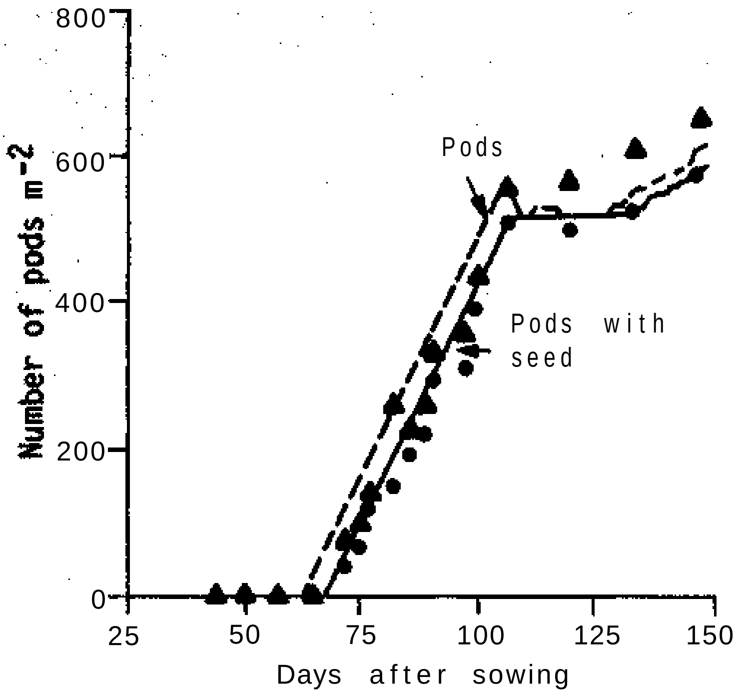

Figure 3. Simulated and measured pod number per m^2 for Florunner groundnut sown 1 April 1981 at Gainesville, Florida. The category pods, consists of fruits which are at or beyond the R4 stage (full-sized fruits), and the category pods with seeds are those at or beyond the R5 stage (fruits with detectable seed growth).

SDPDVR are too large, the maximum THRESH = 0.78 will invoke early termination of seed fill.

Certain of the above parameters can be set easily. THRESH, for example, should be defined from typical shelling percentage for a fully-mature crop grown under irrigation and disease control. The parameter SDPDVR, seeds per pod, is likewise a stable genetic trait. LNGSH = 12 days is consistent with data of Schenk (1961) showing up to 2 weeks' rapid shell growth. More important is the value LNGSH multiplied by SHMAXR, which can be set from average weight per shell. LAGSD was set at 5 d for two reasons. First, seed and shell growth overlap in time, with rapid seed growth starting before shell growth is complete (Schenk 1961, Boote 1982). Secondly, LAGSD at 5 d gave the proper simulated timing of the start of seed growth relative to shell growth and the resulting curve of shelling percentage versus time (Fig. 4). PODADD, number of pods added per day, must be calibrated for each cultivar from actual pod numbers versus time. As used in the model it is normalized by the relative photosynthesis function, which should make it applicable in another year even if photosynthesis is drastically reduced.

The next step in model calibration was to check the partitioning between vegetative and reproductive tissue. The reasons for calibrating pod addition first, is that pod addition has first priority for assimilate with the remaining fraction (1.-XPOD) going to vegetative growth. An important feature to consider here is groundnut's indeterminate vegetative growth. Partitioning to shell and seed growth was limited to a value less than XFRUIT = 0.83 to allow vegetative growth to continue after full pod load was achieved. Figure 2 shows the resulting vegetative and reproductive dry weights simulated by the model using this partitioning approach.

Relative partitioning among leaf, stem, and root was then evaluated. The 1981 field data showed that the ratio of leaf growth to stem growth was 0.30:0.70 between 84 and 102 d. Assuming 0.10 to go to roots, we set 0.10:0.27:0.63 as the final ratio of root:leaf: stem growth after podset. FRRT, FRLF, and FRSTM were allowed to change linearly over time from the values at stage V 7.5 (0.18:0.44:0.38) to values (0.10:0.27:0.63) after pod addition. These values are multiplied by (l.-XPOD) to give actual partitioning coefficients. Leaf-weight growth in conjunction with the SLA function results in the LAI curve shown in Figure 5.

There is a simulated resurgence in vegetative growth and pod addition when the main crop of pods begins to mature and allows assimilate to become available (i.e., partitioning to fruit falls below the limit XFRUIT = 0.83). This could be

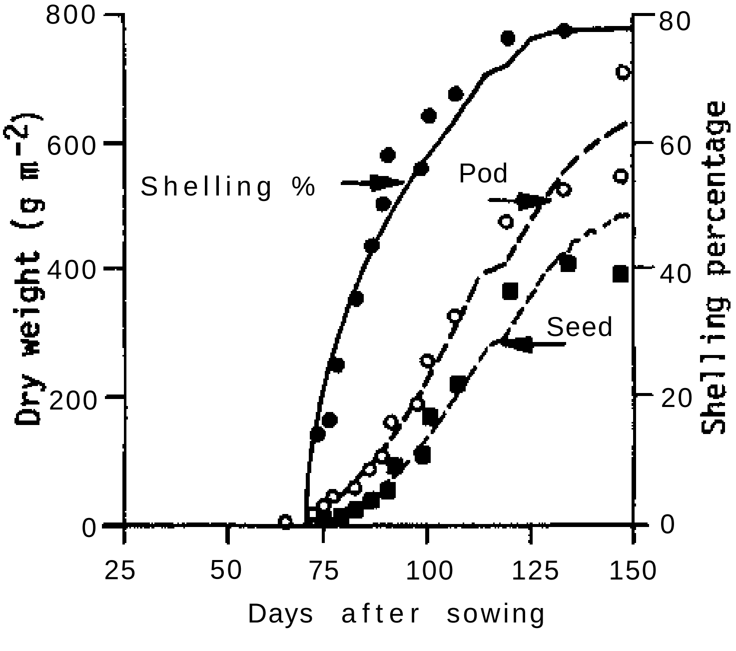

Figure 4. Simulated and measured pod dry weight, seed dry weight, and shelling percentage for Florunner groundnut sown 1 April 1981 at Gainesville, Florida.

