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Groundnut Improvement Research Technology for the Semi-Arid Tropics

by

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Abstract

Groundnuts are one of the most important legume crops of the semi-arid tropics (SAT) and serve as a source of food, cooking oil and a cash income. Yields, however, are low in the SAT due mainly to losses caused by pests, diseases, and unreliable rainfall patterns. The main emphasis of the program is to produce high-yielding breeding material with stable resistance to the major pathogens which include rust, leaf spots, and Aspergillus flavus. *Viruses and insect pests also cause large yield reductions, and sources of resistance are being sought. Large-scale breeding programs are under way and early and advanced segregating populations are being distributed to cooperating national breeders. Efforts are being made to improve the nitrogen-fixing capacity of groundnuts. Yield advantages are being achieved by intercropping groundnuts with pearl millet. Wild* Arachis *species are being exploited for sources of useful genes.*

Groundnuts became the fifth ICRISAT mandate crop in 1976, some four years after the Institute was created. In 1974, a team of four consultants was invited to Hyderabad to review the world research needs of groundnuts, to consider whether ICRISAT ought to help meet those needs and, if so, to suggest a possible program of international research. It was concluded that the crop required international research; it would be an appropriate subject within the mandates of the international agricultural research system, and ICRISAT was the appropriate center as groundnuts are primarily a crop of the semi-arid tropics (Bunting *et al.* 1974). In mid-1976 a detailed plan of research was accepted by the Governing Board of ICRISAT (Gibbons 1976) and breeding, germplasm, pathology, and microbiology programs commenced. Since then entomology, cytogenetics, and some preliminary physiology projects have commenced.

Groundnuts in World Agriculture

Production

The cultivated groundnut, *Arachis hypogaea* L., originated in South America and is now grown on a commercial scale in some 82 countries. In 1976, it was estimated that 19 million hectares were planted and over 18 million tons were harvested at an average yield in shell of 958 kg/ha (FAO Trade Statistics). The limits of present commercial production are within the latitudes 40°N and 40°S. Asia is the largest producer (10.3 million tons), followed by Africa (5.4 million tons), North and Central America (1.8 million tons), South America (0.9 million tons), Oceania (0.29 million tons) and Europe (0.24 million tons). The largest individual producer is India, which in 1976 produced 5.7 million tons of groundnuts in shell from 7 million hectares of land. Large-scale producing countries in Africa are Nigeria, Senegal and Sudan. Approximately 70 percent of world production comes from the developing countries, many of which lie in the semi-arid tropics.

Adaptation

Groundnuts are generally considered to be a day neutral plant, although Wynne *et al.* (1973) have suggested that sensitivity to daylength depends on temperature. The relative insensitivity to daylength means that cultivars developed anywhere in the world can be evaluated at any latitude where favorable growing conditions exist (Varnell and McCloud 1975). Although the ideal soil for groundnuts has been defined (York and Colwell 1951) as a well-drained, light-colored, loose and friable sandy loam which is well supplied with calcium and organic matter, they are grown in practice on a variety of soils which vary from alkaline to acid, and from clays to fine sands.

Generally under rainfed conditions, where supplemental water is not available, the choice of cultivar depends on the length of growing season available. Where season length is limiting, cultivars of *A. hypogaea* subsp. *fastigiata* (Spanish and Valencia) are grown; where the rainy season is longer, cultivars belonging to subsp. *hypogaea* (Virginia) are selected. Maturation also depends on temperature, radiant energy, and elevation. In the West African lowlands for example, Valencia and Spanish types

may mature in 90 days whereas in the Central African plateau areas, which are 1200 meters above sea level, development can take 120 days. Similarly, Virginia cultivars may take only 120 days to mature in West Africa and 150 to 160 days in Central Africa (Smartt 1976).

Uses

Groundnut is the most important legume crop of the semi-arid tropics (Table 1). With 25 percent protein and approximately 50 percent oil, groundnut is also an important food crop in the SAT and, after soybean and cottonseed, is the most important source of edible oil in the world. To the subsistence farmer, it may be considered as another pulse crop and consumed at home; but as a cash crop it may be considered too valuable to consume and the total crop is sold (Smartt 1976). It is estimated that about 66 percent of the total world production is crushed for oil (Woodroof 1973). Traditional SAT exporters of groundnuts for crushing are Nigeria and Senegal, but there is a trend for local oil expressors to be built and the suplus oil exported (Smartt 1976). Nigeria now has a capacity to crush 0.8 million tons of groundnuts annually (Harkness *et al.* 1976).

