The ICRISAT Groundnut Program

D. McDonald*

Summary

In 1976 ICRISAT was designated a world center for the improvement of yield and quality of groundnut and to act as a world repository for the genetic resources of the cultivated Arachis hypogaea *and its wild relatives in the genus* Arachis. *About 67% of the world's groundnuts are produced by small farmers in the semi-arid tropics (SAT), but yields are low at around 780 kg/ha of dried pods. The potential yields are over 5000 kg/ha but cannot be attained because of such constraints as diseases, pests, and unreliable rainfall. This paper discusses these and other production constraints and outlines research being done on them by the ICRISAT Groundnut Improvement Program. The establishment of the ICRISAT Regional Groundnut Program in Southern Africa and our projected cooperative programs for Southeast Asia and West Africa will greatly increase the scope of the ICRISAT Groundnut Program to assist national programs in all aspects of research on groundnut problems.*

Résumé

***Le Programme d'arachide à l'ICRISAT**: C'est en 1976 que l'ICRISAT a été désigné comme centre mondial chargé de l'amélioration des rendements et de la qualité de l'arachide, ainsi que de devenir un dépôt mondial pour les ressources génétiques de l'arachide cultivée (*Arachis hypogaea*) et de ses espèces sauvages du genre* Arachis. *Les petits paysans des zones tropicales semi-arides représentent environ 67% de la production mondiale arachidière, mais leurs rendements restent faibles, de l'ordre de 780 kg/ha de gousses sèches. Les rendements potentiels sont de 5000 kg/ha ou plus, mais les contraintes telles que les maladies, les ravageurs et la pluviosité aléatoire ne permettent pas la réalisation des niveaux pareils. L'article considère celles-ci ainsi que d'autres barrières à la production et donne un aperçu des travaux de recherche en cours au Programme de l'ICRISAT pour l'amélioration de l'arachide. L'établissement du Programme régional de l'ICRISAT pour l'arachide en Afrique australe ainsi que ses programmes coopératifs envisagés pour le Sud-Est asiatique et l'Afrique de l'Ouest, permettront au Programme de l'ICRISAT de mieux aider les programmes nationaux dans tous les aspects de la recherche sur les problèmes de l'arachide.*

The groundnut originated in South America but is now grown throughout the tropical and warm temperate regions of the world. Commercial production is largely within the limits of latitudes 40°N and 40°S. It is estimated that 67% of the world's groundnut production is grown in the semi-arid tropics (SAT), almost entirely by small farmers of limited means. The average yield of 780 kg/ha of dried pods compares unfavorably with the 2900 kg/ha grown in countries with developed agriculture. Yields of over 3000 kg/ha are common on research farms in the SAT, indicating good potential for improving farmers' yields. Constraints to groundnut production in the SAT include damage by pests and diseases, unreliable rainfall patterns with recurring droughts, lack of high-yielding adapted cultivars, poor agronomic practices, and limited fertilizer use. In many of the SAT countries there is a scarcity of well trained, specialized groundnut researchers available to solve the many problems affecting the crop. The need for an international program to strengthen research on

* Principal Plant Pathologist, ICRISAT.

International Crops Research Institute for the Semi-Arid Tropics. 1984. Regional Groundnut Workshop for Southern Africa, 26-29 March 1984, Lilongwe, Malawi. Patancheru, A.P. 502324, India: ICRISAT.

groundnut was recognized when it became the fifth ICRISAT mandate crop in 1976. The Institute was required to serve as a world center for the improvement of yield and quality, and to act as a repository for the genetic resources of the cultivated groundnut, *Arachis hypogaea*, and its wild relatives in the genus *Arachis*. Research at ICRISAT has concentrated on breeding for resistance to production limiting factors. It is evident that breeding is of more value to the small farmer than solutions based on high technology.

Germplasm Base

During 1976—the first year after ICRISAT was designated as a world center for the collection, maintenance and documentation of the genus *Arachis*—2443 accessions were received. The total is now 10111 groundnut germplasm accessions, with over 1000 more awaiting plant quarantine clearance. There are also 171 accessions of 22 described and several undescribed *Arachis* spp., and 2 interspecific hybrids. Derivatives of interspecific crosses will be added to the groundnut germplasm collection when stabilized at the tetraploid level.

The germplasm collection is under the control of the ICRISAT Genetic Resources Unit. Germplasm botanists record a wide range of plant characters when evaluating the various germplasm lines. In consultation with the International Board of Plant Genetic Resources (IBPGR) a set of descriptors has been agreed and data are being entered into the computer.

Since 1976, 19625 seed samples have been supplied to cooperating scientists in many countries. The availability of the world collection has enabled ICRISAT scientists to screen a wide range of germplasm for resistance/tolerance to the various factors that reduce yield of groundnuts.

The Groundnut Improvement Program

The Groundnut Improvement Program has disciplinary Subprograms in Breeding, Cytogenetics, Pathology, Entomology, and Physiology. The Physiology Subprogram includes Microbiology which was previously a separate unit. Most of the research is multidisciplinary, with specific research goals of breeding for

- resistance to major diseases and pests,
- resistance/tolerance to drought,
- increased biological nitrogen fixation,
- high yield and quality,
- earliness and seed dormancy, and
- adaptation to specific photoperiods.

The breeding work depends on identifying sources of resistance to stress factors, understanding basic physiological processes, elucidating disease epidemiology, etc. These data will be useful to develop cultural methods to minimize the adverse effects of stress factors if genetic options are not available or are inadequate.

The Program is involved in cooperative research with other ICRISAT Programs, especially Farming Systems and Economics, with many scientists in SAT countries, and with mentor institutes in developed countries. The establishment of the Regional Groundnut Program for Southern Africa has extended the range of research that can be done by ICRISAT and has improved opportunities for effective cooperation with groundnut research workers within the region.

