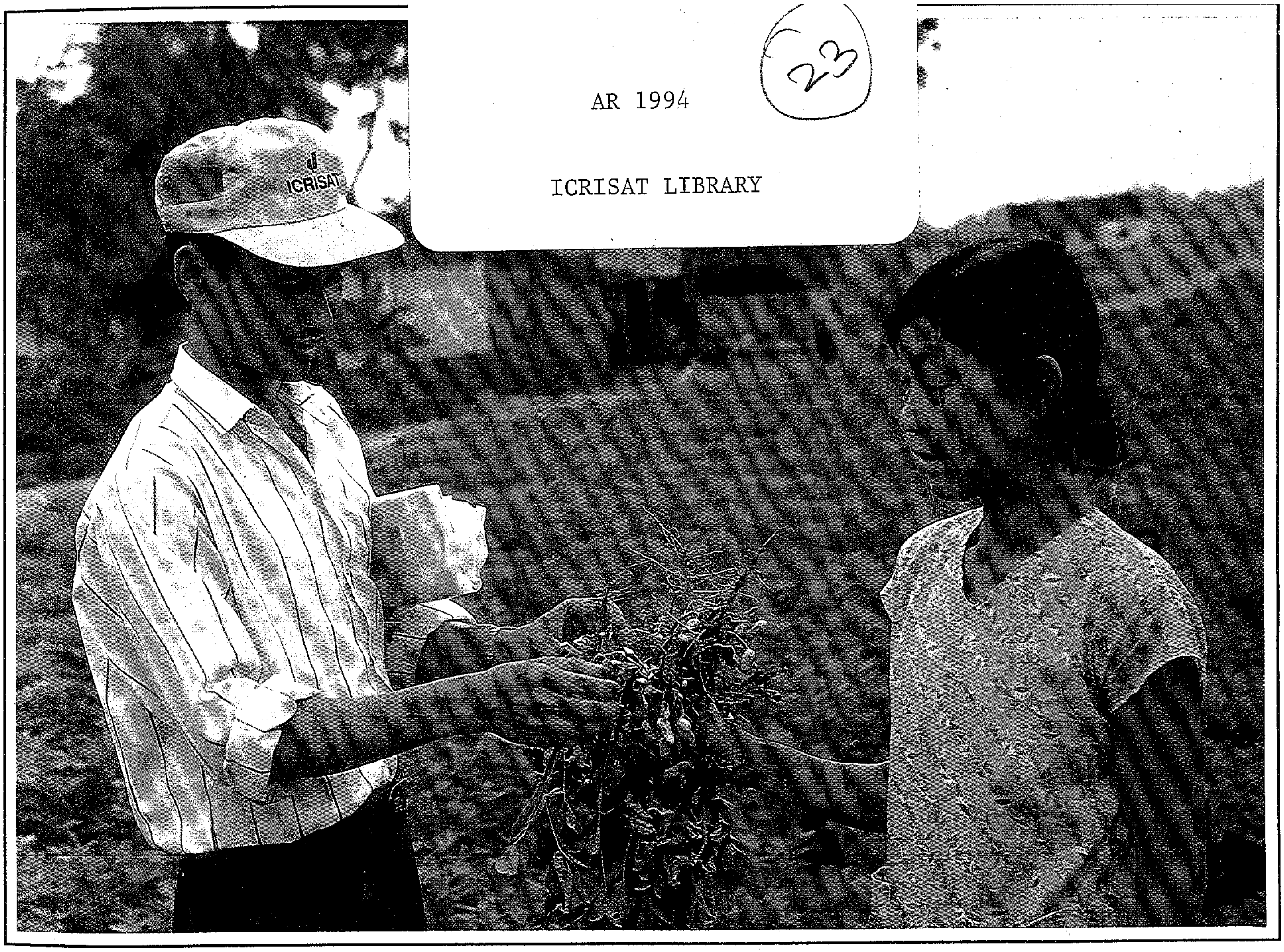
# ICRISAT Asia Region Annual Report 1994





International Crops Research Institute for the Semi-Arid Tropics

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***Cover:** A Vietnamese national program scientist discusses problems of groundnut production with a woman farmer.*

# ICRISAT Asia Region Annual Report 1994

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India
1995

# Contents

# Foreword

*The past year has been a dynamic one for ICRISAT. The matrix mode of organization, with the four regions on the horizontal axis and the seven divisions on the vertical axis has been implemented from 1 Jan 1994. The 22 research projects, which are the basic units of this organization, have been finalized and approved by the Research Planning and Review Committee (RPRC). Project team leaders have been nominated, and sharing of activities by the team members among different projects reinforces the multidisciplinarity of the projects.*

*During the second half of 1994, we went through a severe reduction of staff in the Asia region. The new funding situation and the need to preserve the future of the Institute led ICRISAT to implement a voluntary retirement scheme in August. As a consequence, 381 nationally recruited staff and 169 workers from the Regular Work Force left the Institute by the end of 1994. We would like to thank them for having served ICRISAT, some of them for about 20 years, and acknowledge their contribution to the Institute.*

*The 1994 crop season was quite good in the Asian semi-arid tropics. In Patancheru, we received 800 mm rainfall from June to October, 20% above average. September was dry (62% below average), but the carried-over soil moisture was sufficient for maturity of rainy-season crops. In October, the rainfall was exceptional (248 mm) and helped recharge the soil moisture profile. The postrainy-season crops yielded well.*

*The reports by the seven research divisions on their research activities and interactions with the national programs in the Asia region are presented in this Annual Report. We also report on the activities of the Cereals and Legumes Asia Network (CLAN), Plant Quarantine Unit (PQU), Training and Fellowships Program (TAFP), and Geographic Information Systems (GIS).*

*During 1994, some important visitors have honored the ICRISAT Asia Center: Mr Giridhar Gomongo, Honorable Minister of State for Planning, India, 3 Jan; Dr Ismail Serageldin, Chairman of the Consultative Group on International Agricultural Research, 4 Mar; Dr K. Kainuma, Director General, Japan International Research Center for Agricultural Sciences, Japan, 20 May; and Her Royal Highness Princess Alexandra, UK, 23 Oct.*

*During these difficult times of funding shortage and downsizing of human resources, we would like to thank our donors, collaborators, and the national programs for their help and continued support.*

**Charles Renard**
*Executive Director*

# Report on Research Station

## Weather at ICRISAT Asia Center

In 1994, a total of 850 mm rainfall was received at ICRISAT Asia Center (IAC)—some 10% above long-term average. During the rainy season extending from June to October, 800 mm rainfall was received (90% of total annual rainfall). The seasonal rainfall was 20% above normal.

The rainy season arrived on time, on 10 Jun. Crop sowings were done according to normal schedule. Crop establishment was good. June, July, and August received sufficient rainfall. Although rainfall was deficient in September (–62% of normal), the carried-over soil moisture was adequate for crop maturity. Because of sufficient cloud-free period in September, the grain quality of sorghum was good. There was low infestation of diseases at crop maturity.

October recorded 248 mm rainfall (thrice the monthly mean). Most rain occurred during the first week (164 mm). It helped recharge the soil profile moisture. The establishment of postrainy crops was excellent. The crops yielded well.

Although the total annual and seasonal rainfall during 1994 in the Hyderabad area was above normal, the heavy rainfall events were well spread. Therefore, little runoff occurred. The lake at IAC which is a major source of surface water, remained largely unfilled.

The minimum temperatures during December and January were cooler than normal (by 3° and 1°C). This thermal regime was favorable for the chickpea crop.

## Research Station Management, Cropping, and Services

During 1994 (rainy and postrainy seasons), 325 ha of arable land were cropped. Rainfall distribution was favorable for crop growth and as a result, with timely cultivation, weed and pest control, we had a good crop stand. Supplemental irrigation was given in September and December, when rainfall was deficient.

***Table 1. Rainfall and temperature data at ICRISAT Asia Center, during 1994.***

| | Rainfall (mm) | | Maximum temperature (°C) | | Minimum temperature (°C) | |
|---|---|---|---|---|---|---|
| Month | 1994 | Average | 1994 | Average | 1994 | Average |
| January | 2 | 6 | 29 | 29 | 14 | 15 |
| February | 6 | 9 | 31 | 31 | 17 | 17 |
| March | 0 | 11 | 37 | 35 | 19 | 20 |
| April | 31 | 24 | 36 | 37 | 22 | 24 |
| May | 3 | 31 | 40 | 39 | 26 | 26 |
| June | 144 | 106 | 34 | 34 | 24 | 24 |
| July | 143 | 163 | 29 | 30 | 22 | 22 |
| August | 197 | 148 | 29 | 29 | 22 | 22 |
| September | 66 | 174 | 30 | 30 | 21 | 22 |
| October | 248 | 79 | 29 | 30 | 21 | 20 |
| November | 10 | 25 | 27 | 29 | 16 | 16 |
| December | 0 | 6 | 27 | 28 | 10 | 13 |
| Annual | 850 | 782 | | | | |
| Jun-Oct | 798 | 670 | | | | |

The Farm and Engineering Services Program (FESP) executed about 4000 requests for field operations and 337 greenhouse experiments. Over 1300 work orders and 9600 maintenance requests were completed during the year to support research activities.