The export of kernels, or unshelled pods, for confectionary purposes is also an important source of revenue for countries in the SAT. The traditional main sources of confectionary groundnuts are China, India, and the USA, although the export performances of China and India have been erratic due to large domestic demands. A number of African countries in the SAT--including Malawi, Nigeria and the Sudan--each supply about 10 percent of the total world confectionary groundnuts (Wilson 1975).

Groundnut hay is used extensively in the SAT as cattle feed and can command high prices, particularly in urban areas, for stallfed cattle (Harkness and Dadirep 1978). The shells may be used as a fuel, as a soil conditioner, in cattle feed, and as a source of building material and organic chemicals (Patil 1964).

Production Constraints in the SAT

Yields in the SAT are low, around 800 kg/ha, compared to yields of around 3000 kg/ha--or even higher in localized areas--in the developed world (Gibbons 1977). The major

Table 1. Semi-arid tropical production of food legumes (1971)

('000 tons)

Region of semi-arid tropics	Legume crop					
	Dry beans	Soybeans	Chickpeas	Cowpeas	Pigeonpeas	Groundnuts
Asia	2265	1228	5770	10	1910	6977
Africa	613	65	205	1069	51	3847
Central and South America	3441	2227	173	-	26	1459
Total: Semi-arid tropics	6319	3520	5948	1079	1987	12242
Total: World	11073	48457	6594	1195	2024	18211

Source: FAO Production Yearbook 1972, Rome, Italy (vide Bunting *et al.* 1974)

constraints are pests, diseases, and the unreliable rainfall patterns of the SAT. Certain pests and diseases are worldwide in their distribution and are being studied intensively as part of the ICRISAT research program.

Apart from the natural hazards which restrict production, there are relatively small numbers of groundnut researchers who are available to combat these hazards. Few programs have been mounted to actively breed for resistance to these pests and diseases, which annually cause serious reductions in yield potential. Without the means to control these pests and diseases, the small-scale farmers of the SAT desperately need sources of resistant material which will allow reasonable stable yields of groundnuts to be harvested. Once the farmers have this material they will become much more amenable to adopting other improved farming practices. Many farmers have become discouraged because they know that even with good agronomy and much hard work the natural hazards of pests, diseases, and drought will still ravage their groundnut crop.

Objectives of the ICRISAT Groundnut Program

The main objective of the program is to produce high-yielding breeding lines with resistance to the main factors presently limiting production. Stability of yield is important over years and across sites. However, because of the diversity of groundnut environments, and the uses to which the crop is put (oil crushing or confectionary), it is not possible to foresee the use of relatively few cultivars over very wide areas; nor is it desirable to flood whole areas with single, or closely related, cultivars because of the dangers of genetic vulnerability (Hammons 1972). Requirements vary greatly, even within a country. For example, in the Sudan, large-seeded, long-season groundnuts are grown under irrigation in Wad Medani for export; but under rainfed conditions, small farmers cultivate short-season cultivars which are more adapted to these conditions (Osman 1978). In Malawi, long-season groundnuts, primarily for the confectionary export trade, are grown on the plateau areas; oil-crushing cultivars are grown on the lakeshore; and short-season cultivars are adapted in the low elevation, drier and hotter areas of the Shire Valley (Gibbons 1972).

Research Organization

Although the groundnut research program is divided into subprograms of breeding, cytogenetics, pathology, entomology, physiology, and microbiology the relationship between these groups is close and fully integrated. Similarly, there are close ties with other ICRISAT programs which are concerned with groundnut research. These research programs include the Genetic Resources Unit, and Farming Systems Research, as well as the Training Unit.

As the program is still young, no formal outreach programs have yet been formulated although they have been planned (McGinnis 1979). Linkages with national programs, overseas institutions and individual scientists are being evolved and will be discussed under the individual research technology approaches.

Germplasm Base

ICRISAT has been designated as a world center for the collection, preservation and documentation of the genus *Arachis* by the International Board of Plant Genetic Resources (IBPGR). Since the inception of the Genetic Resources Unit in January 1979 all staff and materials have been transferred to this unit. In September 1979, an *ad hoc* working party consisting of experienced groundnut scientists representing different areas of the world will meet at ICRISAT under the auspices of IBPGR, to :-

(i) assess the present known collections of germplasm, their geographical representation and adequacy.