Diseases

Foliar Diseases

The most important fungi-caused foliar groundnut diseases are the leafspots (*Cercospora arachidicola* and *Cercosporidium personatum*) and rust (*Puccinia arachidis*). At ICRISAT Center rust and late leafspot (*C. personatum*) occur each year in epidemic proportions. Together they have been shown to cause yield losses in susceptible cultivars of up to 70%, while each disease on its own is capable of causing up to a 50% loss. All released Indian cultivars are susceptible. Field screening of the world germplasm collection for resistance to these two diseases was started at ICRISAT Center in 1977, and over 9000 accessions have now been examined. Some 34 genotypes have been found to have good resistance to rust, 24 have resistance to late leafspot, and 17 of the genotypes have good resistance to both diseases (Table 1). The resistant genotypes have been listed in the ICRISAT 1981 Annual Report (ICRISAT 1982) and in research papers. Fourteen germplasm lines with rust resist-

Table 1. Rust, early leafspot, and late leafspot reactions of some groundnut genotypes in field screening trials at ICRISAT Center, rainy season 1983.

	Disease scores[1]		
Genotypes	Rust	Early leafspot	Late leafspot
NC Ac 17090	2.7	8.7	5.7
PI 259747	2.7	7.3	3.0
PI 390593	2.7	8.0	4.7
PI 393646	2.7	8.7	6.3
PI 405132	2.7	7.0	3.0
PI 414332	2.7	8.0	6.0
EC 76446(292)	3.0	7.7	3.0
PI 350680	3.0	7.0	3.3
PI 314817	3.0	8.7	6.3
PI 315608	3.0	7.3	6.7
PI 341879	3.0	8.7	3.3
PI 381622	3.0	8.0	3.3
PI 393517	3.0	7.7	6.7
PI 393527-B	3.0	8.7	6.7
PI 393643	3.0	7.3	6.7
PI 407454	3.0	8.7	6.7
PI 414331	3.0	8.7	7.3
NC Ac 17133-RF	3.3	7.7	3.3
NC Ac 927	3.3	8.7	3.3
USA 63	3.3	8.0	3.0
PI 390595	3.3	8.0	3.3
PI 270806	3.7	7.3	3.3
PI 393526	3.7	8.3	5.7
PI 393531	3.7	8.3	6.7
PI 393641	3.7	7.7	4.7
PI 215696	3.7	8.0	3.3
NC Ac 17132	4.0	8.0	3.3
NC Ac 17135	4.0	7.3	3.7
NC Ac 17127	4.3	9.0	4.3
PI 298115	4.3	8.3	7.7
Krap St. 16	3.7	8.3	3.7
NC Ac 17129	4.7	9.0	4.3
PI 393516	4.7	8.3	3.3
NC Ac 17506	4.7	8.3	3.7
NC Ac 17142	5.0	8.0	4.3
C No. 45-23	6.3	8.3	5.3
NC Ac 17502	7.3	7.3	5.3
NC Ac 15989	8.3	7.0	3.7
RMP 12	8.3	6.7	4.0
NC 3033	9.0	8.0	9.0
EC 76446	9.0	8.7	9.7
TMV 2[2]	9.0	9.0	9.0

Continued

Table 1. *Continued*

Genotypes	Disease scores[1] Rust	Early leafspot	Late leafspot
J 11[2]	9.0	9.0	9.0
JL 24[2]	9.0	8.7	9.0
Robut 33-1[2]	9.0	8.6	8.3
SE ±	0.24	0.36	0.27
CV (%)	9.14	7.71	9.11

1. Mean of field disease scores on a 9-point scale, 1 = no disease and 9 = 50 to 100% foliage destroyed
2. Foliar diseases-susceptible released high-yielding cultivars

ance have been jointly released by ICRISAT and USDA (Hammons et al. 1982a, b, c).

Most of the rust and late leafspot resistant lines are low yielding and have undesirable pod and seed characters. Breeders have been crossing them with high-yielding, but disease susceptible cultivars, and are now well on the way to developing rust- and late leafspot-resistant cultivars with good agronomic characters (Table 2). In one field trial during the 1982 rainy season at ICRISAT four rust resistant lines yielded over 2200 kg/ha dried pods. The susceptible released cultivar JL 24 yielded only 870 kg/ha.

The stability of the resistance to rust and late leafspot has been checked by comparing screening results at ICRISAT over several seasons and by conducting an International Groundnut Foliar Diseases Nursery. The resistances appear to be stable. The biology of pathogens has also been investigated and resistance components have been measured. The physiological implications of disease resistance are now being examined and the findings may influence breeding and disease control strategies.

At ICRISAT the early leafspot disease caused by *C. arachidicola* does not normally become severe enough to permit reliable field resistance screening, but in the 1983 rainy season the attack by this disease was sufficiently severe to allow meaningful screening, and some genotypes showed significant resistance. Early leafspot is commonly present in epidemic form at Chitedze Agricultural Research Station, Lilongwe, Malawi, where an ICRISAT Regional Groundnut Program was established in 1982. ICRISAT germplasm is now being screened for resistance to this disease in Chitedze. Some lines reported resistant to early leafspot in the USA are susceptible in Malawi.

Near-tetraploid derivatives have been developed from crosses between wild *Arachis* species immune or highly resistant to the leafspots and rust diseases, and high-yielding groundnut cultiva... These derivatives have useful resistance to one ... more of these important foliar diseases and are now used in the resistance breeding programs.

Pod Rot Diseases

Pod rots caused by a complex of soil inhabiting fungi cause serious reductions in both yield and quality of groundnuts in a number of countries. The extent of the damage is not always evident at harvest, and it is likely that the incidence of pod rots and the yield losses attributed to this problem have been considerably underestimated. Losses of over 20% have been recorded at ICRISAT for some genotypes. Field screening for resistance has been complicated by uneven disease incidence between and within fields, but 11 genotypes have been shown to have significantly lower incidences of rotted pods than susceptible check cultivars (ICRISAT 1982).

The most important fungi involved in pod rotting at ICRISAT are species of *Fusarium*, *Macrophomina phaseolina* and *Rhizoctonia solani*. Different fungi and varying combinations of fungi have been found associated with pod rots in different places. This variation may have implications for resistance screening and breeding.