A controlled temperature root-pegging apparatus was developed and fabricated for the Agronomy Division. The apparatus was found useful to investigate soil temperature effects on groundnut root and pod development. Among various equipments which were improved and modified for operational efficiency and safety were sprayers, planters, cultipackers, chaff-cutters, threshers, flail shredders, and smoke sensors in the seed dryers.

A screenhouse was constructed for Genetic Resources Division to conserve wild species of groundnut germplasm. Modifications were carried out in the cooling tower, root wash area, building lighting, and steam supply to the laundry to conserve energy and resources.

Various facilities in the controlled environment and greenhouse areas were improved and upgraded, e.g., automation of cooler pump operation and rain water collection system, fabrication of portable ladder to service glass roofs, and streamlining of soil preparation area.

Underground irrigation system was extended to fields used by in-service trainees and rain water storage was augmented by desilting the collection tanks.

Seventeen engineers, managers, and technicians were sponsored to attend workshops and training courses on managerial, supervisory, and technical skills. Twenty-eight staff members attended in-house skill development programs. Nine Farm Managers from the National Agricultural Research Systems attended training in FESP and 130 officials from various organizations visited farm engineering and controlled environment facilities.

AD

# Agronomy Division

*This was the first year of operation of the Agronomy Division, under ICRISAT's organization and management rearrangements for the 1994–98 Medium-Term Plan. Consequently, much of the scientists' time and efforts were devoted to planning and developing projects under the new system. The involvement of Agronomy Division scientists spreads across almost all of the new ICRISAT Project Portfolio. A meeting of all Divisional scientists, including those from Africa was held at IAC in March, to facilitate the planning process.*

*Nevertheless, experimentation and analysis of earlier-obtained results proceeded in earnest, in an attempt to wrap-up work under the previous project system and provide an appropriate transition into the new project system. Also, the second phase of a special project funded by the Government of Japan was completed during this year. This falls under the general title of "Methods of soil management and pulses cultivation in the semi-arid tropics" and the Phase II Project specifically addressed nitrogen dynamics in pigeonpea-based cropping systems. A terminal workshop was held in November.*

*Some of the topics reported below point the way to future research priorities. One such example is a report on use of recently evolved methodology for analysis of genotypes × environment interactions in sorghum and pigeonpea. Another is a report indicating increased understanding of mechanisms of water-use efficiency and of temperature response in groundnut. A further example covers modeling of root systems as part of an overall attempt to improve crop and cropping system modeling capabilities.*

# Cereal Physiology

## Analysis of Genotype × Environment Interaction in an International Sorghum Variety and Hybrid Trial (ISVHAT 92)

One of the major objectives of multi-environment cultivar testing is to assess the relative performance of cultivars across a range of target environments. It is generally observed that the relative ranking of cultivars for grain yield changes across the environments. This inconsistency in relative ranking is due to genotype × environment (G×E) interaction, and complicates breeding efforts. In order to make cultivar selection effective for a given target environment (E), it is essential to diagnose the underlying causes of G×E interactions.

A multi-environment trial (MET) with 26 sorghum genotypes was conducted during 1992 in 26 environments (19 in Asia and 7 in Africa). The additive main effects and multiplicative interaction effects (AMMI) method of statistical analysis and clustering methods were used to interpret the G×E interaction.

*Table 1. Test entries and yield statistics for International sorghum variety and hybrid trial (ISVHAT 92).*

| Cultivar | Origin | Yield (t $ha^{-1}$) | SE |
|---|---|---|---|
| **Cluster 1** | | | |
| ICSH 871001 | IAC[1] | 4.84 | ± 0.55 |
| ICSH 88065 | IAC | 4.40 | ± 0.32 |
| ICSH 89020 | IAC | 4.47 | ± 0.40 |
| ICSH 89034 | IAC | 4.08 | ± 0.36 |
| ICSH 89123 | IAC | 4.56 | ± 0.47 |
| ICSH 90002 | IAC | 4.28 | ± 0.38 |
| SPH 468 | AICSIP | 4.35 | ± 0.40 |
| ICSV 112 | IAC | 4.51 | ± 0.49 |
| ICSH 110 | IAC | 5.09 | ± 0.45 |
| **Cluster 2** | | | |
| ICSH 89051 | IAC | 4.27 | ± 0.38 |
| ICSV 401 | WASIP | 3.81 | ± 0.37 |
| ICSV 111 | WASIP | 4.04 | ± 0.57 |
| **Cluster 3** | | | |
| ICSV 89102 | IAC | 4.27 | ± 0.48 |
| ICSV 89016 | IAC | 3.93 | ± 0.42 |
| ISIAP DORADO | LASIP | 3.67 | ± 0.36 |
| ICSV LM 86513 | LASIP | 3.59 | ± 0.41 |
| **Cluster 4** | | | |
| ICSV 88002 | IAC | 3.88 | ± 0.51 |
| ICSV 88013 | IAC | 3.79 | ± 0.29 |
| ICSV 88032 | IAC | 3.92 | ± 0.41 |
| **Cluster 5** | | | |
| IS 8193 | EARCAL | 3.34 | ± 0.44 |
| IS 9302 | EARCAL | 2.87 | ± 0.28 |
| SD x 160 | EARCAL | 3.02 | ± 0.40 |
| **Cluster 6** | | | |
| KAT/83369 | EARCAL | 4.02 | ± 0.67 |
| IS 23496 | EARCAL | 3.62 | ± 0.65 |
| IS 23509 | EARCAL | 4.21 | ± 0.59 |
| **Cluster 7** | | | |
| SPV 669 | AICSIP | 4.47 | ± 0.67 |

1. IAC = ICRISAT Asia Center; AICSIP = All India Coordinated Sorghum Improvement Program; WASIP = West African Sorghum Improvement Program; LASIP = Latin American Sorghum Improvement Program; EARCAL = East Africa Regional Cereals and Legumes Program.

### Genotype and environment effects

The genotypes (G) and environments (E) accounted for 4 and 71 % of treatment sums of squares, and all were significant ($P \leq 0.01$). The G and E were clustered using environment standardized data and average linkage methods. The genotypes were truncated into seven groups, and the grouping generally fitted well with the origin (Table 1). The genotypes bred at ICRISAT Asia Center (IAC) and those bred in Southern and Eastern Africa (SEA) clustered neatly in different groups. The environments were truncated into six groups. Group A was the largest cluster containing nine locations (seven from Asia and two from Africa), and grain yield among them ranged from 2 to 5.6 t $ha^{-1}$ (Table 2).

**Genotype × environment interaction.** The G×E accounted for 23% of treatment sums of squares. From the biplot of AMMI analysis using G and E main effect means on the abscissa and interaction principal component axes1 (PCA1), the interaction aspects due to G and E can be visualized (Fig. 1). The environment cluster A containing nine members had positive PCA1 scores. In this cluster, IAC and Thimmapur (near IAC) had the highest PCA1 score. Overlaying of selected G clusters in the biplot, indicates that genotypes in cluster 1 had high positive PCA1 value. In contrast, the three Gs from group six, had high negative values. PCA1 scores separated the genotypes based on their origin.