(ii) identify priority areas for collecting material.

(iii) explore quarantine problems and obstacles.

(iv) draw up a list of essential descriptors and descriptor states for characterization of accessions.

Much anticipatory work has been done by the groundnut germplasm botanist at ICRISAT.

Acquisition and Quarantine Procedures

After three years our groundnut accessions now total over 7,000 entries (Table 2).

Table 2. Accessions of groundnut germplasm at ICRISAT.

Year	Accessions received during the year	Total accessions
1976	2443	2443
1977	3565	6008
1978	925	6933
1979*	79	7012

* To end of February only.

Initially, in 1976 and 1977 we received very close cooperation from Indian research centers who handed over to us duplicates of their entire collections. These collections consisted of both exotic and local accessions. The importation of exotic material also commenced in 1976 and accelerated over the subsequent two years. Because of the danger of seed-borne viruses in groundnut the plant quarantine arrangements were fully discussed and agreed with the Government of India. The present arrangements are as follows. Small quantities of seed are received at the Central Plant Protection Training Institute (CPPTI), at Rajendranagar, near Hyderabad. They are examined by quarantine officials and apparently healthy seeds are grown in 80 mesh screenhouses; the plants are examined regularly for up to 6 or 8 weeks. Plants showing any suspicion of disease are destroyed. The healthy plants are then transferred to the post-entry quarantine area at ICRISAT Center, Patancheru, and are again monitored on a weekly basis by CPPTI quarantine staff. Only at maturity are the seeds then released to us from the healthy plants. Any diseased plants are uprooted and burned. Although the procedures are stringent,

and the release of exotic material is slow, we feel that they are necessary to prevent any introduction of new diseases into India.

Maintenance, Multiplication and Evaluation

After release from quarantine the initial multiplication of material takes place on the ICRISAT farm under optimal conditions, including assured irrigation. Apart from germplasm personnel who record a wide range of plant characters, other scientists from the program regularly visit these plots and assess other characters such as reaction to pests and diseases, as well as nodulation capacity and yield potential. New sources of resistance to rust (*Puccinia arachidis*) and insect pests such as thrips and jassids have already been identified from the germplasm collection. Long, medium and short-term storage facilities are being developed but the active exploitation of a dynamic, working collection is emphasized.

Dissemination of Germplasm

Germplasm has been distributed to many countries and these requests are becoming more frequent. Some requests are for specific material and others are for large collections to initiate new research programs. Up to April 1979 nearly 3,500 accessions had been dispatched to cooperators.

Collection

Although the *ad hoc* working group will decide collecting priorities in September, five ICRISAT groundnut-collecting trips have been made in India. An expedition to Malawi, mainly for cereal germplasm, also collected groundnut samples during this year. The groundnut germplasm botanist is currently collecting in Somalia. Earlier this year a groundnut breeder accompanied an IBPGR expedition to South America to collect wild *Arachis* species and primitive landraces. Collaboration also takes place with other international institutes. The germplasm unit of the International Institute of Tropical Agriculture, in Nigeria, has collected groundnuts for us in West Africa and we have collected one of their mandate crops, cowpeas, for them in India.

Documentation

Groundnut germplasm catalogs from 11 institutes in 9 countries have been received. All known accessions of wild *Arachis* species have been entered into the computer and this data will be constantly updated. The printout will serve as a newsletter to scientists involved in their study on worldwide basis. A paper entitled 'Development of a descriptive language for groundnut (*A. hypogaea*)' has been jointly prepared by ICRISAT scientists and staff of the Information Sciences/Genetic Resources Program of the University of Colorado, USA. This paper will be discussed by the *ad hoc* working group in September.

We consider that the germplasm program is the base of the research program and technology being developed.