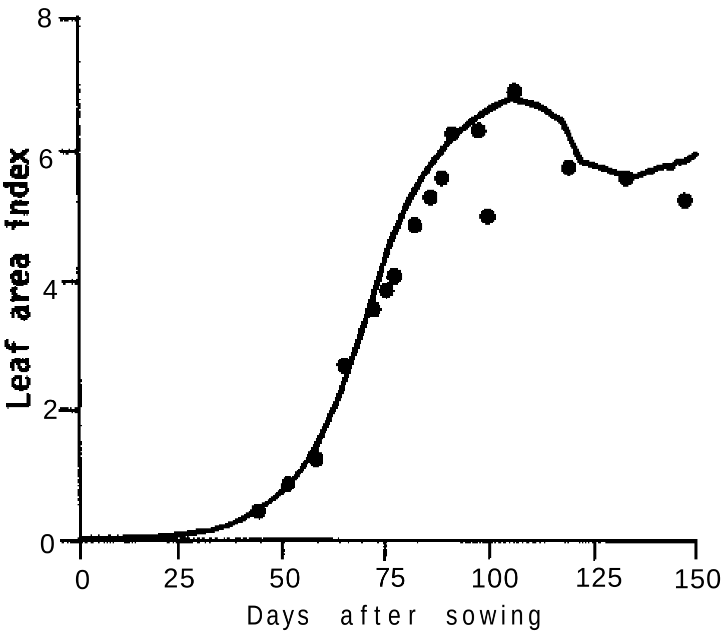

Figure 5. Simulated and measured leaf area index (LAI) for Florunner groundnut sown 1 April 1981 at Gainesville, Florida.

stopped by invoking a limit on pod addition and vegetative growth; however, there is field evidence that field-harvestable yield is the net of pods remaining on the plant where young pods are added, while some older pods may have already abscised. Under good disease control the 1981 Florunner crop at 147 d yielded 5545 kg ha^{-1} of harvestable pods whereas an additional 381 kg ha^{-1} detached pods were also recovered from the soil There was an increase in pod number and pod wall mass and a decrease in shelling percentage between 134 and 148 d.

The process of calibration was not quite as simple as the above description sounds. There were a number of iterations of changing parameters, especially the PGMULT parameter, XFRUIT, PODADD, pod-, and seed-growth traits, and partitioning to various vegetative tissues. Sixty to seventy runs were made to satisfactorily calibrate the model starting from SOYGRO. It was also important to use the actual irrigation record rather than to assume adequate irrigation. If we accept PNUTGRO simulations of drought stress as correct, then the 1981 crop actually suffered several short unintentional drought stresses during the early season, which reduced leaf-area expansion and increased assimilate allocation to roots. Moreover, we found it necessary to change the late-season root-depth profile to minimize the apparent effects of a late-season drought on total growth and leaf senescence. We also reduced the rate of leaf abscision (SENDAY) in response to drought as compared to soybean.

Future Plans

We plan to validate PNUTGRO against independent data sets to test its response to shading, soil-water deficit, and insect defoliation. We will further develop model response to leafspot diseases and to soil fertility. Direct soil-water and calcium effects on fruiting will be developed. We plan to maintain individual classes of fruits by fruitage all the way from shell addition to seed maturation to simulate individual fruit maturation and subsequent fruit abscission. This will allow computing maturity data for harvest relative to number of pods lost to abscission and relative to late addition of new young pods.

We plan to work closely with international groundnut researchers and with the peanut systems research group in the USA to develop additional validation data sets and to derive cultivar-specific traits such as assimilate partitioning and crop growth stage progression in response to temperature and drought. We will also work with entomologists to assist in coupling pest models to PNUTGRO. After appropriate validation of PNUTGRO, we plan to release a FORTRAN version adapted to IBM-PC compatible microcomputers. That version will have user-friendly input, output, and graphics very similar to SOYGRO Version 5.0 for IBM-PC compatibles.

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Applications to Groundnut Cultivation

Discussion

D. Smith:
Would you anticipate a similar response to rust in the model as you do with leaf spot?

K. J. Boote:
I think that it would be somewhat similar. I don't know if rust causes the same degree of leaf loss. You need to characterize the effect on senescence, photosynthetic response, and lack of stomatal control or water loss.

J. H. Williams:
We have looked at the response of a range of varieties to leaf spot or rust. The yield response is fairly linear regardless of the type of the disease.

S. M. Virmani:
One of the things that we found lacking in the model, especially in the SAT, is the soil resistance. Here pegging takes place towards the end of the season and soil resistance in the top 5-10 cm is very important to formation of pods or gynophores. The entry is just not there. There is abortion at that point. Do you think a subroutine on that would be required? We have the basic penetrometer readings on pegs that enter the soil, particularly on the Alfisols.

K. J. Boote:
I think it would be nice to develop a subroutine which considers soil strength on pegging as well as the influence of water status and calcium on the initial development of fruits.

E. T. Kanemasu:
You have said earlier that crop-growth rate for groundnut is 24% higher than for soybean, and now you say that the transpiration is similar to soybean. That means transpirational efficiency is much higher for groundnut than for soybean.

K. J. Boote:
I think that would be a correct conclusion but I do not know if it is true.

S. M. Virmani:
I would like to pursue the question of future collaboration. As far as I know this is the only working model that exists for groundnut. I think it would be best to work under the overall umbrella of the IBSNAT project. We have several data sets that we could transfer to you. But if you give us the model, we could check it out for you. We followed a similar pattern of validation for the SORGF model Our intention at that time was to check whether SORGF works or not and if any changes are required. It needed 5 years of work with SORGF to validate it for another agroclimatic environment. Ritchie's water-balance subroutine is good, but it fails under semi-arid conditions. We have modified Ritchie's model which worked for sorghum. We will be pleased to transfer it to you. I hope it will work for groundnut.

Another issue that emerges from work done at ICRISAT Center, particularly by Dr. Williams, is that drought stress and yield response are independent of the growth stage of groundnut. This is very important and we were always concerned about this response. It is an indeterminate crop, and we were concerned about how it would perform under drought stress. If that is the case, the revised Ritchie's version should work for groundnut.