***Table 2. Trial site characteristics and mean grain yield (t ha$^{-1}$) for International sorghum variety and hybrid trial (ISVHAT 92).***

| Region | Location | Location: Latitude | Location: Longitude | Mean grain yield (t ha$^{-1}$) | SE |
|---|---|---|---|---|---|
| **Cluster A** | | | | | |
| South Asia | Bhavanisagar, India | 11° | 77° E | 2.31 | ± 0.15 |
| South Asia | Jalna, India | 19° | 75° E | 3.17 | ± 0.54 |
| South Asia | ICRISAT Asia Center, India | 17° | 78° E | 4.74 | ± 0.31 |
| South Asia | Surat, India | 21° | 72° E | 3.98 | ± 0.46 |
| South Asia | Thimmapur, India | 17° | 78° E | 4.00 | ± 0.61 |
| South Asia | Yusafwala, Pakistan | 31° | 74° E | 2.46 | ± 0.57 |
| Western Asia | Kharaj, Iran | 35° | 51° E | 7.61 | ± 0.63 |
| Western Africa | Marua, Cameroon | 10° | 14° E | 3.48 | ± 0.79 |
| Northern Africa | Shandaweel, Egypt | 26° | 31° E | 5.05 | ± 0.58 |
| **Cluster B** | | | | | |
| Southeast Asia | Khon Kaen, Thailand | 16° | 103° E | 2.39 | ± 0.15 |
| Southeast Asia | Mahlaing, Myanmar | 21° | 95° E | 3.14 | ± 0.51 |
| Eastern Africa | Wad Medani, Sudan | 14° | 33° E | 3.97 | ± 0.70 |
| **Cluster C** | | | | | |
| Southeast Asia | Muneng, Indonesia | -7° | 113° E | 5.10 | ± 0.69 |
| Southeast Asia | Yezin, Myanmar | 19° | 96° E | 2.54 | ± 0.53 |
| Southeast Asia | Myingyan, Myanmar | 21° | 95° E | 3.81 | ± 0.72 |
| Western Africa | Farako Ba, Burkina Faso | 10° | 6° W | 2.26 | ± 0.37 |
| Western Africa | Sikasso, Mali | 11° | 5° W | 2.43 | ± 0.32 |
| Southern Africa | Lucydale, Zimbabwe | -20° | 28° E | 3.01 | ± 0.43 |
| Southern Africa | Matapos, Zimbabwe | -20° | 28° E | 5.53 | ± 0.46 |
| **Cluster D** | | | | | |
| Southeast Asia | Suphanburi, Thailand | 14° | 99° E | 5.62 | ± 0.36 |
| Southeast Asia | Tuloc, Vietnam | 20° | 105° E | 3.12 | ± 0.19 |
| **Cluster E** | | | | | |
| Southeast Asia | Muara, Indonesia | -7° | 107° E | 3.38 | ± 0.67 |
| South Asia | Khumaltar, Nepal | 27° | 85° E | 4.63 | ± 0.67 |
| **Cluster F** | | | | | |
| South Asia | Medchal, India | 17° | 78° E | 2.09 | ± 0.22 |
| Southeast Asia | Bontobili, Indonesia | -5° | 119° E | 3.58 | ± 0.62 |
| Southeast Asia | Pakchong, Thailand | 14° | 101° E | 11.85 | ± 0.42 |

The three genotypes in group five, even though originated from SEA, showed different responses among themselves for PCA1 score (Fig. 1). The genotype IS 9302 bred in Ethiopia, showed a positive PCA1 score, while the genotype SD × 160 from Burundi and IS 8193 from Kenya had negative PCA1 scores. This indicates that IS 9302 had a positive interaction, while the latter genotype group showed a negative interaction in the IAC environment. This differential interaction pattern by genotypes in group five at IAC could be explained by the differences in time to flowering. The two genotypes SD × 160 and IS 8193 were late in flowering at IAC and showed a negative interaction while IS 9302, an early genotype, showed a positive interaction. The genotypes in group six were all late flowering and showed a negative interaction at IAC. Time to flowering played a major role in causing G×E interaction.

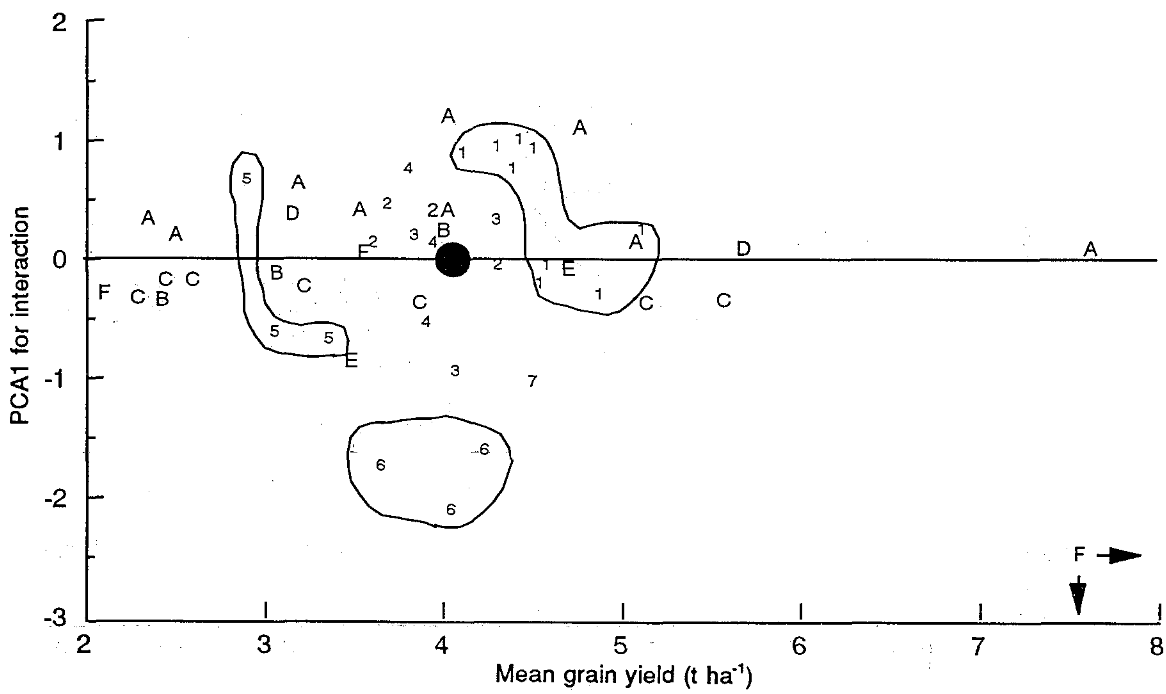


***Figure 1.** Biplot of mean grain yield and principal component axis 1 (PCA1) scores of 26 sorghum genotypes in 26 environments. Genotypes are represented by numeric values indicating the clusters in which they were grouped (Table 1). Environments are represented by letters indicating their groups (Table 2). Three selected genotype groupings are delineated by solid lines. The trial mean yield is represented by the solid circle. Environment in lower right corner is Pakchong, Thailand, whose values fell out of range of the figure.*

The PCA1 and PCA2 scores accounted for 58% of G×E interaction total sums of squares, and were used in the AMMI biplot (Fig. 2). The PCA1 forms a contrast between genotypes using days to 50% flowering (DFL) as a characteristic. On the negative side of the biplot, DFL for those genotypes was above 67 d, while on the positive side of the abscissa for all genotypes except one, DFL was less than 67 d. This clearly shows that PCA1 discriminates genotypes based on DFL as evident from the negative relationship between PCA1 and DFL ($r = -0.69$, $P \leq 0.001$).

The adaptation of a G to an E is derived directly from the biplot (Fig. 2) by projecting a line on to the site line. If the projection of a G line falls into the site line, then the G is positively adapted to that E. If the site line has to be extended beyond the origin of the biplot to meet the G projection line, then the G is unadapted to that E. In this MET, genotypes that originated from IAC are specifically adapted to the IAC environment because the genotype projection lines fall on to the site line, whereas genotypes originating from SEA are unadapted to this E.

**Conclusion.** Most of the G×E interaction in this MET was caused by three genotypes that originated at SEA. The environments IAC and Thimmapur (India), Muara (Indonesia), and Karaj (Iran) caused most of the G×E interaction. A major component of the interaction was identified as a contrast between early- and late-flowering genotypes in this MET. Genotypes such as ICSV 112, ICSH 110, and ICSH 89123 were identified as most widely adapted cultivars, as they possessed PCA1 values nearer to zero.

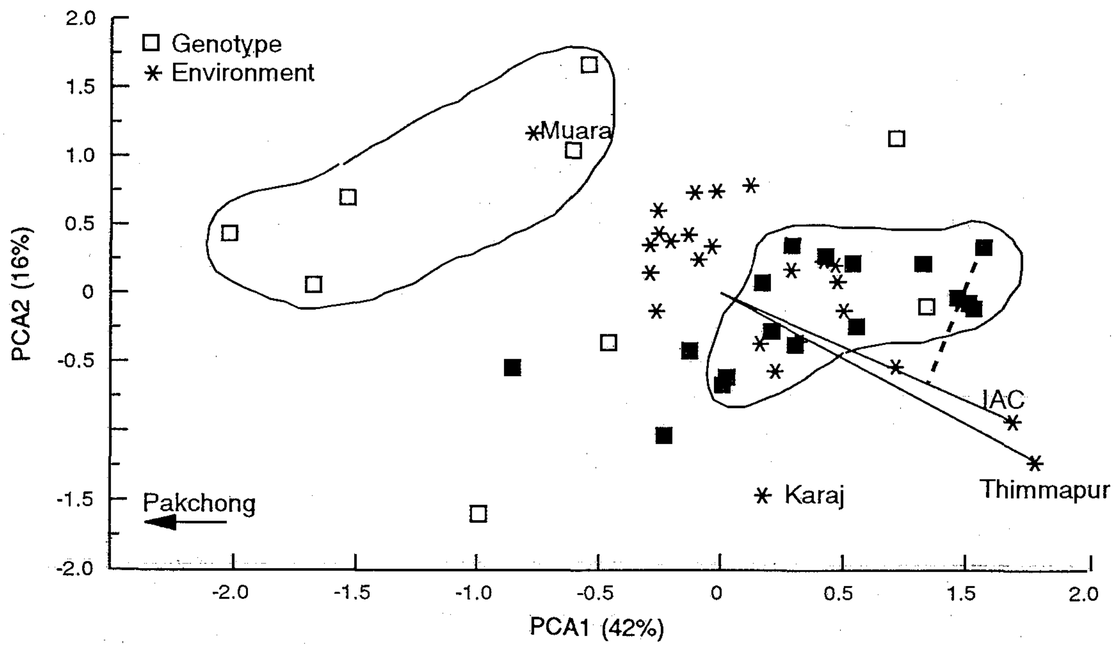


***Figure 2. Interaction biplot of the first two principal component axes of additive main effects and multiplicative effects analysis. Site lines for IAC and Thimmapur (solid) and genotype line (broken) are indicated. Genotypes specifically adapted (closed symbols) and poorly adapted (open symbols) to the two environments are delineated. The PCA1 values for environment Pakchong fell out of range of the figure.***