Integrated Research Technology

Some of the research approaches to solve the major problems restricting good yields are discussed below:

Disease Resistance

Rust

Rust of groundnuts, caused by the fungus *Puccinia arachidis* Speg., has become a worldwide problem since 1969 (Subrahmanyam *et al.* 1979). Although this disease can be controlled by certain fungicides, they are costly and are not readily available to small-scale farmers in the SAT. At ICRISAT the germplasm collection was thoroughly screened for additional sources of resistance to the cultivars already reported in the literature to be resistant (Table 3). New sources were found and are listed in Table 4. In a cooperative program all the previously reported sources of resistance, which had been assembled in Georgia, USA, have been transferred here and, together with the new sources, they will be jointly assessed by USDA and ICRISAT scientists later this year. With an assured inoculum at Patancheru, suitable screening techniques have been evolved. Known susceptible cultivars are sown systematically through the test fields and infected with rust uredospores. Spreader plants, already infected with rust, are also placed systematically through the field. During the postrainy season further screening of material is possible by using a perfo-

irrigation system to ensure high humidity and disease development (Subrahmanyam *et al.* 1978).

Table 3. Sources of marked resistance to rust in Arachis hypogaea L.

Identification	Plant introduction (PI) numbers	Botanical type	Origin
Tarapoto	259747, 341879 350680, 381622, 405132	Valencia	Tarapoto region of Peru
Israel line 136	298115, 315608	Virginia	Introduction to Israel from the USA
DHT 200	314817	Valencia	Juanji, Peru
FESR lines 1-14	Hybrids between 298115 and an unknown pollen donor	Segregating	Puerto Rico, from the USDA rust nursery

The rust-resistant cultivars (PI 259747, PI 298115, NC Acc 17090 and EC 76446 (292) have been used extensively in hybridization programs with a wide range of high-yielding susceptible parents. Segregating populations are subjected to the previously described screening procedures, and resistant selections are advanced. Basic studies on the inheritance of resistance to rust are being carried out. Some F_3 populations received from the USDA rust nursery in Puerto Rico have been carefully screened and studied here on an individual and family basis to the F_8 generation. From these, it appears that resistance is controlled by at least several genes. These advanced selections are now being yield-tested here, and they will shortly be sent out for multilocational testing. Early generation hybrids, bred at ICRISAT, have also been sent out for selection to various centers.

Table 4. New sources of resistance to rust in *Arachis hypogaea* L., identified at ICRISAT.

Cultivar	Origin
* NC Acc 17090	Peru
* EC 76446 (292)	Uganda
NC Acc 17129	Peru
NC Acc 17130	"
NC Acc 17132	"
NC Acc 17135	"
NC Acc 17124	"

* Cultivars with greater resistance to rust at ICRISAT than the Tarapoto lines PI 259747 and Israel line PI 298115.

The biology, distribution, and dispersion of the fungus have been extensively studied in India initially (Subrahmanyam *et al* . 1979, Subrahmanyam 1980 *in litt.*). A collection of cultivars, with known reactions to rust, has been distributed to centers in India to ascertain whether races of the fungus occur on a national basis. Negotiations are also under way for rust samples from all over the world to be studied in the United Kingdom, a non-groundnut growing country, to identify races if they exist.

Leaf Spots

The leaf spots, caused by *Cercospora arachidicola* Hori and *Cercosporidium personatum* (Berk. and Curt.) Deighton, are the most serious diseases of groundnut on a worldwide scale. Bunting *et al.* (1974) estimated that these fungi alone cause the loss of about 3 million tons of kernels per year. Losses in kernel yields of around 10 percent have been estimated in the USA, where fungicide application is normally practiced (Jackson and Bell 1969). In the SAT, where

chemical control is rare, losses in excess of 50 percent are commonplace (Garren and Jackson 1973).

Although fungicides are being tested at ICRISAT, the main emphasis is on incorporating resistance to these diseases. Limited resistance has been reported in the cultivated groundnut and these accessions are being studied. The germplasm has also been extensively screened at ICRISAT for resistance to *C. personatum* and cultivars have been identified which have restricted lesion growth, sparse sporulation on the lesions and infected leaves which do not readily defoliate. Interestingly some of these cultivars are also rust resistant and include NC Acc 17090, EC 76446 (292) and PI 259747. The cultivar, PI 259747, has also been reported as showing resistance to *C. arachidicola* in the USA (Sowell *et al.* 1976). Therefore, progenies in the rust-breeding nurseries are also being screened for their reaction to the leaf spot fungi. *C. personatum* is the dominant leaf spot pathogen at Patancheru; therefore, sites are also being selected where *C. arachidicola* dominates to test material for resistance to this fungus as well. Laboratory and field-screening techniques are being jointly used as it has been shown that the former alone can give misleading results (Hassan and Beute 1977).