K. J. Boote:
The sensitivity of crop-growth stage to water deficit should be built into a simulation model like this. In one respect it continuously computes the crop coefficients which Mr. Frere described. In addition to that the natural consequence of where the carbon is going will determine that the reproductive stage is very sensitive.

Index of Meteorological Parameters for Agrometeorological Information

D.Rijks*

The index summarized in Table 1 aims at providing agrometeorologists with rapid information on some relationships between meteorological parameters and agrometeorological information used in pest and disease control in groundnut as they were presented in some of the communications. It should facilitate analysis of primary observations for practical advise to the farming community.

Table 1. Index of meteorological parameters for agrometeorological information.

Country	Disease(s) pest(s)	Climatic elements	Agrometeorological information	Author(s)
S.E. USA, Virginia	Leafspot *Arachidicola* *Cercosporidium personatum*	$T_N > 21$°C, r.h.>95% (simple graphical presentation)	Spray advisories 4 treatments less per season	Smith
Nigeria	Termites Microtermes	Water depletion in top soil; low late-season rainfall	Increased damage to tap root	Lynch
Senegal	Millipedes	Water depletion in top 0.10 m of soil	Attacks on immature pods	Lynch
General	Aflatoxin *Aspergillus flavus* *Aspergillus parasiticus*	Synoptic: weather pattern, wind velocity and direction, cloud cover, solar radiation, relative humidity, frequency and, amount of precipitation	Extent of development of aflatoxin	Pettit
Oklahoma	Invasion of *A. flavus* early in season	T = 20-35℃, r.h. = 85-89%	Extent of development of aflatoxin	Pettit
Georgia, U.S.A	*A. flavus* Invasion of mature pods in the ground	Rain or high r.h. following drought; causing swelling and subsequent cracking of dry pods, allowing infection	Extent of development of aflatoxin	Pettit

Continued.

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1. Chief, World Climate Applications Program, WMO, Geneva, Switzerland.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT.

Table 1. *Continued.*

Country	Disease(s) pest(s)	Climatic elements	Agrometeorological information	Author(s)
Nigeria	A *flavus* contamination during drying	Rain on dry pods followed by non-drying conditions	Extent of development of aflatoxin	Pettit
	Contamination during drying	r.h. $> 85\%$	Extent of development of aflatoxin	Pettit
	Contamination during storage	Seed moisture $> 9\%$ r.h.$>80\%$,$T>30°C$	Danger of contamination	Pettit
	Contamination during storage	When r.h. $< 70\%$	Aerate only when r.h. $< 70\%$	Pettit
Georgia, U.S.A.	Aflatoxin *A. flavus*	When $26<T<31°C$ for 31 days and drought occurs	Great infection especially immature pods	Sanders
Sahel Senegal	A. *flavus*	$TSOL>25°C$ $T = 30\text{-}35°C$ r.h. $> 85\%$ or 10-30% in pods at 30°C T increasing	Important production of aflatoxin; increased toxicity	Picasso
		Adaptation of crop-cycle length to season length	Reduce aflatoxin incidence	
	Rosette (Aphis Leguminosae Theo., *Aphis craccivora)*	Sufficient water during dry season (~ 900 mm a^{-1})	Multiannual persistance of aphid population	
	Aphis craccivora	($24<T<28.5°C$ and r.h. $\sim 65\%$ during 10 days) 35 days beforehand	Optimal development of *Aphis craccivora*	
		Presence of tornadoes	Aphid flights impeded or aphid populations decimated	
	Rouille, *Puccinia arachidis* S.	$28 < T < 32$ and $60 <$ r.h. $< 80\%$ between 10-14 h	Strong liberation of spores	
		Wind > 25 km h^{-1} and direction	Distribution of spores	
		Free water on leaves or r.h. $> 90\%$ $T \sim 27°C$	Maximum germination of spores	

Tsol = Soil temperature (°C)
Tn = minimum temperature (°C)
Tx = maximum temperature (°C)
T=mean temperature (°C)
T = temperature (°C)
r.h = relative humidity (%)

Plenary Session

Chairman: C.R. Jackson
Co-chairman: D.L. Ketring

Rapporteur: M.V.K. Sivakumar

Summaries and Recommendations

Session I: Global Groundnut Production

Three comprehensive presentations were made in this session. The first two dealt with the moisture-supplying capacity of the environment and the third with the biological constraints, some of which are influenced by the climate.

The first presentation by G. Higgins of FAO (made by M. Frere) dealt in a general manner with the climatological and physical environment of the groundnut-growing regions of the world. Of interest was the definition of eight temperature zones of the world and distribution of groundnut largely in the "hot-tropics" of Africa, Asia, and the Americas. To properly evaluate the agroclimatological constraints, the first step was to compile all available climatic data which appeared for Africa as a two-volume bulletin in 1984. Using the inventory of maturity cycle of traditional varieties grown by farmers, length of growing season, and soil type, it has been possible to delineate the zones where groundnut has a potential.

The second presentation, 'Agroclimatological Characteristics of Groundnut-Growing Regions in the Semi-Arid Tropics' was made by S.M. Virmani and Piara Singh of ICRISAT. The first part dealt with ecological features of groundnut-growing regions. The crop is grown in many diverse environments and this is indicated by the rainfall amounts received (400-1500 mm), the moisture-storage capacity of the soils, and the various times of the year when the crop is sown and harvested. Generally the growing season is short and is characterized by intermittent droughts. The second part dealt with agroclimatic analysis using clustering techniques to identify six locations to represent the four major groundnut-growing regions. Of particular interest was the third part, where changes in rainfall environment in sub-Sahelian Africa, which barely meets the climatic water demand, were discussed. An analysis of four West African locations consistently showed a trend of increasing below-average rainfall years in 1960-75. For Dakar (Yoff), a 10-12-week growing period was obtained in 8 years out of 10 during 1947-55, 6 years in the period 1956-65, and 4 years in 1966-75. As a growing season of 84 days is the minimum required for production, the constraints imposed by reduction in the length of the growing season could have major effects on the way groundnut is traditionally grown. A plea was made for integrated farming-systems research to evolve improved systems for stable and increased production.