Aspergillus flavus and Aflatoxins

Aflatoxins are toxic secondary metabolites produced by strains of fungi of the *Aspergillus flavus* group when growing on suitable substrates. Groundnut seed and groundnut products are very effective substrates for production of the toxins. Invasion of groundnut seeds by the toxigenic fungi is favored by damage to the developing pods by pathogenic fungi, insects, drought stress, and cultivations Damaged harvested and stored pods and seeds, as well as wet seeds, are at increased risk from fungal invasion Aflatoxin contamination can be minimized by adopting farming and produce

Table 2. Performance of some rust resistant advanced lines at ICRISAT Center, rainy season 1983

Trial	Pedigrees	Yield (kg ha)		
		HI[1]	LI[2]	Rust disease score[3]
F_6	(RMP-91 x Dht 200) F6 B(S1)	4060	1970	3 2
	(RMP 91 x Dht-200)-F6-B(S2)	3730	2180	3 0
	(Robut 33-1 x PI 298115) F5 B	3650	2060	3 5
	NC Ac 17090 (Resistant check)	3890	1570	3 2
	Robut 33 1 (Susceptible check)	2810	1716	6 7
	JL 24 (Susceptible check)	2190	780	5 7
	SE ±	142	119	0 4
	Trial mean	3640	1610	3 9
	CV (%)	8	13	19 5
F_{10} (Selections from rainfed fields)	(NC Fla 14 x NC Ac 17090)F9 B	3150	1790	3 7
	(Tifspan x Nc Ac 17090) F9 B	3060	1320	3 0
	(Gang 1 x PI 259747) F9 B	2430	1930	4 0
	NC Ac 17090 (Resistant check)	3240	1750	3 2
	Robut 33 1 (Susceptible check)	2670	1490	7 2
	JL 24 (Susceptible check)	2290	840	7 0
	SE ±	197	94	0 3
	Trial mean	2520	1430	4 0
	(CV %)	13	11	14 3
	(Ah-65 x NC Ac 17090) F8-B	4160	2200	3 3
	(NC Ac 2190 x NC Ac 17090) F8 B	4150	2020	3 2
	(JH 60 x Nc Ac 17090) F8 B	3340	2240	3 2
	NC Ac 17090 (Resistant check)	3290	2040	2 8
	Robut 33-1 (Susceptible check)	2410	1620	8 3
	JL 24 (Susceptible check)	2280	1010	7 7
	SE ±	165	148	0 4
	Trial mean	3160	1790	3 6
	CV (%)	9	14	20 8
	(NC Ac 1107 x NC Ac 17090) F9-B	4070	2080	2 8
	(JH 60 x PI 259747) F9-B	3850	2530	2 8
	(Ah 65 x NC Ac 17090) F9-B	2740	2470	3 0
	NC Ac 17090 (Resistant check)	3670	1820	3 0
	Robut 33-1 (Susceptible check)	2560	1740	4 7
	JL 24 (Susceptible check)	2710	1080	4 7
	SE ±	182	144	0 3
	Trial mean	2890	1830	3 1
	CV (%)	11	14	16 5

1 HL = High input (60 kg/ha P_2O_5 with irrigation and insecticidal sprays)
2. LI = Low input (20 kg/ha P_2O_5 rainfed and no insecticidal spray).
3 Recorded from rainfed trials on a 9-point disease scale, 1 = no disease, and 9 = 50 to 100% foliage destroyed

handling methods designed to avoid damage to pods and seeds. But unfortunately few farmers in the SAT follow the recommended procedure, so attention has therefore been concentrated on utilizing genetic resistance. Breeding lines with testa resistance to invasion of rehydrated dried seeds were reported from the USA. This resistance was confirmed at ICRISAT Center and several more dry seed resistant genotypes identified (Mehan et al. 1981). It is of interest that some of these genotypes were also found to be resistant to pod rots.

Several of the genotypes identified as resistant to colonization of the dried seeds by *Aspergillus flavus* (J11, PI 337409, PI 337394F, UF 71513-1, Ah 7213, Var. 27, and U4-4-1) have been extensively crossed with susceptible but high-yielding cultivars. Derivatives of these crosses have been selected which have good yield and seed quality, and have levels of seed resistance to *Aspergillus flavus* colonization comparable to those of the resistant parents.

A number of germplasm lines have also been tested for resistance to aflatoxin production following invasion of seeds by toxigenic strains of *A. flavus*. All genotypes supported aflatoxin production but significant varietal differences in accumulation rates and total toxin produced were found (Mehan and McDonald 1984).

Virus Diseases

Virus diseases of groundnuts are common and can be serious, but it has often been difficult to estimate the losses caused by specific diseases because of confusion about their identification and distribution. Identification has too often been based only upon symptoms. At ICRISAT emphasis has been placed on the purification and precise characterization of groundnut viruses and on the production of antisera. This research has been accompanied by field and screenhouse evaluation of germplasm for resistance or tolerance to virus diseases such as bud necrosis, peanut mottle, and peanut clump. Some 7000 genotypes have been screened for resistance to bud necrosis (caused by tomato spotted wilt virus), but all were susceptible. Wild *Arachis* species are now being screened, and *Arachis chacoense* has been found resistant in mechanical and thrips inoculation tests. Almost 500 germplasm lines have been screened for resistance to peanut mottle using a field mechanical inoculation technique. All proved susceptible but four lines showed less than 5% yield loss compared with 12-60% losses from infected plants of other lines. Two genotypes were found to have no seed transmission of peanut mottle virus from infected mother plants. Resistance breeding using the tolerant and the no seed transmission genotypes has just started. Screening for resistance to the soil-borne peanut clump virus disease has been in progress for several seasons, but with conflicting results. These are probably due to virus strains with different virulence for different host plant genotypes.