An intensive program has been established at ICRISAT to utilize the wild relatives of the cultivated groundnut as sources of resistance to the leaf spot fungi. Within section *Arachis* two wild diploid species, GKP 10017 (*A. cardenasii - nomen nudum*, Krap and Greg., unpub.) and GKP 10602 (*A. chacoense - nomen nudum*, Krap and Greg. unpub.) have been reported as immune and highly resistant to *C. personatum* and *C. arachidicola*, respectively (Abdou 1966, Sharief 1972, and Abdou *et al.* 1974). Hammons (pers. comm.) observed that HLK 410, another diploid species in section *Arachis* (*A. stenosperma - nomen nudum*, Krap and Greg. unpub.), was not infected with either leaf spot in the field in Georgia, USA. Hybrids between these wild species and the cultivated groundnut have been made in the USA (Sharief, 1972), the United Kingdom (Spielman and Moss 1976) and at ICRISAT. The F_1 hybrid is triploid and sterile. Colchicine treatment restores fertility at the hexaploid level (Fig 1). Hexaploid progenies have been assessed at ICRISAT, under a high incidence of *C. personatum*, and in Malawi with *C. arachidicola* as the dominant fungus. Leaf spot-resistant hexaploids are currently being backcrossed to the cultivated groundnut; the

pentaploids obtained will again be backcrossed to obtain near tetraploid, high yielding leaf spot-resistant cultivars. Alternative methods are also being used to produce tetraploid interspecific hybrids for use in the leaf spot-resistance breeding program (Fig 2).

Aspergillus flavus and Aflatoxins

Aflatoxins are toxic secondary metabolites produced by strains of fungi of the *Aspergillus flavus* group growing on suitable substrates. Research on aflatoxins dates back to 1960 and the outbreak of Turkey 'X' disease, which killed young birds fed on a diet containing groundnut meal (Blount 1961).

Factors found to favor invasion of groundnut seed by *A. flavus* include damage to pods by other fungi, perforation of pods by termites and other insects, mechanical damage to pods during cultivation and at harvest, overmaturity by delayed harvesting and drought stress. Poor drying conditions are also a common reason for fungal invasion and aflatoxin contamination.

Simple recommendations for growing the crop and handling the produce to minimize aflatoxin contamination have been made but are often not followed by the small farmer of the SAT.

Research technology at ICRISAT includes the incorporation of resistance to invasion of the testa by the fungus. Two breeding lines with this character have been identified in the USA (Mixon and Rogers 1973). However, if the testa becomes damaged or split, then this resistance breaks down. The new approaches being initiated at ICRISAT include the testing of cultivars which may support the growth of *A. flavus* but in which the toxin is not produced. This happens with seeds of soybean and cowpeas, which get infected, but aflatoxin is rarely produced. Pre- and post-harvest infection, or lack of infection, is being studied on developing and mature pods and seeds of many cultivars. The entomologist is also studying cultivars for resistance to pod damage by soil fauna.

Other Fungi

Many other fungi affect groundnuts but rust, leaf spots, and *A. flavus* are the major ones on a worldwide scale. We are

interested in seedling diseases and germplasm is being screened for sources of resistance to such common fungi as *A. flavus*, *A. niger*, *Fusarium*, *Pythium*, *Rhizoctonia*, etc. Any cultivars with reported sources of resistance to any disease are being acquired by the germplasm unit.

Viruses

Virus diseases of groundnuts are common and serious. In Africa, groundnut rosette virus (GRV) is important south of the Sahara. Approximately 0.5 million hectares of groundnuts were destroyed by this disease alone in Nigeria in 1975 (Yayock *et al.* 1976). Peanut mottle virus (PMV) was estimated to cause losses amounting to $ 11.3 million in Georgia alone in 1973 (Kuhn and Demski 1975). This disease is worldwide in distribution. In India, bud necrosis virus (BNV) can cause serious yield losses of up to 50 percent (Chohan 1972).