## Photothermal Interaction in Sorghum Landraces

An understanding of how environment controls the number and rate of leaf appearance and thereby the time to 50% flowering in sorghum is important to comprehend the adaptation of sorghum genotypes to different global climatic regions. Such information is essential to successfully model leaf area development and crop canopy. The phyllochron (heat units required for leaf appearance) is the key input in many simulation models for leaf area determination. In quantitative short-day plants such as sorghum, lengthening of photoperiods results in delaying of time to 50% flowering. Under noninductive photoperiods or nonoptimal photoperiods, there is a delay in time to 50% flowering that is associated with an increase in total leaf numbers that are related to the photoperiod. The delay in time to flowering or increase in leaf number in relation to increasing daylength is termed as photoperiod sensitivity. In most studies involving the effects of photoperiods, the photoperiod treatments are usually fixed time-periods, while in nature, the crop encounters a changing photoperiod with time.

Therefore, we conducted field experiments during the postrainy seasons of 1992/93 and 1993/94 at IAC (17°30'N; 78°16'E) by simulating photoperiods at different latitudes (10, 15, 17, 20, and 29° N) during the cropping season, in a set of diverse sorghum landraces representing different agroclimatic regions of the sorghum-growing areas. The natural photoperiod was extended by incandescent bulbs suspended over the crop to obtain the required photoperiod of the latitude (e.g., Fig. 3). The experiment was also conducted in the field during the normal rainy season (1994) at IAC to determine any effect of temperature differences between rainy and postrainy seasons at the same photoperiod treatment. Photoperiod sensitivity based on thermal units to flowering across the postrainy season suggests varying degrees of photoperiod sensitivity (Table 3; Fig. 4). Genotypes showed considerable variation in their intrinsic earliness (thermal time to 50% flowering in inductive-photoperiods) with the landraces from Western Africa and Central America generally being late. Landraces from China, India (postrainy), and Botswana, and lines from USA were generally early and were less sensitive to increasing photoperiods (Fig. 4). Thermal time to 50% flowering in the rainy season was greater compared with the similar simulated latitude treatment (17°N) in the postrainy season, suggesting possible photoperiod x temperature interactions. Leaf numbers increased with increasing latitudes in photoperiod-sensitive genotypes. More heat units were required for leaf expansion during the rainy season compared with the postrainy season. Landraces which were photoperiod sensitive were also relatively more sensitive to temperature, i.e., both leaf numbers and thermal time to 50% flowering increased during the rainy season (landraces from Nigeria and Central America). Landraces which were insensitive to photoperiod were also insensitive to temperature (landraces from China, India, and USA; Table 3). We have proposed a detailed experiment to examine the possible interaction of photoperiod and temperature in these landraces, along the altitude gradient in Kenya, with simulated photoperiods of different latitudes.

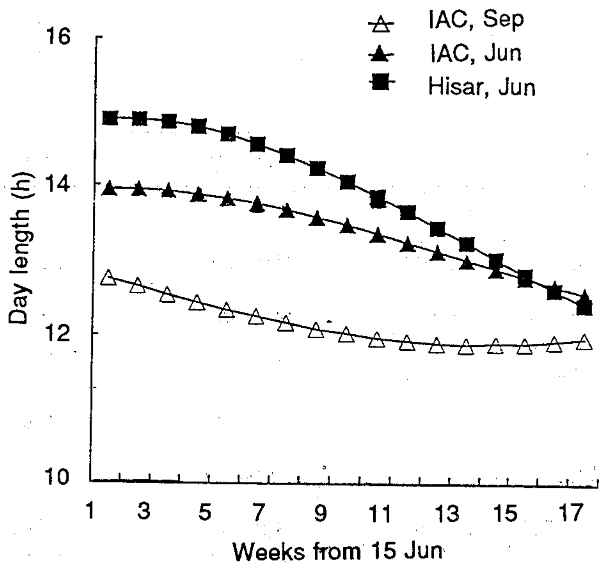


***Figure 3. Actual photoperiod during the postrainy season (Sep) at IAC (17°N), and simulated photoperiods at IAC (17°N), and at Hisar (29°N) beginning 15 Jun.***

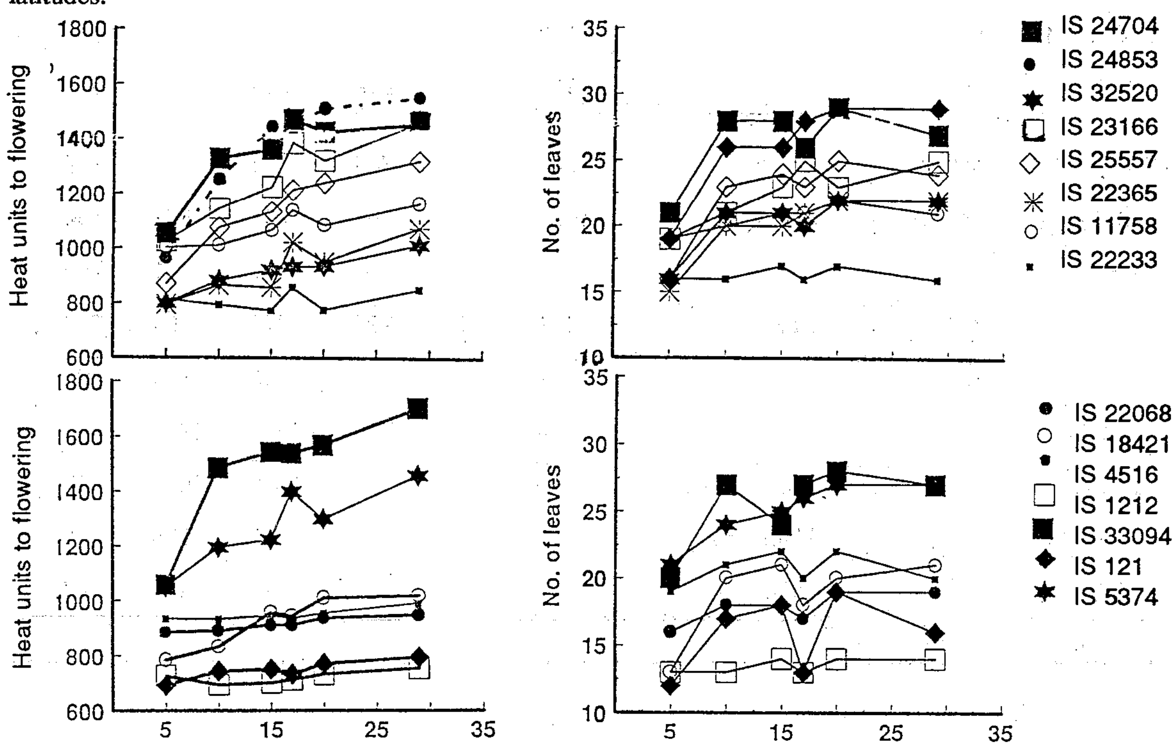


***Figure 4. Heat units (°C days) to flowering and total number of leaves at flowering at different simulated latitudes in the 15 sorghum landraces.***