Rosette disease is the best known and most important virus disease of groundnut in Africa south of the Sahara. High-level resistance to this disease was found in some West African germplasm, and breeders in Senegal, Nigeria, and Malawi have successfully bred rosette resistant cultivars with good agronomic characters (Gibbons 1977, Gillier 1978, Harkness 1977). Rosette resistant genotypes are being used in seve[ral] ICRISAT Center breeding programs, and a program to breed for rosette resistance has now started at the ICRISAT Regional Groundnut Program for Southern Africa in Malawi. Although groundnut rosette has been known for several decades, the viruses involved have not been properly characterized. ICRISAT is now involved in coordinated international research to resolve this problem. Studies are in progress to characterize the two viruses involved in rosette and to develop reliable identification methods. These can then be used to clarify the situation in Southeast Asia where a "rosette" disease has been reported, but indications are that the disease(s) described are not identical to African groundnut rosette.

The groundnut virus disease situation differs considerably between Africa, the Indian subcontinent, and East Asia. Rosette seems to be confined to Africa, bud necrosis is most important in India, and witches broom (probably caused by a mycoplasma) is serious only in East Asia. Peanut mott[le] is worldwide. High priority should be given to establishing the identity and distribution of groundnut diseases caused by viruses and mycoplasmas. The need for immediate attention being given to this problem is highlighted by the recent report of peanut stripe virus disease being introduced into the USA in seed from East Asia (Demski et al. 1984).

Bacterial Disease

The only important bacterial disease of groundnut is the wilt caused by *Pseudomonas solanacearum*.

This disease is common and serious on groundnuts in East Asia and has been reported from South Africa and the USA, but because it has not been found so far in India, it has not been investigated at ICRISAT Center. Cooperative linkages will have to be established with national programs in East Asia so that ICRISAT germplasm can be screened for resistance to this important disease.

Pests

Over 300 insect and mite species have been recorded from groundnut, but most are of limited distribution. Yield losses worldwide have been assessed at 17% from field pests and 6-10% from storage pests. No research on storage pests has been done at ICRISAT although there are indications of genetic resistance to some important insect pests. Research has concentrated on problems caused by aphids, jassids, thrips, the tobacco caterpillar, leafminers, bollworms, and termites. Particular emphasis has been given to research on vectors of virus diseases.

Surveys

All major groundnut growing areas of India have been surveyed to identify pest problems and measure yield losses. The surveys have shown recent shifts in pest incidence, some insects becoming more damaging, and others less so. The overall trend is towards increased pest damage, and one factor that may be responsible for this is the recent increase in cultivation of irrigated groundnuts in the postrainy season. In 1968 there were only four important pests of the crop, but in 1984 nine pests are considered to be of major importance (Table 3). Leafminers have become a serious problem wherever irrigated groundnuts are cultivated on a large scale. The value of groundnuts lost by pest damage each year in India is estimated at US$ 160 million.

Table 3. Major field pests of groundnut in India (Rai 1976).

1968	1984	
Aphids	Leafminer	White grub
Leafminer	Thrips (vectors)	Thrips (pests)
Hairy caterpillar	Aphids	Tobacco caterpillar
	Jassid	Hairy caterpillar
Termite	Termite	

Virus Vectors

Insect pests may be important because of both the direct damage they do and their role in transmission of virus diseases. For instance, sap sucking by the groundnut aphid, *Aphis craccivora*, can cause severe damage or even death to young plants, particularly when large populations build up during early season droughts. However, of much greater economic importance is the spread of peanut mottle virus worldwide and groundnut rosette virus in Africa by these aphids. Similarly, thrips are more important as vectors of tomato spotted wilt virus in India than they are as direct foliage-feeding pests.

At ICRISAT the entomology research emphasis has been to effectively combine cultural practices and host plant resistance to develop integrated pest management systems.

For management of bud necrosis disease it was necessary to understand the epidemiology of the disease. Factors influencing buildup and migration of the vector thrips and associated spread of the disease were investigated. *Frankliniella schultzei* was identified as the major vector. It was found that by

- early sowing,
- close plant spacing,
- intercropping groundnuts with pearl millet, and
- use of the high-yielding virus susceptible but "field resistant" cultivar Robut 33-1,

the incidence of bud necrosis disease could be reduced by 90-95%, and yields increased by 15-20 times. Although Robut 33-1 shows 50-80% lower field incidence of bud necrosis disease than commonly grown cultivars such as TMV-2, it is equally susceptible to the virus. Even lower field incidence of the disease has been recorded for progeny of the cross Robut 33-1 × NC Ac 2214. This line and similarly promising lines have been used in the resistance breeding program.

Field Pests

The effects of cultural practices on the incidence of other important pests are being studied with particular attention being given to the effects of intercropping. The high-yielding and multiple pest-resistant genotype NC Ac 343 has been used in developing a breeding line with good resistance to thrips, jassids, and termites.

Breeding for Pest Resistance

Breeding for pest resistance was started in 1980 to combine resistance to leafhoppers, thrips, and termites into high-yielding genotypes. An extensive hybridization program was initiated and a large number of single and multiple crosses were made using NC Ac 2214, NC Ac 2232, NC Ac 2240, NC Ac 2242, NC Ac 2243, NC Ac 2230, NC Ac 1705, NC Ac 343, NC Ac 16940, and NC Ac 785 as sources of resistance to thrips, leafhoppers, and termites. The materials from these crosses are in different generations and are subjected to both natural and artificial infestation under field and laboratory conditions. Thrips populations are abundant in rainy and postrainy seasons, and material is screened in both seasons under natural field conditions. However, the leafhopper population in the postrainy season is very low and screening for resistance to this insect is done mainly during the rainy season. If natural leafhopper populations are too low, laboratory bred insects are released on the test material to ensure sufficient pest pressure.

Based on the amount of damage to the leaf at the time of maximum infestation, progenies resistant or tolerant to thrips and leafhoppers are selected for advancing. Through repeated testing and selection, several high-yielding progenies have been developed which have good resistance to thrips and leafhoppers (Table 4). The segregating material from crosses using lines such as NC Ac 343, NC Ac 2242, and NC Ac 1705, which are resistant to pod-scarifying termites, was screened for termite resistance in termite infested fields. Some termite resistant progenies were identified and further tests are in progress to confirm their resistance.

Observations indicate that presence of trichomes and thick leathery and waxy leaves were associated with leafhopper resistance in groundnut. The genetics of the different resistance mechanisms is under investigation.