However, much confusion exists in the literature on the distribution and identification of these viruses. Identification has often been solely on the appearance of symptoms which are confusing and variable. At ICRISAT we are attempting to precisely identify the causative viruses by purification and electronmicroscopy. Sensitive serological techniques are being used to help in the identification of the viruses (Reddy *et al.* 1978). Antisera are also being prepared and sent to cooperating laboratories to aid them in their studies. Mass screening techniques are being developed to identify sources of resistance both in the cultivated and wild species of *Arachis*. So far PMV has been identified in India (Reddy *et al.* 1978) and BNV has been shown to be caused by tomato spotted wilt virus (TSWV). A new disease of economic importance in northern India has been shown to be caused by a soil-borne virus. This virus has been purified and an antiserum has been produced (Reddy *et al.* 1979). Cooperative projects are being established with workers in West Africa who are investigating a similar soil-borne virus. Cultivars with resistance to rosette are being used in our breeding programs and have been crossed with high-yielding cultivars and those which are resistant to other diseases.

Insects

Although many insect pests are limited in their distribution

and importance, some are of worldwide importance. Among the latter are aphids, jassids, thrips, and termites. At ICRISAT, screening of germplasm has commenced to identify sources of resistance to these important pests. Sources of apparent resistance to jassids and thrips have been identified; they are presently being reassessed in special pesticide-free areas specifically set aside for this purpose at the ICRISAT farm. Control of pests by insecticides and agronomic practices is also being examined.

Two species of thrips have been identified as the vectors of bud necrosis virus (BNV), and the biology and bionomics of these pests are being studied. Alternative hosts of BNV, including both crop plants and weeds, have been identified (Amin, unpublished data). Observations carried out in breeding blocks by the entomologist have shown that some advanced rust-resistant lines show promise for thrips resistance also. Material emanating from the entomology program will be tested over different environments for stability of resistance, and will be extensively used in the breeding programs.

Nitrogen Fixation

Very little work has been done previously on groundnut symbiosis outside of the United States. At ICRISAT, we trying to manipulate both the *Rhizobium* and host plant component of the symbiosis in an attempt to increase nitrogen fixation--and yields--as well as the residual benefit to subsequent crops.

We have collected, isolated and tested for nitrogen-fixing ability some 40 *Rhizobium* strains. Surveys of farmers' fields indicate a large range in nodulation capacity and nitrogenase activities.

Nitrogen fixation has been measured for several released cultivars during the growing season, using N uptake and acetylene reduction assays. The nitrogenase activity per gram of nodule tissue in groundnuts is probably the highest recorded for any legume. With groundnuts, nitrogen fixation continues well into the pod-filling stage but there are large differences between cultivars, as well as seasons, in nodule number, nodule weight and nitrogenase activity (Fig 3). Nodule distribution also varies considerably between cultivars. Some lines have nodules extending to the hypocotyl and even to the bases of the stems. From this

array we are selecting lines for the breeding program to try and incorporate desirable features into high-yielding or disease-resistant cultivars. Close cooperation exists between the groundnut microbiology programs at ICRISAT and North Carolina State University USA. We are jointly assessing material--both under advanced farming conditions and those of the semi-arid tropics--to try and enhance fixation by this widely adapted crop.

Two new discoveries will aid us in this program. Non-nodulating lines of groundnuts have been identified in crosses between two normally nodulating parents. These will be very useful controls for any N balance studies. A new field assay technique for simultaneously measuring plant nitrogen uptake from the nodules, and from soil, is based on recent findings that legume nodules export more than 90 percent of the fixed nitrogen for their nodules as allantoin. This substance, and nitrate, can be measured in very small quantities in bleeding xylem sap or extracts of stem tissues. This assay will provide us with a method for comparing nitrogen fixation and soil nitrogen uptake over a wide range of field situations, which is not possible with previously used techniques.

Cropping Systems

Although intercropping is part of the Farming Systems Program, we have been cooperating particularly in the choice of cultivars to fit into pearl millet/groundnut combinations. This method of intercropping is common in many parts of the SAT, particularly in Africa (Okigbo and Greenland 1976). Willey and Rao (1979) have demonstrated yield advantages up to 25 to 30 percent when these combinations have been tried at ICRISAT. The magnitude of the yield advantage was mainly determined by the groundnut genotype, whereas the proportion of groundnut yield to millet yield was mainly determined by the millet genotype (Reddy and Willey 1979).

We are also breeding for earliness in groundnuts. A very early cultivar would fit into relay cropping systems, particularly after the rice crop is harvested in Southeast Asia. Sources of earliness (Chico, 91176 and 91776) have been identified and are being crossed with high-yielding and disease-resistant cultivars.