***Table 3. Heat units for flowering (°C days) in 20 sorghum landraces in three experiments during postrainy seasons 1992/93 and 1993/94.***

| Genotype | Origin: Latitude | Origin: Country | 1992/93 (postrainy) Normal | 1992/93 (postrainy) Simulated photoperiods of latitudes 17°N | 1992/93 (postrainy) Simulated photoperiods of latitudes 29°N | 1993/94 (postrainy) Simulated photoperiods of latitudes 10°N | 1993/94 (postrainy) Simulated photoperiods of latitudes 15°N | 1993/94 (postrainy) Simulated photoperiods of latitudes 20°N | 1994 Normal |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | °C days | | | | |
| IS 24704 | 12°N | Nigeria | 1054 | 1470 | 1454 | 1328 | 1362 | 1424 | 2067 |
| IS 24853 | 10°N | Nigeria | 964 | 1454 | 1551 | 1255 | 1442 | 1509 | 2115 |
| IS 32520 | 5°N | Somalia | 800 | 933 | 1012 | 883 | 921 | 935 | 1214 |
| IS 23166 | 10°S | Tanzania | 1025 | 1384 | 1459 | 1145 | 1224 | 1321 | 1978 |
| IS 25557 | 5°S | Rwanda | 871 | 1213 | 1319 | 1075 | 1133 | 1240 | 1400 |
| IS 22365 | 15°N | Sudan | 795 | 1021 | 1072 | 865 | 858 | 949 | 1494 |
| IS 11758 | 8°N | Ethiopia | 1002 | 1139 | 1163 | 1010 | 1065 | 1085 | 1347 |
| IS 22233 | 20°S | Botswana | 814 | 858 | 851 | 794 | 773 | 776 | 861 |
| IS 22068 | 15°N | India | 885 | 911 | 948 | 890 | 910 | 936 | 1009 |
| IS 18421 | 20°N | India | 783 | 943 | 1016 | 831 | 956 | 1008 | 1418 |
| IS 4516 | 20°N | India (postrainy) | 933 | 933 | 989 | 932 | 944 | 954 | 1124 |
| IS 1212 | 35°N | China | 726 | 712 | 754 | 694 | 701 | 732 | 743 |
| IS 33094 | 15°N | Honduras | 1058 | 1534 | 1696 | 1483 | 1539 | 1564 | NF |
| RS 610 | 42°N | USA | – | – | – | 725 | 740 | 750 | 804 |
| IS 121 | 42°N | USA | 692 | 732 | 794 | 743 | 750 | 770 | 929 |
| IS 20408 | 14°N | Niger | – | – | – | 846 | 875 | 921 | 1261 |
| IS 34969 | 8°N | Central Africa | – | – | – | 1586 | 1661 | 1748 | NF |
| IS 34787 | 6°N | Central Africa | – | – | – | 1429 | 1549 | 1645 | NF |
| IS 26717 | 18°S | Zimbabwe | – | – | – | 879 | 884 | 911 | 1193 |
| IS 5374 | 10°N | India | 1049 | 1396 | 1453 | 1193 | 1221 | 1297 | 2009 |

– = Data not available.

# Legumes Physiology

## Chickpea

### Development of traits to improve yield and resistance to important abiotic stress factors in chickpea

**Genetic enhancement of drought resistance.** Chickpea experiences terminal drought as it is grown mostly as a rainfed crop in the postrainy season. A large and deep root system would, therefore, enable maximum extraction of available moisture in the soil profile enhancing crop growth, dry matter production and its partitioning into seed yield.

ICC 4958, a drought-resistant chickpea germplasm, was characterized for morpho-physiological traits and was found to have a large root system (ICRISAT Annual Report 1988, pp. 60–61). Genetic enhancement of drought resistance was then initiated jointly by the scientists of the now Genetic Enhancement Division (GED), Agronomy Division (AD), and Crop Protection Division (CPD). A three-way cross involving ICC 4958 (a drought-resistant parent), Annigeri (a cultivar with high and stable yields), and ICC 12237 (a wilt-resistant germplasm) was made in the 1985/86 postrainy season.

Segregating $F_2$ and $F_3$ populations of this cross were screened in a wilt-sick plot. A divergent selection pressure was exerted from $F_4$ generation onwards. One approach was to select for yield and its components in $F_4$ and further generations (yield-based selections adopted by GED). The other was to select for root size to advance from $F_4$ to $F_7$ generations (root-selections adopted by the AD). Yield evaluation of root selections was done in $F_8$ generation. The most promising advanced generation selections, nine each of root-and yield-based selections, were evaluated for drought resistance in field trials conducted during the 1993/94 postrainy season.

Two methods were used to screen for drought resistance. In one method, standardized residuals, taken as drought resistance indices, were computed by performing a multiple regression analysis (ICRISAT Legumes Program Annual Report 1991, pp. 3–7). The nonirrigated yield (dependent variable) was regressed on irrigated yield (near potential yield) and days to 50% flowering (escape from drought). Data to compute these drought resistance indices were obtained by conducting experiments on Alfisol and Vertisol with irrigation and no-irrigation treatments in the main plot and genotypes in the subplots.

The other method was to fit linear regressions of the yield of individual genotypes (in each environment) on the mean yield (of all the genotypes) in those environments (ICRISAT 1992. Plant Material Description no. 33). Genotypes that combined higher intercepts with lower slopes were considered most drought resistant. Seven different treatments were created at IAC by selecting for soil types (Alfisol and Vertisol), difference in soil depths, sowing date (late sowing in one treatment) and by applying irrigation treatments. Differences in yields of these treatments were considered to reflect differences in soil moisture availability, because the climatic conditions were similar across experiments (except in the late-sowing treatment), and because of the known lack of response to applied N and P fertilizers in chickpea at IAC.

Data on yield and drought resistance (using the first method) of the root- and yield-based selections on a Vertisol are given in Table 4. Drought tolerance indices of the three root-based selections were positive and high, compared with yield-based selections. Differences in nonirrigated yield (intercepts), however, were not large or significant. This may be because the intensity of drought was not severe in this year. The nonirrigated yield (1.5 t $ha^{-1}$), although equal to 50% of potential yield of this region (3 t $ha^{-1}$), was high, compared with the average rainfed yield (0.6–0.7 t $ha^{-1}$).

According to the second method used to evaluate drought resistance, the root-based selections (mean of nine elite selections) exhibited a greater degree of drought resistance compared with the yield-based selections (Fig. 5a). When the linear response line was extrapolated to estimate genotypic yield response around 0.6 t $ha^{-1}$ of the mean yield of environment, the potential yield advantage of root selections appeared to be large. The response of the best and worst yield- and root-based selections are shown in Figure 5b. Although the differences are not large, the intercepts of the two root-based selections were higher than the yield-based selections.

One genotype, ICC 94912, was found superior in drought performance using both these methods. Further evaluation of these genotypes using line-source sprinkler irrigation treatments on Alfisol and Vertisol is proposed for the 1994/95 postrainy season.

## Genotypic differences in root growth of promising drought-resistant selections

Studies on root growth of Annigeri, ICC 4958, and three promising root-selections were reported earlier (ICRISAT Legumes Program Annual Report 1993, pp. 17–22). These studies showed genotypic differences in root size, its pattern of growth, and in extracting soil moisture. A field experiment was conducted in 1993/94 to validate these results.

ICC 4958 and the root selections ICCVs 94912 and 94913 were earlier [50% flowering at 42 days after sowing (DAS) and maturity at 83–85 DAS] than Annigeri and ICCV 94915 (50% flowering at 44–46 DAS and maturity 86–89 DAS).

Root growth (total root length and root plus nodule mass) followed a typical sigmoid growth curve (Fig. 6). Maximum root growth occurred around 72 DAS, which then decreased, coinciding with senescence associated with maturity at the late pod-fill stage. ICC 4958 and ICCVs 94912 and 94913 produced significantly higher root mass and total root length compared with Annigeri or ICSV 94915 up to 41 DAS. Roots of Annigeri and ICCV 94915 grew rapidly at later stages.

Rooting depth of the genotypes was not different at any stage of crop growth. Maximum rooting depth was around 120 cm, observed at 72 DAS. The root front, computed from periodic observation on increase in root length, moved at an average rate of 17 mm per day. Genotypic differences in root length density at various soil depths were significant. ICC 4958 and ICCV 94912 produced significantly higher root length density in the surface soil layers at early growth stages (data not shown), whereas Annigeri and ICCV 94915 produced higher root length densities at soil depths between 60 and 90 cm at later crop growth stages (72 DAS).

ICC 4958 (Fig. 7) and ICCVs 94912 and 94913 (data not shown) extracted greater amounts of soil moisture compared with Annigeri (Fig. 7) from 0–30 cm soil depth until about 28 DAS. However, difference among entries disappeared at maturity (Fig. 7). Development of a vigorous root system during early growth seems to be useful in efficient crop use of surface soil moisture which would otherwise be lost through evaporation. A large amount of soil moisture below 60 cm depth remained unextracted at maturity as the root length density was less at greater soil depths.