The third presentation dealt with the biological constraints to increased production, and was made by R.W. Gibbons of ICRISAT. Wherever groundnuts are grown, a wide range of fungal, viral, and bacterial pathogens, and attacks by insect pests drastically reduce yields. The pathogens that cause rust, leaf spots, virus (like PMV), and aflatoxins are important. Among the insects, aphids are important as vectors of viruses. Progress made at ICRISAT Center in the identification, utilization of resistances, and integrated management schemes to control major biological constraints was presented. The important role of climate in distribution of rust and vectors of viruses was illustrated.

Recommendations

- It would be useful to extend the FAO agroecological zones study to include groundnut.
- There is an urgent need for an interdisciplinary approach involving agroclimatologists and plant-improvement scientists to gain a better understanding of the disease-amplifying effects of climate and climate-dependent interactions between the host, pathogens, and insect pests. Climate-driven models of groundnut production need to account for moisture supply-demand and disease and insect-pest incidence.
- Further analysis of climatic data is needed to investigate if the 'shortened growing seasons' found at several stations occur more widely throughout the Sahel. Guidelines for plant improvement and resource management scientists to breed improved varieties and develop new technologies are urgently needed.
- Research on the influence of climate on nutrient availability, and the methods being developed to measure moisture retention will contribute towards optimum utilization of these two limited resources.

Session II: Water Relations of Groundnut

There were three presentations in this session. In the first, Dancette and Forest reminded us that water is the most difficult (expensive) parameter to control in Sahelian farming, so it is naturally the most important aspect of groundnut production. An understanding of the water use of various crops or cultivars of a single crop permit estimation of potential yields in specific rainfall areas. This knowledge permits us to recommend specific cultivars for particular climatic zones.

Models using parameters estimated from simplified biological and physical systems can be used to make first-order yield estimates in varying environments. Pan evaporation data and Penman potential evaporation calculations can both be used to give similar yield estimates. These parameters along with rainfall data describe the water deficit or surplus during the growing season, and can therefore be used to determine probabilities of plant status at any given time during the growing season. The procedure is applicable to different crops and can be used to select the best crops and cultivars for each area.

Using these techniques, two important points were made:

- the change in weather after 1968 has moved the area where groundnut can be grown considerably southward.
- We can map areas where different cultivars of groundnut can be grown (example: Luga, Bambey, and Nioro du Rip stations show very different potentials for long- and short-season groundnut production).

Suggestion: An effort should be made to use available and newly generated data to better define groundnut cultivar recommendations in various parts of the Sahel. (Note: management practices can affect this map).

The paper by M.V.K. Sivakumar and P.S. Sarma looked at the effects of the time and severity of drought stress on groundnut production during the growing season. This stress, applied in a gradient from mild to severe water deficiency by using a line-source sprinkler system, was applied during one or more quarters of the groundnut life cycle.

The results demonstrated that certain groundnut cultivars are quite adaptable in their ability to recover from stress and that, in general, early drought stress had minimal effect on later pod yield. This adaptability may be due to:

- changes in root morphology as a function of drought stress.
- The plant's ability to rest "dormant" during stress.
- The use of "escape mechanisms" (e.g., leaf loss) during stress.

Other factors which may affect groundnut resistance to drought include:

- plant spacing and orientation
- plant physical structure
- cultivar differences in time of sensitivity to stress such as physical problems (peg entry into soil) or biological factors which permit avoidance and recovery.

In general, if drought stress is relieved by the peg-initiation stage, yield loss will be minimized. This suggests that water-saving management practices and advantageous sowing strategies exist and can be exploited.

As a subtopic, measurement of plant stress was discussed. Although soil-water tension gives a good first approximation to plant water stress, plant and cultivar differences require data from the plant itself. These include leaf-water potential, rates of transpiration, stomatal conductance, and canopy temperature. However, none of these methods are suited for large-scale cultivar testing for stress resistance. Faster, simpler techniques such as leaf rolling, trip burn, or wilting are needed.

The third paper, by J.H. Williams, R.C. Nageswara Rao, R. Matthews, and D. Harris, went a step further than the previous two to look in more detail at the effect of duration, intensity, and timing of drought stress on 22 groundnut cultivars with similar growth patterns (specifically, length of time to flowering). Differences between genotypes in resistance, avoidance, and recovery from a given drought stress (as defined by irrigation rate) relative to potential evaporation show that:

- drought stress decreases yield proportionately to the plant's ability to meet the evaporative demand of the atmosphere, and
- different cultivars have different methods of escape/avoidance/recovery, including different rates of dry-matter accumulation and different partitioning in the event of drought.

Knowing the patterns of cultivar susceptibility permits one to "fine tune" cultivars to environments based on historical characteristics and drought periods at each site. Strategies available include:

- the use of high potential-yield cultivars, which, although being generally more sensitive to end-of-season drought, have advantages because of their yield potential in these circumstances, and

- the selection of cultivars for their escape/avoidance/recovery abilities to midseason droughts with high potential yields.

A good example of the importance of management was discussed: the application of gypsum decreased the susceptibility of most groundnut cultivars to drought.

Recommendations

- Changing rainfall patterns (shorter duration of the rainy season, drought periods during the rainy season with differing frequencies and durations) in the SAT require a continuing determination of the limits of where groundnut remains an economically viable crop.
- Agrometeorological data is important to determine where groundnut can be grown and what general types of groundnut fit the climatic pattern, e.g., a 90-, 110-, or 120-day cycle cultivar. Interdisciplinary collaboration can contribute to cultivar improvement to take better advantage of the available rainfall in the SAT. Broad based collaboration in groundnut research is imperative.

Session III: Climatic Requirements of Groundnuts

Three papers were presented in this session, two on the response of groundnuts to agroclimatic factors and one on the breeding criteria and methods for providing groundnut varieties better adapted to uncertain rainfall conditions.

The paper by C.K. Ong on "Agroclimatological factors affecting phenology" emphasized that the study of phenology had been concerned more with the timing of developmental processes rather than with the rate of development. By relating the reciprocal of the duration of the developmental process (i.e., rate) to agroclimatological measurements, a more useful descriptor of plant response is obtained. Ong developed this concept by relating temperature to growth for a particular phenological period divided by thermal time. Germination of groundnuts using thermal growth rate indicates that there is a conservativeness as far as the base temperature requirement is concerned, but genotypes did differ in the maximum temperature requirements. These genotypic differences may be very useful in selecting new genotypes for heat tolerance in the semi-arid tropics (SAT). Ong further developed this concept for other phenological stages and emphasized the need for more research to verify the importance of thermal growth rate. Other agrometeorological factors which affect phenology discussed in the paper are daylength, saturation deficit, and rainfall distribution. Ong recommends integration of crop phenology and growth responses, and the further evaluation of the concept of thermal growth rate for groundnuts.