Since it is suspected that insect resistance and high yield are negatively correlated, a two-stage breeding strategy is being followed to overcome this undesirable linkage. In the first stage, high-yielding lines with moderate resistance levels are developed, then in the second stage these lines are intermated to increase the levels of resistance to various insects. Intermating of early generation selections made on the basis of pest damage and/or on the basis of morphological traits such as thick leathery and waxy leaves with or without trichomes should increase the favorable genes for resistance.

Drought

Drought research is conducted mainly in the postrainy season because of lack of water control in the

Table 4. Some high yielding pest-resistant breeding lines.

High-yielding pest-resistant breeding lines	Pod yield (kg/ha)	
	High input	Low input
Manfredi 68 x NC Ac 343 (F7)	2604	1236
(Gangapuri x MK 374) x (Robut 33-1 x NC Ac 2214) (F7)	2583	1212
Robut 33-1 x NC Ac 343 (F9)	2536	1500
28-206 x NC Ac 10247 (F7)	2286	1361
Robut 33-1 x NC Ac 2214 (F7)	2286	1360
Robut 33-1 (Check)	2106	1149
NC Ac 343 (Check)	2020	1201
JL 24 (Check)	1552	531
J 11 (Check)	1627	430
SE ±	10.6	10.9
Mean (44 breeding lines)	1836	882
CV %	11.0	23.0

rainy season. Two simultaneous efforts have been made in drought research. One has been to develop a method to screen germplasm and breeders' lines, and to screen as much material as possible. The second has concentrated on examining in detail the physiological responses of groundnuts to drought stress, the factors which determine the use of water, water use efficiency, and the physical and physiological basis for genetic differences in drought responses.

The Physiology Subprogram has cooperated with other groups both within and outside ICRISAT. These collaborative efforts have been very fruitful and have accelerated progress by utilizing an expanded resource base to study the problem.

Drought Screening

Drought screening began in the 1980/81 postrainy season with a small range of treatments applied to 80 genotypes. Drought stress was induced at different stages in crop development but only two levels of stress were imposed: full irrigation for a control treatment and no irrigation for a dry treatment. Lines with 'tolerance' to drought were identified and the hypothesis that time of stress x genotype interactions existed was confirmed. Variability was substantial and an unexpected aspect of drought added a confounding factor because the crop was irrigated to facilitate harvest and one replicate was harvested each day. On the second day of lifting, pod rots were prominent and on the third day most pods had rotted. This observation is being exploited by the pathologists to improve their screening methods for pod rots resistance. Screening for drought resistance has been modified to overcome this factor.

In 1981/82 line source irrigation was used to create six levels of water application in each of four drought timings. Drought timings were selected to simulate the most commonly occurring droughts of the SAT and see if genetic variability existed in responses to them. One set of treatments represented variations of midseason drought, another set represented early drought, and a third represented environments where rainfall is always less than potential evaporation.

Lines from this screening were tested at Anantapur, a site in India where drought commonly occurs, and two of them were found to be significantly better than the local check cultivars (TMV-2 and Robut 33-1). In a season with no rainfall for 63 days after sowing and a total during the crop's life of only 220 mm, yields of 1.15 t/ha were produced.

In 1982/83 a drought screening evaluation of 25 lines selected from the previous drought screening used 12 patterns of drought stress, each with eight intensities of stress. These treatments were designed to examine the genetic variability and interactions of genotypes to multiple droughts, and variable durations and timings of drought. The trial provided 96 treatments differing mainly in the water component of the environment (temperature, photoperiod, and most other aspects of the environment were constant). The results of this trial are still being analyzed but preliminary analysis indicates that early stress definitely provides adaptive advantages in the event of a second drought at a later stage. Long droughts with occasional short periods of good water relations do not change the nature of the basic response to that drought pattern.

Lines have been identified from these trials which have consistently yielded better under drought than other cultivars.

Drought Physiology Studies

These have been conducted to investigate the effects of

- drought intensity and time,
- plant population on water use and development of drought, and
- timing of stress on the drought recovery responses.

Research on the effects of timing of stress has shown that early stress can increase yield by 14-30% and that for Robut 33-1 late stress has a much greater impact on yield than midseason stress. For water management and efficiency, irrigation management to withhold water early and apply evenly deficient amounts during pod growth was better than utilizing the available water early, leaving no irrigation at later stages.

Investigations of population effects on water use and the development of drought stress have provided basic information on the development of root growth, leaf area development, stomatal resistance, and the interrelationship of these factors.

The detailed comparision of different genotypes in droughts utilized four contrasting genotypes identified by drought screening. Differences in water-use efficiency between drought tolerant and susceptible lines were demonstrated. Major differences in reproductive development during and after the drought were the reasons for differential performance.

Nutrient Stress

Biological Nitrogen Fixation

Although most cultivated soils of the tropics contain large populations of *Rhizobium* bacteria capable of forming nodules with groundnut cultivars, and although the groundnut is an efficient fixer of nitrogen, there is potential to increase nitrogen fixation by manipulation of *Rhizobium* strain, host genotype, and environment, as well as their interactions.

Inoculation with Rhizobium

There are several reports of *Rhizobium* inoculation increasing groundnut yields in fields where the crop had not previously been grown. In trials at ICRISAT Center over the past seven years, inoculation of groundnut genotypes with a very effective strain of *Rhizobium* increased nitrogen fixation and pod yield when the crops were grown in fields well populated with effective strains of *Rhizobium* (Table 5). The *Rhizobium* strain NC 92 was very efficient, particularly when in symbiosis with cultivar Robut 33-1. Field inoculation trials at ICRISAT Center with this strain and cultivar increased yields by 18-34% while a similar trial at Dharwad in Karnataka State resulted in a 40% yield increase. Strain NC 92 was also very effective in combination with several other genotypes.