Yield

Although we feel that the incorporation of stable disease resistance is a primary objective to help the small farmer of the SAT, yield *per se* is also obviously important. This is not being neglected. High-yielding cultivars are being used to generate breeding material on a large scale (some 60,000 pollinations can be made in the two growing seasons per year at the ICRISAT farm). Replanting normally dormant cultivars or progenies immediately after harvest, to ensure a rapid advance of generations, is achieved by treating seed with a commercial ethylene-releasing dust. Since the program commenced in 1976, we are now in the position of being able to send out F_5 and F_6 generations for national breeders to test and select from.

The Future

We have been operating for a very short time, so we obviously have a long way to go before we can achieve marked success for the farmer of the SAT. We feel, however, that our major research emphasis on stable disease resistance and increased yield will begin to be achieved in the not too distant future. We need to expand our programs at ICRISAT and particularly our cooperation with national and regional programs. We have the capacity to generate large quantities of breeding material with desirable characteristics. It is now our duty to disseminate this in a logical manner to areas with specific requirements for their groundnut crops.

Major developments are needed at ICRISAT Center. One is a full-scale physiology program with emphasis on drought resistance; another is to expand our entomology program; and the third is to exploit the untapped sources of the wild *Arachis* species. The species are not yet fully collected and those that are, have not been completely assessed for desirable characters. We do know, however, that sources of resistance to diseases, insects, and nematodes--as well as yield and quality aspects--which are not present in the cultivated groundnut are available (Moss 1979). Incompatability barriers occur between sections of the wild species, and with *A. hypogaea*; they have to be overcome before these useful genes can be incorporated into the cultivated groundnut. Much basic work is being done on this aspect at North Carolina State University, with whom we have close working relationships. These joint ventures of basic and applied research will pay dividends in the future.

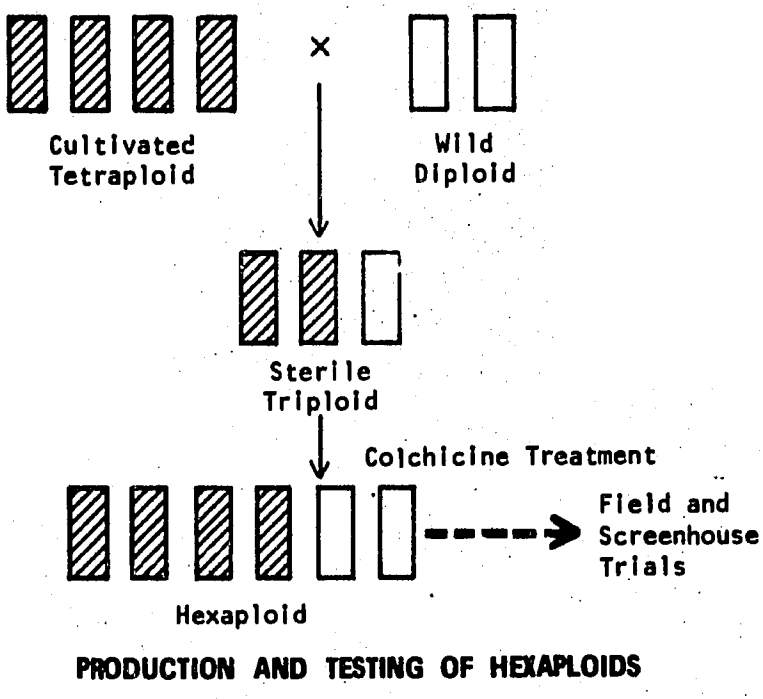
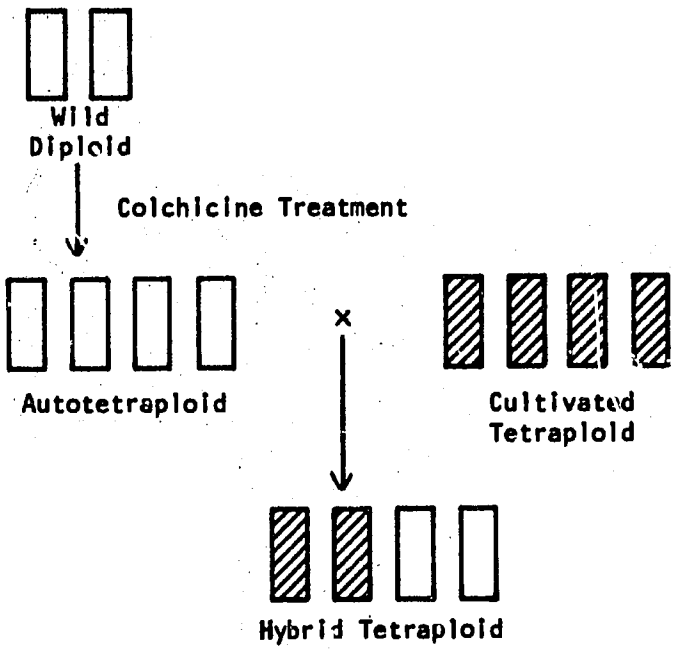