The paper by D.L. Ketring, "Physiological response of groundnut to temperature and water deficits-breeding implications pointed out important differences between groundnut genotypes in their response to supraoptimal temperatures. This work has come out of the disastrous effects of high midseason growing temperatures (>35℃) on groundnut yields in the USA. Using controlled-environment procedures Ketring found differential response among groundnut genotypes to high-temperature tolerance. These genotypes also differed in heat tolerance indicated by membrane thermostability using the in vitro leaf-disc method with leaf tissue from field-grown plants. Ketring describes in his paper the development of selection techniques for improved hydration. Emphasis was placed on improved rooting traits and favorable water-potential components. Genetic diversity was found for these characteristics in field and greenhouse experiments. A useful selection technique for improved hydration maintenance was the measurement of sap-flow velocity. This measurement indicated differences between genotypes in their ability to maintain water flow through the plant under drought-stress conditions. Ketring concluded from his study that the traits for heat and drought tolerance are genetically transferable.

The third paper of the session presented the relationship of climatic requirement of groundnuts from the perspective of the groundnut breeder. J.L. Khalfaoui, in his paper "Breeding groundnut varieties for the semi-arid zones", outlined the lack of genotypes previously well-adapted to the different rainfall zones of Senegal over the last 15 years. He developed the concept of "fitting" the variety to the length of the growing or rainy season. By examining the last two decades of seasonal rainfall, he was able to predict the likelihood of failure or success of groundnuts of different growing periods at Bambey and Louga. This analysis pointed out the need to develop earlier-maturing genotypes. In his paper Khalfaoui also highlighted the importance of poor rainfall distribution resulting in drought stress not only at the end of the season, but at other times throughout the growing season. The paper also discussed the classical and recurrent-selection techniques presently being used to attempt to improve the adaptation and resistance of groundnut genotypes to shorter growing seasons and poor distribution of the seasonal rains.

In the discussion of Ong's paper the need to verify the concept of thermal growth rate in the various phenological stages was recommended. Although some doubt was expressed about giving research priority to temperature in sub-Saharan Africa, Ong felt that examination of soil- and air-temperature data in relation to growth and yield needed to be examined. It was pointed out that not only high-temperature effects but suboptimal-temperature effects may prove to be important in the region.

The Ketring paper raised the issue of the close relationship between heat and moisture-deficit tolerance. Some participants felt a need to separate these two effects, although invariably drought and temperature stress occur together. The importance of understanding and measuring root growth and function were discussed and further refinement of the methods for simplicity need to be undertaken if the behavior of different groundnut varieties under drought is to be understood.

Discussion on the Khalfaoui paper largely centered on the problem of ensuring that parental materials meet the criteria used for selection. The possibility of exploiting earliness in lines other than Chico, as well as using genes from the Valencia and wild types was raised. ICRISAT has a number of other sources of earliness. In developing simple screening methods to select for important drought-response characteristics, Ong informed the participants that ICRISAT had developed a soil-depth gradient to nondestructively differentiate between genotypes for rooting depth.

Session IV: Climate and Groundnut Production

Session IV focused on groundnut-production problems that are conditioned or modified by variations in climatic conditions. Five interesting presentations were made by Picasso, Pettit, Lynch, Sanders, and Willey. Climatic effects relating to biological production problems were exemplified by discussions about three organisms.

Mycotoxins, produced by *Aspergillus flavus* and *A. parasiticus* were recognized as a very serious production problem because of their effect on seed quality. Although these fungi can cause seedling diseases, they produce mycotoxins that are highly carcinogenic and weaken or destroy body immune systems. Climatic factors, especially moisture and temperature, were described as being extremely important in the growth of these fungi and in the production of mycotoxins. Infection of groundnut by *A. flavus* and *A. parasiticus* is possible during all stages of production beginning with seed germination, and continuing through pod development, drying, storage, and even after processing. Fungal growth and infection may occur when temperatures equal or exceed 25°C and the humidity is 83-99%. However, toxin production is greatly reduced or inhibited at high temperatures, (i.e., 39℃).

Drought, especially during stages of maturation, favors infection and growth of the fungi. Early sowing to enable maturation of the seed prior to the end of summer rains, or supplementary irrigation to prevent stress during this reproductive stage suppress infection. The shell and testa are natural barriers to soilborne fungi, but disruption of these scarifiers, rehydration after drought or after digging to cause suture weakening or fracture, mechanical breakage during picking and threshing, or any other damage, facilitates fungal penetration. Immature groundnuts have a higher moisture content than mature ones, and require a longer drying time. They are often highly susceptible to infection by the *A. flavus group* of fungi during storage. Thus, utilization of varieties and cultural management systems that favor maximum maturation of the fruit before digging should be beneficial in reducing mycotoxin problems. In-season drought delays maturation, and thus is detrimental not only to production but also increases the likelihood of *Aspergillus* spp infection. (Could it be that accelerated maturation by late-season leafspot infection is instrumental in reducing incidence of *A. flavus* and *A. parasiticus?)* Stress also affects quality factors such as seed size and uniformity, fatty acid ratio, storage life, and palatability.

Genetic differences in pod and seedcoat structural features that can be correlated with resistance to soil borne fungi have been identified. However, more research on these structures is needed and the available germplasm should be screened. In addition, recent research at ICRISAT Center has indicated that two genotypes have cotyledonary resistance to aflatoxin production. Further confirmation of this discovery under varied moisture and temperature combinations is needed. Following confirmation, efforts to incorporate cotyledonary resistance and favorable pod and testa structures into adapted genotypes with varied growth durations should be a high research priority.