***Table 4. Seed yield, and drought tolerance index of some root-trait and yield-based chickpea selections, made for increased adaptation to drought, Vertisol, ICRISAT Asia Center, postrainy season 1993/94.***

| Chickpea selection | Seed yield (t ha$^{-1}$) Non-irrigated | Seed yield (t ha$^{-1}$) Irrigated | Drought tolerance index |
|---|---|---|---|
| | | Root based | |
| ICCV 94911 | 1.61 | 2.27 | ~~1.18~~ |
| ICCV 94912 | 1.61 | 2.14 | 1.41 |
| ICCV 94913 | 1.64 | 2.36 | 1.26 |
| ICCV 94914 | 1.41 | 2.10 | -0.03 |
| ICCV 94915 | 1.28 | 2.10 | -1.09 |
| ICCV 94916 | 1.40 | 2.27 | -0.45 |
| ICCV 94917 | 1.26 | 1.93 | -0.91 |
| ICCV 94918 | 1.31 | 2.04 | -0.70 |
| ICCV 94919 | 1.06 | 1.77 | -2.40 |
| | | Yield based | |
| ICCV 94920 | 1.46 | 2.65 | -0.58 |
| ICCV 94921 | 1.50 | 2.41 | 0.14 |
| ICCV 94922 | 1.37 | 2.13 | -0.46 |
| ICCV 94923 | 1.44 | 2.30 | -0.14 |
| ICCV 94924 | 1.45 | 2.91 | -1.21 |
| ICCV 94925 | 1.35 | 2.13 | -0.56 |
| ICCV 94926 | 1.59 | 2.69 | 0.37 |
| ICCV 94927 | 1.62 | 3.03 | 0.01 |
| ICCV 94928 | 1.52 | 2.08 | 0.84 |
| **Controls** | | | |
| Annigeri | 1.59 | 2.00 | 1.51 |
| ICC 4958 | 1.51 | 1.86 | 1.17 |
| Mean | 1.45 | 2.26 | |
| SE | | | |
| Irrigation | | 0.093* | |
| Genotypes | | 0.103*** | |
| Irrigation × genotype | | 0.145* | |
| Interaction at the same level of irrigation | | 0.170 | |

* $P \leq 0.05$; *** $P \leq 0.001$.

Genotypic differences in early shoot growth were, in general, similar to those in root growth. ICC 4958 and root selections were vigorous and produced more shoot mass compared with Annigeri (data not shown). These significant differences in shoot mass were maintained up to 56 DAS. Beyond 56 DAS, shoot growth of Annigeri was rapid and culminated in a shoot mass similar to ICC 4958 at harvest. Shoot mass, seed yield, and harvest index did not vary significantly among the genotypes (Table 5).

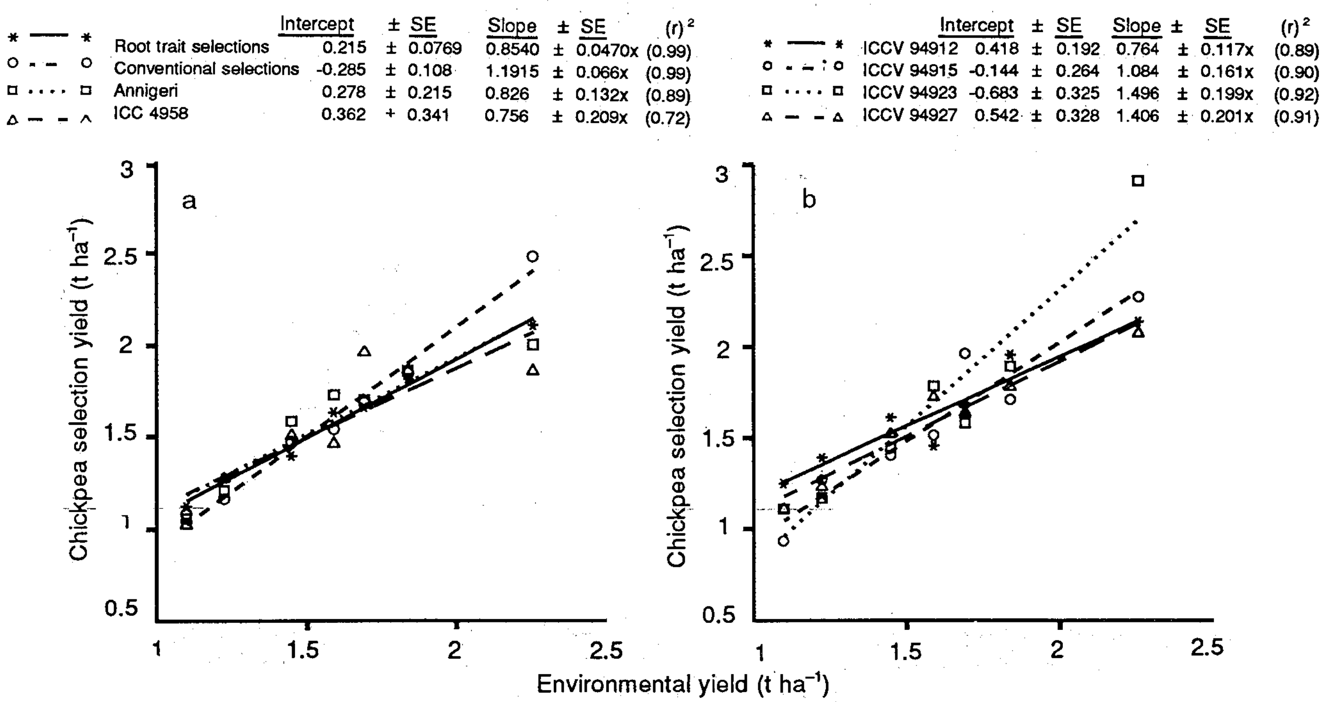


*Figure 5. Genotype × environment interaction response of (a) mean yield of nine each of root-trait and yield-based selections, compared with Annigeri and ICC 4958, and (b) seed yields of best and worst of each root-trait and yield-based selection.*

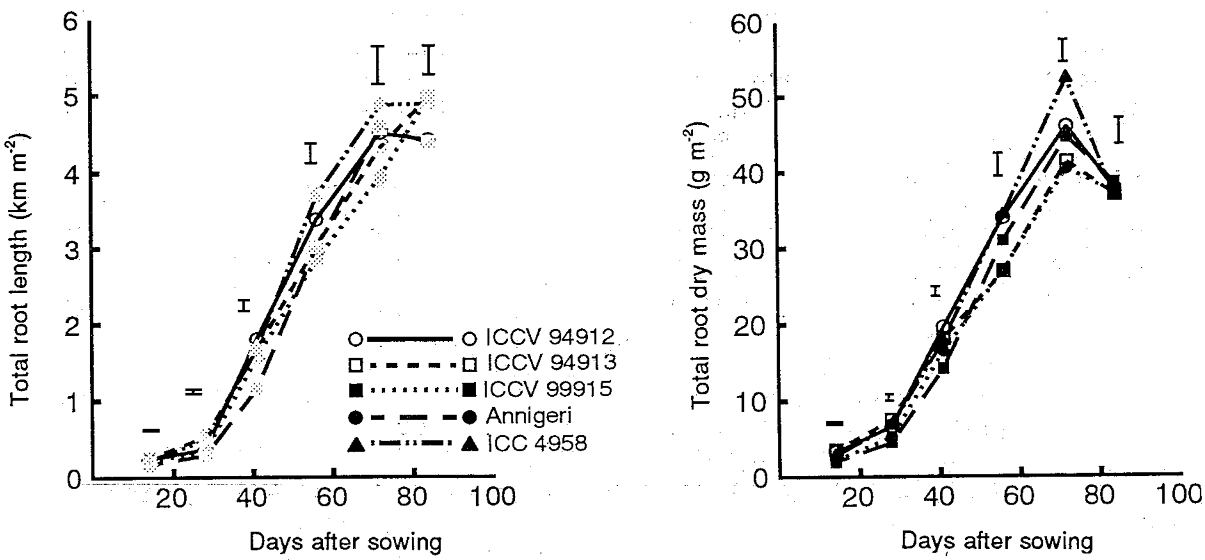


*Figure 6. Seasonal changes in root growth of two genotypes and three selections of chickpea grown on deep Vertisol under progressively receding soil moisture conditions, ICRISAT Asia Center, postrainy season 1993/94 (vertical bars denote SE).*