Method of inoculum application was important. Because groundnut seeds are fragile, direct application of *Rhizobium* inoculum can cause significant damage and actually decrease yields. It was better to apply the inoculum directly to the soil by the easy and cheap method of mixing peat containing *Rhizobium* with water and pouring the mixture into the furrow just before sowing the seed. This method also effectively reduces incompatibility problems of *Rhizobium* inoculum and fungicide seed protectants. An animal drawn seed planter has been modified for direct application of *Rhizobium* inoculum to the soil.

Studies of inoculum concentration indicated that a minimum of 10^6 rhizobia per seed was needed for good nodulation. Studies with strain NC 92 have shown that inoculation for a few years may be sufficient to establish a good soil population of a desired *Rhizobium* strain. This work was made possible by the use of enzyme linked immunosorbent assay (ELISA) for identifying *Rhizobium* strains in nodules.

Improving Host Genotypes

Over the past five years many germplasm lines were screened for nitrogen fixing ability. In general, the spanish types were found to fix less nitrogen than the virginia types, however, one spanish line, x-14-4-B-19-B, showed high nitrogenase activity and will be used in the breeding program to increase the nitrogen fixation of spanish types. The virginia line, NC Ac 2821 showed high nitrogenase activity and some progenies of this line were high yielding. This suggests that it may be possible to increase yield potential by incorporating high nitrogen fixing lines in the breeding program. Inciden-

Table 5. Summary of responses of cv Robut 33-1 to inoculation with *Rhizobium* strain NC 92.

Season trials	Pod yield (kg/ha) Uninoculated	Inoculated with NC 92	SE ±
Postrainy (1978/79)	3500	4500	291.2
Rainy (1979)	870	1160	24.3
Postrainy (1979/80)	4280	4400	104.7
Rainy (1980)	1350	1640	77.4
Postrainy (1980/81)	3210	3300	78.8
Rainy season (Site 1) (1981)	2350	2760	187.8
Rainy season (Site 2) (1981)	1100	1160	34.5
Rainy season (Site 3) (1981)	1530	2150	176.5
Mean	2274	2634	56.3

tally, this line also showed high nitrogenase activity when tested in fields in North Carolina, USA (Wynne, J.C. personal communication).

Nitrogen Fixation as Affected by Agronomic Practices

In collaboration with the Cropping Systems Program the effects of intercropping on nodulation and nitrogen fixation of groundnut were studied. Groundnut, when intercropped with nitrogen fertilized millet, maize, or sorghum, fixed less nitrogen than as a sole crop. This suggests that high nitrogen input on the cereal component reduces the advantage of the nitrogen fixation ability of groundnut.

Many farmers practice deep sowing to make use of residual moisture for germination. This results in the development of an elongated hypocotyl, poor nodulation, and reduced nitrogen fixation, especially in spanish cultivars. Most spanish types lack the ability to nodulate on the hypocotyl. Hypocotyl nodulation contributes substantially to the nitrogen fixation of the deep-sown crop. For example, in a deep-sown virginia cultivar, Kadiri 71-1, hypocotyl nodules contributed around 50% of the nitrogenase activity at 70 days after planting. Hypocotyl nodulation in spanish types could be beneficial where deep sowing is practised.

Measurement of Nitrogen Fixation

Nitrogen fixation was measured by estimating nitrogenase activity assayed by acetylene reduction, by nitrogen balance methods using nonnodulating groundnut, and by an isotope dilution technique using ^{15}N labeled fertilizer.

There is a marked diurnal variation in nitrogenase activity of field-grown groundnuts. Soil moisture, temperature, and light intensity also influence nitrogen fixation. Intercropping has a marked effect on groundnut nitrogen fixation.

During the 1978 rainy season some F_2 progenies in a rust screening nursery segregated for nonnodulation. Some of these have been purified to obtain nonnodulating lines. Nitrogen fixation was estimated as the difference in nitrogen uptake of the parental lines and nonnodulating lines. Values ranged from 67-145 kg/ha N. The nonnodulating line utilizes soil nitrogen poorly, and the yield, even when supplied with 400 kg/ha N, was not equivalent to that of the nodulating crop grown without nitrogen fertilizer.

The 'A' value method of Fried and Broeshart (1975) was used to estimate nitrogen fixation using ^{15}N labeled ammonium sulphate and nonnodulating groundnut as the nonfixing control. A maize crop was grown in the previous season to deplete and even out soil nitrogen available for the groundnut crop. Estimates of nitrogen fixation ranged from 153 kg/ha N in Robut 33-1 to 100 kg/ha N in J-11.

Calcium Nutrition Research

Calcium deficiency is a major limiting factor for groundnut production in many parts of the world and gypsum application has been recommended for most areas.

Research was initiated to investigate reported genetic differences in calcium uptake 'efficiency' of pods of different genotypes. The work concentrated on the interactions of drought, gypsum, and genotype.

Consistent and significant genotype × drought × gypsum interactions were demonstrated in a series of three experiments. Gypsum applied at 500 kg/ha increased yields of groundnuts in droughts by as much as 30% in selected genotypes by enhancing early pod initiation and thus providing (or inducing) a drought 'escape' mechanism.

Development of Genotypes with Specific Attributes

High Yield and Quality

As an attempt to stabilize production over years and locations, breeding for resistance to various constraints has had the highest priority. But breeding for yield per se is also important, particularly for areas without constraints or where progressive farmers can afford inputs such as pesticides and fungicides. High-yielding lines are also needed in the constraint-based breeding programs and to counteract the rising cultivation costs.

Advanced breeding populations are evaluated in two different seasons at ICRISAT Center. In the rainy season they are evaluated under two management levels: high input (60 kg/ha of P_2O_5 with supplementary irrigation and insecticidal sprays when required) and low input (20 kg/ha P_2O_5 rainfed with no insecticidal sprays), but under high input only in the postrainy season. Very mild selection for yield is practiced in the early generations, but in later generations pod shape and seed size are also used as selection criteria. Most of the material is bulked into uniform groups for further evaluation and selection by cooperators in national programs.

Several high-yielding lines with acceptable pod and seed characteristics and a good shelling percentage have been developed. Based on consistently good performance, 62 lines have been entered in national trials in India.