Picasso pointed out in this session that rosette virus is another important disease of groundnuts in Africa. The incidence and severity of this disease is also affected by varied climatological factors. The virus is borne by the aphid *Aphis craccivora,* which develops and reproduces most rapidly at 65% relative humidity and temperatures between 24 and 28.5℃. Winged forms of the insect are rapidly spread for long distances by wind. The aphid reproduces parthenogenetically and populations increase rapidly. Reproduction rates are greatest about 35 days after minimum daytime humidities of 65% have occurred for 10 days. Barren soil is beneficial to aphid infestation. Rosette virus nearly eradicated groundnut in Burkina Faso 20 years ago. Resistant varieties are now available and have been effective in the control of this disease.

Rust is a relatively new disease of groundnut that has the potential to cause great crop loss. It's occurrence was first noted in Africa in 1974. Rust is favored by periods of high moisture and high humidity. Economic crop losses are confined mostly to regions with more than 600-700 mm of annual rainfall. It occurs annually in the southern, more humid regions of the SAT and can cause crop losses of 50%. Only the uredial state of the fungus has been found in Africa and the infection time of the groundnut varies with regions. Temperature is very important in its development and multiplication, with an optimum of 27℃. High humidity, but not free moisture on the leaflets, is required for spore germination and infection. Chemical control is possible but impractical for African farmers. Resistance has been discovered and is being transferred into adapted cultivars.

The effects of climate on the development and spread of these biological systems are illustrative. Lynch reported that more than 200 species of arthropods have been reported on groundnut in Africa, assessments by ICRISAT scientists rank termites, aphids, goundhopper, jassids, and millipides as the most important. A preliminary survey in Burkina Faso in 1984 revealed thrips, jassids, termites, and millipides to be of great importance. Storage insects such as the groundnut bruchid are also important. Leaf spots, seedling diseases, pod and root diseases, nematodes, and other biological pests are also present and each have their own climatic requirements. A better understanding of climatic factors with regard to the biology and conditions of infestation or infection of these organisms can help forecast outbreaks and identify weak periods in the developmental cycles that may be useful for developing integrated methods of control.

The final paper of the session presented methods to circumvent some of the problems of climate and pests by the use of intercropping. An interesting point made in this paper was that increased biomass per hectare could be obtained with intercropping as compared to sole cropping. Partitioning of dry matter was also affected. The harvest index of sorghum and groundnut was higher under intercropping than in the sole crop during drought stress. Causes for the benefits of intercropping are not known, but moisture utilization, solar-energy use, temperature, and evaporation are suspected. Cooperative studies to decipher such factors are needed to design superior farming systems.

Recommendations

- Resistance is the most efficient means for disease and arthropod control, and research to develop resistant cultivars must be pursued. However, evaluation of resistance under varied environmental factors is necessary to determine effectiveness over the range of conditions in semi-arid and subtropic areas.
- Verification of cotyledonary resistance to *Aspergillus flavus* under varied temperatures, humidities, and other environmental factors is needed. A combination of genetically controlled dry seedcoat resistance, shell traits that restrict fungal penetration, and cotyledonary resistance into early and midseason adapted genotypes should be encouraged.
- Characterization of soil and within-canopy climatic measures (such as temperature, available moisture, and humidity) in relation to arthropod and disease development and in association with ambient environmental measures is needed. This information, coupled with controlled-climate measures of pathogen-host, arthropod-host, and pathogen- arthropod-host systems should help design cultural and production systems, and effective

controls that will enhance harvestable yield of a high-quality product.

- Characterization *of* biological production constraints, threshold levels, and climatic factors associated with growth and attack of the crop in different regions under varied cultural and production systems should be continued.
- Finally, effective, early agrometeorological forecasts based on historical records to advise agriculturists of conditions conducive to the development of biological production constraints, preferably prior to sowing, could help in cultivar choice, cultural management systems, and other measures to reduce crop loss and stabilize yield.

Session V: Applications to Groundnut Cultivation

The session opened with a paper by Yayock and Owonubi, who gave a detailed account of weather-sensitive agricultural operations in groundnut production in Nigeria. This account included several aspects of the planning of the season and described the influence of relevant agroclimatic factors in many of the daily farming operations. They stressed in particular the need to understand the influence of the environment on each of these steps, especially because many farmers practice mixed cropping.

The paper on crop-monitoring by Frere stressed the potential use of the crop-monitoring method for both the rapid assessment of the season's yield and as a within-season tool for advice to farmers. The use of this method for yield assessment requires the establishment of the relationship between yield and crop-water satisfaction index for each crop and region. The method holds promise for governments to assess food crop availability before harvest, to plan marketing, and to establish the need for food stocks and international food purchases. An exchange of views by different users of the method on it's validation and adaptation was encouraged.

A paper on leaf spot disease forecasting by Smith presented the use of agroclimatic information on a real-time basis for monitoring, forecasting, and combating this disease. The basic principle of the method should be applicable to other insect pests and other diseases, and the development of more such information was encouraged.

Boote presented a paper on the use of a crop-growth model relating agroclimatic factors and their influence in each stage of growth and development of a crop to final yield. The step-by-step analysis increases the understanding required for research projects and provides insights into the specific influence of agroclimatic parameters in day-to-day farm decision making. Boote stressed that the model needs careful validation before it can be used operationally and he received enthusiastic offers for contributions to this validation.

The discussion stressed the desire of the participants that basic and processed agroclimatic information should be made available rapidly to help in the definition of research orientation and to allow application of practical knowledge that already exists. The most immediate application areas were considered to be monitoring the development of insect pests and diseases and their subsequent control and advice to the agricultural community for day-to-day planning and decision making in groundnut cultivation. These points are expressed in the recommendations of Planning Group I.