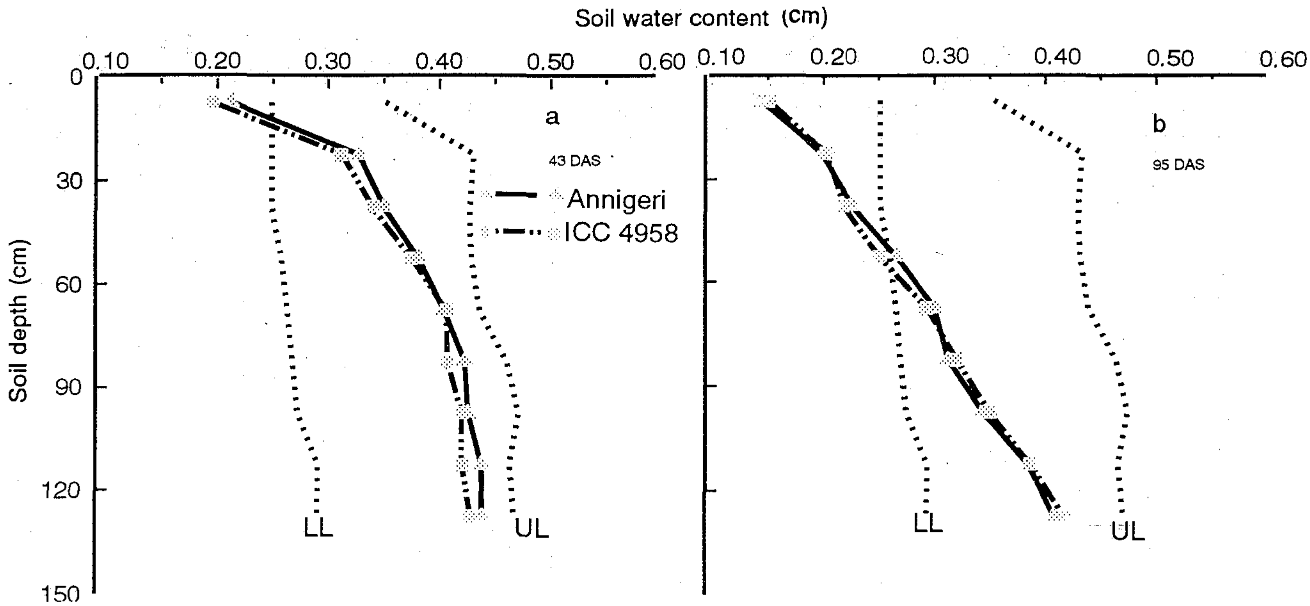


***Figure 7. Distribution of soil water content with soil depth under genotypes Annigeri and ICC 4958, grown in receding soil water conditions; (a) at 43 days after sowing (SE for genotypes within a depth is 0.0026 cm and depths within a genotype is 0.0056 cm) and (b) at 95 days after sowing (SE for genotypes within a depth is 0.0038 cm and depths within a genotype is 0.0081 cm) in deep Vertisol, ICRISAT Asia Center, postrainy season 1993/94. (UL and LL indicate the upper and lower limits of available soil water).***

## Relationship between leaf thickness, carbon discrimination, and water-use efficiency

Leaf thickness (inverse of specific leaf area—leaf area $cm^2$ $g^{-1}$ leaf mass) and carbon discrimination are reported to be closely correlated with transpiration efficiency in groundnut. A set of 33 chickpea genotypes, including elite breeders selections and germplasm, were grown rainfed on an Alfisol. Another set of 40 genotypes, consisting mostly of elite ICRISAT breeding selections, were grown rainfed on a Vertisol. Specific leaf area was computed and chemical analysis for carbon discrimination was performed at the Australian National University, Canberra, Australia. Specific leaf area was positively correlated with delta carbon values, but the correlation coefficients were small (Alfisol r=0.32, n=33; r=0.42, n=40), explaining only 9–16% variation in delta carbon values.

***Table 5. Differences among chickpea root-trait entries in shoot biomass, grain yield, and harvest index in a deep Vertisol, ICRISAT Asia Center, postrainy season 1993/94.***

| Chickpea | Shoot mass ($t\ ha^{-1}$) | Seed yield ($t\ ha^{-1}$) | Harvest index (%) |
|---|---|---|---|
| ICCV 94912 | 3.3 | 1.9 | 58 |
| ICCV 94913 | 3.3 | 1.7 | 51 |
| ICCV 94915 | 3.3 | 1.6 | 49 |
| Annigeri | 3.3 | 1.8 | 56 |
| ICC 4958 | 3.4 | 1.9 | 56 |
| SE | ± 0.13 | ± 0.13 | ± 2.4 |

In the 1993/94 crop season, 80 chickpea genotypes with large differences in leaf size and thickness were grown on a Vertisol to study differences in leaf thickness and carbon discrimination, and relate them with dry matter production and yield. Leaf samples are being processed for carbon discrimination analysis and computation of delta carbon values.

## Evaluation of drought resistance of improved varieties and advanced breeding lines

Thirty-eight advanced breeders' selections were screened for drought resistance and nonirrigated yield, and compared with the two control genotypes, ICC 4958 and Annigeri. Characterization for drought resistance was done by computing standardized residuals as drought-resistant indices (ICRISAT Legumes Program Annual Report 1991, pp. 3–7). Genotypes were grouped in categories labeled as stable yielding, drought resistant, drought susceptible, and poor performers. This grouping needs to be further confirmed. Very few genotypes appeared to combine stable yield with a greater degree of drought resistance.

## Seed/pod volume ratio as a selection criterion for harvest index and rainfed yield in chickpea

Selections for pod number and pod size (indirect criteria for yield components—seed number and seed size) are commonly used in crop improvement programs as field selection criteria to identify high-yielding genotypes. A characteristic such as seed volume/pod volume ratio is not very simple to observe and use as a field screening criterion. We evaluated the usefulness of seed volume/pod volume ratio as a potential criterion to select for higher harvest index and yield.

In a preliminary study (nonreplicated) conducted in the 1992/93 postrainy season, seed volume and pod volume were measured by the water displacement method, to compute seed volume/pod volume ratios in 120 genotypes. These genotypes comprised of diverse (with respect to yield components) germplasm accessions and elite breeding material. Variation in seed volume/pod volume ratio ranged between 17.1 and 34.9%.

In the 1993/94 postrainy season, 48 genotypes out of the 120 studied in 1992/93, were selected on the basis of contrasting differences in pod volume and seed volume and seed volume/pod volume ratios. These were evaluated in a replicated field experiment on a Vertisol. The objective was to relate seed volume/pod volume ratio with yield, harvest index, and seed size under terminal drought conditions. Genotypes affected by fusarium wilt disease were excluded from the study. Seed and pod volumes were measured in a random subsample of 60 pods which were harvested from 10 or more plants in each treatment.

Out of the 48 genotypes studied, only 36 flowered in 60 days after sowing, the upper extreme limit of adaptation of chickpea to short-duration conditions, such as at IAC. This subset of 36 genotypes was used to determine correlations between pod and seed traits with harvest index and yield. The seed volume/pod volume ratio ranged between 13 and 36%. Diversity in 100-seed mass, harvest index, and yield was equally large.

A significant positive correlation between the seed volume/pod volume ratio with harvest index and seed yield suggested that the trait could be useful as a selection criterion for higher harvest index and seed yield, although the correlations were not very strong (Table 6). A nonsignificant correlation of the ratio with 100-seed mass suggests that the trait may be independent of seed size.

***Table 6. Relationship of seed/pod volume ratio with yield and its components (n=36).***

| Trait | Seed/pod volume ratio | Seed yield (kg ha$^{-1}$) | Harvest index |
|---|---|---|---|
| Seed yield (kg ha$^{-1}$) | 0.435** | | |
| Harvest index (%) | 0.631*** | 0.879*** | |
| 100-seed mass (g) | -0.110 | 0.075 | 0.150 |

** $P \leq 0.01$; *** $P \leq 0.001$.

## Incorporation of desired ideotype traits

Chickpea germplasm with contrasting morphological traits was evaluated for drought resistance in field experiments at IAC (ICRISAT Annual Report 1989, p. 86). Two accessions, one with fewer pinnules (ICC 5680, 7 pinnules in contrast to 11–13 in other germplasm material) and the other with a large root system (ICC 4958), were found to be drought resistant. A backcross program was then initiated jointly with GED to introgress the easily observable morphological trait of fewer pinnules using ICC 5680 as nonrecurrent parent. Recurrent parents were genotypes selected for various specific traits known to be useful (Table 7). The objective was to generate tailored genotypes of desired pinnule number and to study utility of the trait in genetic enhancement of drought resistance. This material is currently in various backcross generations, and showed varied degree of expression in different genetic backgrounds.