Figure 1. Method of producing interspecific hexaploids for leaf-spot resistance.



PRODUCTION OF HYBRID TETRAPLOID FROM DIPLOIDS

Figure 2. Method of producing tetraploid interspecific hybrids for leaf-spot resistance.

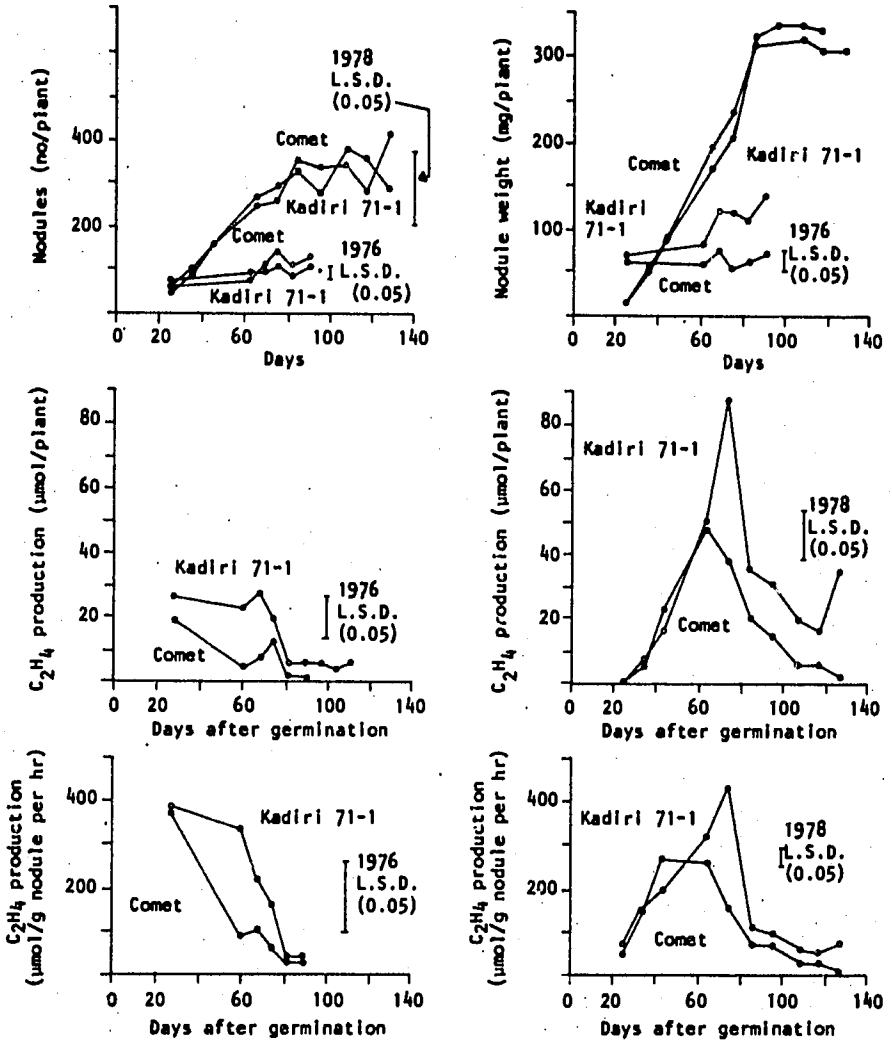


Figure 3. Seasonal variation in nodule number and nodule weight per plant and nitrogenase activity per gram nodule weight and per plant in cv Kadiri 71-1 and Comet grown during rainy season 1976 and postrainy season 1977 at ICRISAT Center. The postrainy season planting was irrigated.

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