In the early years of the program cultivars that yielded well in the rainy season did not necessarily yield well in the postrainy season and vice versa, indicating a strong genotype × environment interaction. It was therefore decided to make selections in the postrainy season to develop cultivars suitable for postrainy season irrigated cultivation. Several high-yielding lines suitable for this purpose have now been developed. Lines ICGS 30 and 21 have yielded over 6500 kg/ha of pods, which compares well with the 5500 kg/ha of the check cultivars J 11 and Robut 33-1 (Table 6).

High-yielding lines suitable for rainy season use have also been developed. ICGS 50, 30, and 1 did well under both low input and high input conditions at ICRISAT Center and several are under test in Indian national trials.

The research on quality has concentrated on oil content. The oil contents of 35 ICGS lines ranged from 42-50%, while protein was between 22 and 33%. Several lines have higher oil and protein content than the standard check cultivars J 11 and Robut 33-1.

Table 6. Performance of some high yielding ICRISAT selections during postrainy season trials at ICRISAT Center.

	Pod yield (kg/ha)	
Entry	1981/82	1982/83
ICGS 30	6600	7340
ICGS 21	6500	7040
ICGS 26	6430	6280
ICGS 16	6420	6550
ICGS 25	6300	6950
ICGS 23	6240	6680
ICGS 37	6150	7230
ICGS 35	6060	6770
ICGS 44	6060	6860
J 11 (Check)	5440	5440
JL 24 (Check)	4760	3360
Robut 33-1 (Check)	5450	6180
SE ±	289	297
CV (%)	10	10

Earliness and Dormancy

In the SAT, growing seasons can be very short because rains stop early. Earliness combined with good seed size and yield would provide stable production in poor rainfall years. Efforts are in progress to identify early-maturing groundnuts and to breed for increased yields. Use of early-maturing groundnuts increases the probability of rain on the crop at or after maturity, so it is necessary for early-maturing cultivars to have fresh seed dormancy.

In the initial years of this research two early spanish types (Chico and 91176) and a mid-early virginia line (Robut 33-1) were crossed with other high-yielding bunch and runner types. Recently I No. 95A, TG 1E, and TG 2E were identified as new sources of earliness and used extensively in crosses. Several hundred crosses have yielded selections for earliness and high yield, as well as lines with uniform plant growth habit, maturity, and pod and seed characters. Useful high-yielding early-maturing material has been generated. Results of a 1982 rainy season trial are presented in Table 7. Currently, 63 early progenies are undergoing yield testing in three different trials at ICRISAT Center. Twenty new early flowering lines have been identified from germplasm and will be used in the crossing program.

Seed dormancy has been difficult to introduce because of its almost complete absence from spanish bunch types. However, dormancy screening methods have been evolved and several early-maturing, dormant lines have been identified from within populations derived from early nondormant types crossed with dormant long-season types.

Photoperiod Studies

Photoperiod studies have been made possible by GTZ support to the University of Bonn for collaboration with ICRISAT on this aspect of groundnut physiology.

Although photoperiod effects had been discounted as a major factor in the adaptation of groundnuts, the work was initiated because phytotron studies at North Carolina State University showed (in unrealistic daylengths) that major changes in reproductive development could result from daylength changes.

Table 7. Performance of early-maturing groundnut selections, ICRISAT Center, 1982 rainy season.

Entry	Days to flowering	Days to maturity	Pod yield (kg/ha)
(Ah 330 x 91176) F5-B1	18	93	2440
(NC Ac 2748 x Chico) F10B1	22	101	2120
(72-R x Chico) F9B [1]	23	104	2130
(JH 89 x Chico) F9B	23	92	2000
(Chico x NC 344) F5	19	91	1980
Chico[1]	20	91	1780
J 11[2]	27	104	1920
JL 24[2]	27	108	2190
SE ±	0.6	1.4	116
CV (%)	5	3	13

1. Early maturity parent
2. National check cultivars

The ICRISAT objective was to establish the significance of photoperiods to groundnut yields within daylength ranges which occur in actual cropping environments. After preliminary experiments to examine the light intensity necessary to induce photoperiod effects, experiments were conducted under field conditions. Six genotypes were studied in long days (16 hours), and short days (11-12 hours), and large yield changes were observed for some cultivars. In some cultivars yield could be decreased by 50% by long days, while in others, long days resulted in slight yield increases. At present research is continuing in this field in order to develop a reliable method of screening.

Utilization of Wild *Arachis* Species

There are an unknown number of wild species of *Arachis*. Those that have been collected are maintained in major living collections in Brazil, USA, and at ICRISAT. There are about 100 accessions at ICRISAT; some are named species, others are collections whose identity and taxonomic status are not yet known.

All these accessions are screened for desirable characters as soon as possible after release from quarantine. Emphasis has been placed on disease resistance, especially resistance to leafspots and other diseases where resistance has not been found within *A. hypogaea*.

Not all resistances can be transferred. The most accessible genes are those in species closely related to *A. hypogaea*. These species are in the section *Arachis*, and can be crossed with *A. hypogaea* by conventional means, but the hybrids produced are partially or completely sterile. Species outside the section *Arachis* cannot be crossed with *A. hypogaea* by conventional means. Some intersectional hybrids have been produced in the USA, and their potential in bridge crosses explored, but with no success. All sections other than *Arachis* are therefore effectively isolated from *A. hypogaea*, but some accessions have characters that are of prime importance in groundnut improvment, such as resistance to viruses.

The emphasis in cytogenetics has therefore been on three fronts

- to overcome the problems of gene transfer associated with sterility in section *Arachis* hybrids,
- to overcome intersectional barriers, and
- to develop the basic knowledge of the genomic constitution of the genus and the relationship between groundnut and potential gene sources.

The sterility in crosses within the section *Arachis* has been successfully overcome by ploidy manipulations. The initial hybrids were triploids. Chromosome doubling produced hexaploids, but subsequent backcrossing produced an unacceptable range of plant types, many of which were sterile.