Report of Planning Meetings

J.S. Kanwar

Group I

Practical Applications of Agrometeorological Information for Increased Groundnut Production in the Semi-Arid Tropics

Recommendations

- Publish rapidly all available basic and analyzed/processed information on dry periods: timing, intensity, duration, and probabilities of drought; date of onset and cessation of rains; rainfall probabilities for 10-day periods; potential evaporation for 10-day period; water balance of crops and cropping systems; stress periods; length of the growing season. Provide for regular updating of these publications.
- Publish information on wind, sunshine, and temperature data that influence growth and development, including information on growth-critical maximum, minimum, and base temperatures and on thermal time. Publish information on relevant soil temperatures.
- Request WMO to promote and make available results of studies on trends, variability, and change of the climate in the semi-arid zones and to promote the preparation and issue of 5-10 day forecasts; provide advice to groundnut breeders on the existence of such trends; ask national meteorological services to adapt the observation of soil temperatures to the needs of groundnut growing.
- Collect and publish information on the values of temperature and other weather parameters that influence the development of insect pests and diseases, and formulate practical techniques that allow national meteorological services to provide operational information and warnings on climatic factors that affect the development and control of the most prominent insect pests and diseases of groundnut.
- Request the competent organizations to study and publish in an operational format the existing knowledge on the mechanisms of spread of insect pests and diseases.
- Collect and publish information on the agrometeorological factors that affect research options and day-to-day agricultural planning and farming operations throughout the season. This information should exploit the farmers' knowledge of the sensitivity to agroclimatological factors of his day-to-day operations and changes therein. It should permit real-time use of agrometeorological information for applications in a farmer-acceptable manner. It should also include the use of crop monitoring models and crop-growth models to allow the formulation of within-season advice for day-to-day operations and drought monitoring.
- Request national meteorological services to provide daily information and forecasts for agricultural operations and pests and disease control.

Group II

Collaborative Research Network for Improved Understanding of Climate/Groundnut Interactions

Collaboration on Agroclimatic Data: Acquisition, Management, Analysis, and Exchange of Information

It was suggested that those involved in the collection and interpretation of agrometeorological data for the groundnut-growing areas in the SAT need to pool their resources. A standardized method of collecting minimum crop, soil, and climatic data should be followed. As far as possible the data storage, retrieval, and processing should be undertaken on a uniform basis. It is recommended that initially the AGRHYMET Center of the WMO and ICRISAT should jointly undertake this task for the West African countries. A similar study should be made for the SADCC countries in the next few years.

Microclimatological Research on Groundnut-based Cropping Systems

The group identified energy balance, water balance, and environmental humidity as the main parameters affecting crop production and disease and insect pest infestations in the groundnut-growing areas. A clear understanding of these parameters would be extremely useful for planning agricultural activities. It is recommended that a regional cooperative effort should be launched to collect and disseminate soil, crop, and climatic information on a uniform basis for use in these studies. The drought-related research should be emphasized. The institutions that may be involved are: ICRISAT, ISRA, ABU, CIEH, University of Nottingham, Tropsoils, CIRAD, and ORSTOM.

Studying Effects of Agrometeorological Factors on Groundnut Growth, Insect-Pest Population Dynamics, and Disease Infestations

The group discussed this aspect at some length. There is a need to collect uniform data sets on crop, soil, and climatic parameters for crop performance and crop losses due to insect pests and diseases. It is recommended that agroecological conditions in which the losses to groundnut production and quality occur should be defined and documented. Some of the priority research items are: research on aphids, rosette, leaf spots, rust, termites, millipedes, aflatoxins, *Aspergillus niger,* storage, etc. The institutions suggested for this research are: Peanut CRSP, ISRA, and INRAN.

Simulation of Groundnut Growth and Production by Climate-Driven Models in the Semi-Arid Tropics

There is a need to develop a simple and reliable groundnut growth and development model. It should be used for aggregation of yield response using a spatial agrometeorology network. The group believes the use of a modeling approach would hasten the process of technology development and transfer. There is a real need to define cultivars by their phenological development and partitioning in response to temperature, daylength, and drought. Not only are these traits needed to run the model, but the model should be used to help define the ideal type of cultivars for a given temperature, daylength, and rainfall environment.

There are two methods for model validation in response to weather and soil. One involves final yield measurement, whereas the other requires periodic sampling of dry matter during the season. Only the latter can help improve the model's capability for prediction. IBSNAT, ICRISAT, University of Florida, and WMO are suggested institutions for collaborative research in this area.

Group III

Training Needs of Agrometeorologists and Agronomists for Efficient Use of Available Meteorological Information

- The group suggests that future training workshops should be of longer duration to enable participants to discuss more fully diverse aspects of agricultural meteorology. It is also recommended that participation of interdisciplinary groups at the national level be encouraged at such workshops. On the other hand, such workshops could be held at the national level The possibility of organizing such workshops every year to discuss the previous year's cropping situations should be explored by AGRHYMET and ICRISAT. Training of agrometeorologists at the university level should be intensified to strengthen the national research capabilities. Suggested universities include: Florida State University, Reading University, (UK), Fondation Universitaire Luxembourgeoise (Belgium), Nairobi University. Funding this type of training is a potential problem.
- Popularization and standardization of crop models will require close collaboration between national and international organizations such as WMO and FAO, particularly for the acquisition of precision instruments to strengthen national program capabilities. It is suggested that the available data be published in both English and French to reach a wider audience. In addition, manuals on agrometeorological information could aid agronomists in their activities.

Report on the Pre-Symposium Training Workshop

M.V.K. Sivakumar

The symposium was preceeded by a week-long training workshop on 'Operational Applications of Agrometeorology'. This workshop was designed for agrometeorologists in Africa working on the applications of operational agrometeorology to improve groundnut production. The workshop was jointly funded by the World Meteorological Organization (WMO) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Objectives

- To provide a forum for agrometeorologists in the semi-arid tropics (SAT), especially in the West African region, to discuss methodologies available for operational applications of agrometeorology to groundnut cultivation.
- To disseminate proven techniques of monitoring groundnut response to environment in the semi-arid regions, and to discuss means for utilizing this information operationally.
- To provide hands-on experience in the use of simple models for analysis of rainfall data and of soil water balance models using a computer, and to encourage use of these models in the national programs.

Participation

The workshop participants included 12 agrometeorologists from the national programs of 10 countries in Africa. A list of participants at the training workshop is given in Appendix 1. Ten of the participants were from the West African region.

Workshop Program

The training workshop emphasized the soil-plant-atmosphere continuum approach. This recognizes the fact that future progress in increasing and stabilizing groundnut yields in the SAT depends upon a more complete understanding of the interactions between the soil, the plant, and the atmosphere. The program for the training workshop hence emphasized the following areas:

- Collection and acquisition of climatic data and its analysis, models of rainfall analysis.
- Soil-water balance: meteorological factors affecting the soil-water balance, measurements of soil water with emphasis on the use of the neutron probe, and use of simple soil-water balance models.
- Plant responses: use of plant measurements of drought stress, monitoring phenology of groundnut crop, diseases of groundnut in relation to environment.
- Integration of the knowledge of the soil-plant-atmospheric continuum using crop models for operational applications in agrometeorology.