Doubling the chromosome number of the wild species to produce autotetraploids or amphiploids, followed by crossing with *A. hypogaea* at the tetraploid level, produces a wide range of segregants with disease resistance and acceptable plant types. These segregants have arisen by backcrossing selections with *A. hypogaea* to allow chromosome segregation and meiotic recombination to take place. The latter is especially important for elimination of undesirable characters. Cytogenetic analyses of chromosome complements of the newest collections indicate the presence of new genomes in the section *Arachis*. These genomes may not recombine meiotically with *A. hypogaea* chromosomes (those from other sections almost certainly will not) and the elimination of undesirable characters will be impossible. In the meantime, we have made progress in using some wild species as sources of desirable characters, and have selected *A. hypogaea*-like lines with disease resistance, acceptable plant characters, and good yield.

Considerable progress has been made in overcoming barriers to intersectional hybridization. The major advance has been in the use of a simple technique to apply growth hormones to the flower at pollination time and at intervals thereafter. Careful attention to concentration, types, timing, and application sequence of hormones has enabled the development of ovules, which would otherwise degenerate, to the stage at which they can be successfully transferred to in vitro culture.

Tissue culture technology has been applied to the culture of young ovules from wide crosses. These grow successfully in culture, and develop roots and shoots but are difficult to transfer to soil. Most cultures have been of crosses between sections *Arachis* and *Rhizomatosae*, but other intersectional crosses have also been transferred to culture. The current emphasis is to investigate the causes for the difficulty in transferring cultures to soil.

The Future

We hope that over the next few years we can expand our cooperative efforts to Southeast Asia and West Africa by placing scientists or coordinators in these regions. This will enable us to better identify materials adapted to regional geographical areas. Materials developed at the ICRISAT Center in India will continue to be fed into the regional and national programs. While much of the material may be directly useable, other materials will have to be modified by crossing with locally adapted materials. Specific problems will also be identified in the regional programs where intensive work can only take place in situ because they are locale specific, e.g., bacterial wilt and witches' broom in Southeast Asia.

Our policy of supplying early generation breeding materials will also continue. This will give breeders and others the chance to select adapted material and advance it under their own agroclimatic conditions. This policy is already succeeding in India. Several cultivars which originated from ICRISAT crosses are now being entered national breeders into national or state trials.

References

Demski, J.W., Reddy, D.V.R., and Sowell, C., Jr. 1984. Peanut stripe, a new virus disease of peanut. Phytopathology 74:627. (Abstract.)

Fried, M., and Broeshart, H. 1975. An independent measure of the amount of nitrogen fixed by a legume crop. Plant and Soil 43:701-711.

Gibbons, R.W. 1977. Groundnut rosette virus. Pages 19-21 *in* Diseases, pests and weeds in tropical crops (Kranz, J., Schmutterer, H., and Koch, W., eds.). Berlin, Federal Republic of Germany: Verlag Paul Parey.

Gibbons, R.W. 1982. Registration of peanut germplasms Tifrust-1 to Tifrust-4 (Reg. No. GP18 to GP21). Crop Science 22:453.

Gillier, P. 1978. [New horizons for the growing of groundnuts resistant to drought and rosette disease.] Nouvelles limites des cultures d'arachides résistantes à la sécheresse et à la rosette. (In Fr. Summary in En.). Oléagineux 33:25-28.

Hammons, R.O., Branch, W.D., Bromfield, K.R., Subrahmanyam, P., Rao, V.R., Nigam, S.N., Gibbons, R.W., and Goldin, E. 1982a. Registration of Tifrust-13 peanut germplasm (Reg. No. GP30). Crop Science 22:697.

Hammons, R.O., Subrahmanyam, P., Rao, V.R., Nigam, S.N., and Gibbons, R.W. 1982b. Registration of peanut germplasms Tifrust-1 to Tifrust-4 (Reg. No. GP18 to GP21). Crop Science 22:453.

Hammons, R.O., Branch, W.D., Bromfield, K.R., Subrahmanyam, P., Rao, V.R., Nigam, S.N., and Gibbons, R.W. 1982c. Registration of Tifrust-14 peanut germplasm (Reg. No. GP 31). Crop Science 22:697-698.

Harkness, C. 1977 The breeding and selection of groundnut varieties for resistance to rosette virus disease in Nigeria Report submitted to African Groundnut Council

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1982 Annual report 1981 Patancheru. A P 502 324. India ICRISAT

Mehan, V.K., McDonald, D., Nigam, S.N., and Lalitha, B. 1981 Groundnut cultivars with seed resistant to invasion by *Aspergillus flavus* Oléagineux 36 501-507

Mehan, V.K., and McDonald, D. 1984 Research on the aflatoxin problem in groundnut at ICRISAT Plant and Soil 79 255-260

Rai, K. 1976 Pests of oilseed crops in India and their control New Delhi, India Indian Council of Agricultural Research 121 pp

Discussion on Paper on the ICRISAT Groundnut Program

Taylor: Who grows minikit and other evaluation trials in India?

McDonald: Groundnut varietal evaluation is organized by the All India Coordinated Project on Oilseeds (AICORPO), a central government body, and trials are conducted in different zones of the country by State Research Institutes, Agricultural Universities, etc. Some AICORPO trials are carried out at ICRISAT Center.

Doto: Does ICRISAT Center offer a facility for identifying diseases on plant materials sent from countries outside India?

McDonald: No. Plant Quarantine regulations prevent us from importing diseased materials. However, we do make available antisera for identification of disease caused by viruses, and if funds were available we could assist other countries by sending specialist staff to cooperate in disease surveys. We are currently preparing information bulletins on important diseases.

Simons: Bud necrosis and other diseases occur at the same time. How do you arrive at a figure for yield loss from bud necrosis and other diseases and how reliable are the loss estimates?

McDonald: The severity of bud necrosis disease at ICRISAT Center can vary a great deal from season-to-season, from negligible to over 70%. Accurate loss estimates can be made by tagging diseased plants and measuring yield from healthy and diseased plants separately. Other diseases show much less seasonal variation, for instance rust and late leaf spot diseases regularly cause yield losses of around 70% on susceptible cultivars at ICRISAT Center in the rainy season.