The program for the training workshop is given in Appendix 2.

Workshop Faculty

Since the workshop was interdisciplinary and covered soil, plants, the atmosphere, and the use of models, the invited faculty was drawn from seven disciplines. It included a meteorologist, two agrometeorologists, a soil physicist, two plant physiologists, a statistician, a plant pathologist, and a computer software specialist. The faculty for the training workshop is given in Appendix 3.

Location and Facilities for the Workshop

The workshop was held at the AGRHYMET Center, the WMO regional center for training in agricultural meteorology and hydrology located in Niamey.

Since the participants of the training workshop came from both anglophone and francophone countries in Africa, the workshop was bilingual Facilities for simultaneous interpretation were available at the AGRHYMET auditorium. WMO provided the services of two interpreters (listed in Appendix 3).

The workshop emphasized techniques for monitoring groundnut response to environment. These techniques included:

- measurements of soil water using a neutron probe,
- use of a steady-state porometer to measure stomatal conductance and transpiration in groundnut,
- use of an infrared thermometer for measuring canopy temperature and canopy-air temperature differential,
- monitoring phenology of groundnut, and
- observation of diseases of groundnut.

To facilitate this work, eight groundnut varieties with different morphological characteristics and growth maturities were sown at the AGRHYMET Center. The participants had the opportunity to make measurements on the crop and familiarize themselves with the instruments used.

The workshop also emphasized the use of simple models for rainfall analysis and soil-water balance models. The facilities of the AGRHYMET computer center were made available to the participants. One full day was used to acquaint the participants with the use of the computer, followed by use of the models. Participants used data from West African countries familiar to them so that the analysis was particularly relevant.

Participant Interaction

The workshop was interactive with emphasis on active participation. The participants were encouraged to exchange ideas and evolve concepts to better utilize available methodologies for operational applications. The morning session on the final day was devoted to presentations by the participants on the current work in the respective national programs and the need for improvements. This interaction helped the participants and the faculty appreciate the country needs and discuss future plans.

Workshop Evaluation

In order to facilitate the evaluation of the training workshop and help obtain feedback from the participants, an evaluation form was circulated on the final day. A summary of the participant evaluation of the training workshop is shown in Appendix 4. In general the workshop was rated good to excellent. Copies of the evaluation forms have been sent to WMO for follow-up action on the suggestions made by the participants.

Overall, the workshop has been a success. It was held in an atmosphere of free discussion and friendly exchanges. It has been an educational experience for us to work closely with the participants from the national programs.

Acknowledgements

On behalf of ICRISAT, I wish to thank Dr. Rijks of the Climate Applications Program of WMO for providing us the opportunity to help organize this training workshop. Dr. Coly, the Director General of AGRHYMET has been highly supportive of the workshop. Our grateful thanks to him and all the staff of AGRHYMET Center for their generous cooperation and help.

Appendix 1

List of Participants

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Appendix 2

Program for the Training Workshop

12/13 August

Participants arrive in Niamey

14 August

0800	D. Lambergeon, AGRHYMET Center Climatic-data management: acquisition, retrieval and utilization
0900	M. V. K. Sivakumar, ICRISAT Climatic-data acquisition using an automatic weather station. Visit to ICRISAT Sahelian Center
1230	Lunch
1530	M. V. K. Sivakumar, ICRISAT Analysis of automatic weather station data. Display on the AGRHYMET computer and computation of potential evapotranspiration

15 August

0800	S. M. Virmani, ICRISAT Meteorological characteristics particularly related to soil-water balance of typical groundnut-growing areas
1000	Sharon LeDuc, NOAA Applications of crop models for operational Agrometeorology
1230	Lunch
1530	D. L. Ketring, USDA-ARS and M. V. K. Sivakumar, ICRISAT Measurements of plant-water stress in groundnut. Use of steady-state porometer and infrared thermometer

16 August

0800	M. V. K. Sivakumar, ICRISAT Analysis of rainfall data: use of probability models, monthly rainfall statistics
1000	R. C. Chase, Texas A & M University Practical training in the measurement of soil moisture using a neutron probe
1230	Lunch
1530	S. M. Virmani and M. V. K. Sivakumar, ICRISAT Use of simple models for defining the moisture adequacy for groundnut: soil-moisture models

1630 D. Lambergeon, AGRHYMET Center
AGRHYMET computer system for users in CILSS countries

1730 S. K. Kaw, AGRHYMET Center
Operational features of AGRHYMET computer

17 August

0800 M. V. K. Sivakumar, ICRISAT

Use of rainfall models on the AGRHYMET computer

1230 Lunch

1530 M. V. K. Sivakumar, ICRISAT
Use of soil-moisture models on the AGRHYMET computer

18 August

Sunday Free

19 **August**

0800 J. H. Williams, ICRISAT

Phenology and growth characteristics of groundnut

1000 Phenological observations in the field

1230 Lunch

1530 D. H. Smith, Texas A & M University
Diseases of groundnut crop. Role of meteorological factors in their infestation

20 August

0800 Presentations by participants

1230 Lunch

1530 Workshop evaluation and final synthesis

Appendix 3

Faculty for the Workshop

R. C Chase, Senior Soil Physicist, Texas A&M University, ICRISAT Sahelian Center, Niamey, Niger

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Appendix 4

Summary of Participant Evaluation of the Training Workshop

Item	Rating (%)			
	Excellent	Good	Fair	Poor
1. Arrangements				
Travel/Hotel/Transportation	62	38	-	
2. Workshop schedule				
Program	71	29	-	
Time allocation to each subject	13	66	21	
3. Lectures				
Quality	47	53	-	
Content	40	60	-	
4. Computer-related work				
Practical work pertaining to:				
Automatic weather station and transfer of data	79	21	-	
Simple models of rainfall	57	43	-	
Soil-water balance models	57	36	7	
5. Field work				
Practical work related to:				
Neutron-probe technique	80	7	13	
Steady-state porometer	67	27	6	
Infrared thermometer	50	43	7	
Phenology	14	72	14	
Diseases	46	46	8	

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