*Table 7. Recurrent parents, their traits, and backcross generations with ICC 5680 as nonrecurrent parent.*

| Pedigree | Desired morphophysiological trait in recurrent parents | Backcross generation |
|---|---|---|
| ICC 4958 | Drought tolerance | $BC_2F_2$ |
| ICC 8923 | Tall and lodging tolerance | $BC_2F_2$ |
| Pant G 114 | Long duration, high yield | $BC_4F_2$, $BC_2F_2$ |
| Annigeri | Short duration, high yield | $BC_2F_2$ |
| ICC 88505 | Chilling tolerance | $BC_4F_2$, $BC_2F_2$ |
| ICC 5680 | Fewer pinnules (nonrecurrent parent) | |

### ICAR-ICRISAT trials on drought resistance

A chickpea drought research network in peninsular India was initiated and coordinated by the Agronomy Division in 1989. Later, it was jointly operated by ICAR, Indian Institute of Pulses Research (IIPR), Kanpur, India, and IAC. Results of these trials were reported earlier (ICRISAT Legumes Program Annual Report 1991, pp. 3–7; ICRISAT Legumes Program Annual Report 1992, pp. 3–5). In 1993/94 postrainy season, no trials were conducted at IAC. Indian Institute of Pulses Research, Kanpur, took the lead this year, with active support of AD in extending the drought research network activities in the central and northern Indian locations. A meeting of the chickpea drought working group to conclude and document the activities of the drought network is proposed in 1995.

## Pigeonpea

### Drought

**AMMI analysis of a line source-irrigation trial to identify drought-resistant genotypes.** Trials involving line-source irrigation to study drought resistance have been conventionally analyzed using a linear regression approach. A comparison of the slopes of linear response of genotypes across moisture environments indicates the relative susceptibility/resistance of the genotypes included in the test. This approach, however, essentially requires that the responses of the test genotypes to moisture should be linear. For pigeonpea, this requirement is generally not fulfilled because of the susceptibility of the crop to both excess and deficit of moisture, resulting in a curvilinear response to moisture level (ICRISAT Annual Report 1987, p. 184). This limits the usefulness of line-source irrigation studies in identifying drought-resistant genotypes. To overcome this lacuna, we attempted to analyze the data from a line-source trial using another statistical method called additive main effects multiplicative interaction (AMMI) effects analysis. The method quantified the main effects of genotypes, environments, and their interaction, and further partitioned the interaction effects in terms of significant principal component axis. The analysis revealed that about 45% of the variation in yield was accounted for by genotype, 41% by moisture environments, and 14% by their interaction in the particular trial. Of the 14% variation due to interaction, 50% was accounted for by the only significant first principal component axis (PCA1).

A biplot graph of AMMI results (Fig.8) presented the main effects plus the contributions to the first PCA. The contribution of each genotype and environment to the interaction was plotted on the vertical axis of the biplot and the average (main effect) of the same genotype across all 10 environments, and for the same environments across all 46 genotypes on the horizontal axis. The biplot captured about 93% of the total variation in yield, and with the help of only 56 points which depicted the effect of 460 treatments, identified the genotypes and moisture environments with highest means (on horizontal axis), and the magnitude of positive or negative contributions to interactions (PCA scores) on the vertical axis. Genotype yield in a given environment is simply the average yield

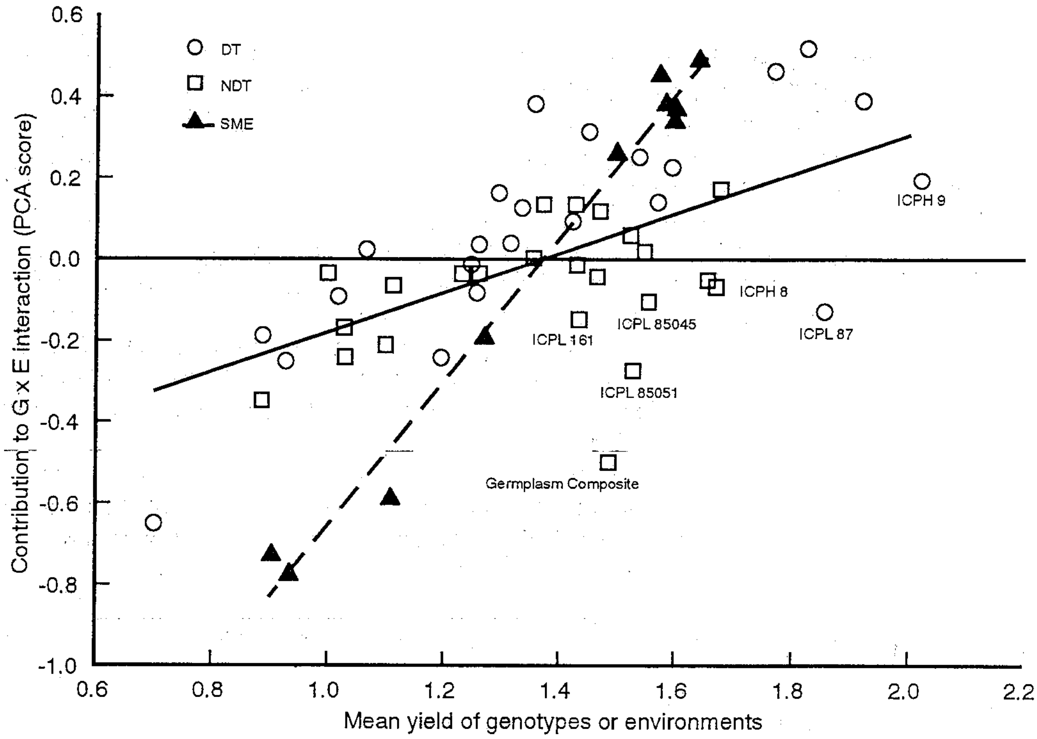


***Figure 8. Additive main effects and multiplicative interaction effects biplot of unadjusted mean yield (t ha$^{-1}$; x-axis) of 23 short-duration determinate (DT) genotypes, 23 indeterminate (NDT) genotypes across 10 soil moisture environments (SME), and 10 SME, across 46 genotypes and principal component axis 1 (square root of yield t ha$^{-1}$; y-axis). Solid line is common regression for genotypes and dashed line for environments.***

plus the interaction effects (derived by multiplying PCA score of a genotype with the PCA score of a given environment). The genotypes and environments with PCA1 scores of the same sign (positive or negative) have positive interaction effects, while a combination of opposite signs results in a negative interaction. Therefore, especially those genotypes whose average yield was also high and had high negative scores, may have a yield advantage in the low-moisture environments (with negative PCA scores). The genotypes/irrigation treatments with zero PCA score had no interaction. As the amount of irrigation increased, environments had higher average yield, and their PCA scores tended to increase from more negative to more positive, following a strictly linear pattern. Although a somewhat similar pattern emerged with the genotypes, the points were more widely scattered, indicating subtle differences in responses among the genotypes. ICPH 9 was the highest-yielding genotype, but it had a positive PCA score. Most of the determinate genotypes fell above the regression line and most of the indeterminate genotypes fell below the regression line. At a given average yield level, the PCA scores of indeterminate genotypes (square symbols) were more negative than those of determinate genotypes (round symbols), although there were some exceptions. The analysis suggests that with similar average yields, indeterminate genotypes may do better than the determinate genotypes in the dry environments. Indeterminate genotypes, ICPL 161, ICPL 85045, ICPL 85051, ICPL 288, ICPH 8, and a germplasm composite and determinate ICPL 87, with average yields similar to or more than the average yield of irrigated environments, but having high negative PCA scores, may have traits which confer them drought resistance. This, together with their average yield, may determine their performance in drought environments. The analysis suggests that it should be possible to distinguish resistant and susceptible genotypes in a line-source trial using this approach.

## Adaptation

**Relative adaptation of extra-short-, short-, and medium-duration genotypes to Alfisols and Vertisols.** Alfisols and Vertisols are among the common soil types on which pigeonpea is grown. The plant available water-holding capacity of Vertisols is high (200 mm), but the crop faces waterlogging during the rainy season, when grown on these soils. In contrast, Alfisols have low (50–100 mm) water-holding capacity due to which they are prone to intermittent drought, whenever there is a long dry spell in the rainy season, and to terminal drought in the postrainy season. To compare the relative adaptation of the newly evolved extra-short-duration (ICPLs 90002, 90004, 90007, 90011, 91002, 83015, 84023, 85010, 88032, and 88039), short-duration (ICPLs 89018, 89008, 88009, 87, and 86012) and medium-duration (ICPs 8379, 7035, 14199, ICPLs 227, and 87119) genotypes to Alfisols and Vertisols, a set of these genotypes was grown on each type of soil, with and without irrigation. Some of the genotypes (ICP 8379 and ICP 14199) have been identified as resistant to waterlogging and were thus expected to perform well on Vertisols. Likewise, the extra-short- and short-duration genotypes were expected to do well on Alfisols due to their drought escape advantage. However, a 247-mm rainfall in October reduced the intensity of drought for the medium-duration genotypes on the Alfisol. The AMMI statistical analysis was used to understand the genotype × soil environment interaction for the prevailing climatic conditions.

The genotypes accounted for 26%, environment 66%, and G×E interaction 8% of the treatment sums of squares and all were significant ($P \leq 0.01$). Figure 9 depicts the genotype and soil environment main effects on the abscissa and the only significant PCA1 on the ordinate in an AMMI biplot. The genotypes and environments with PCA scores

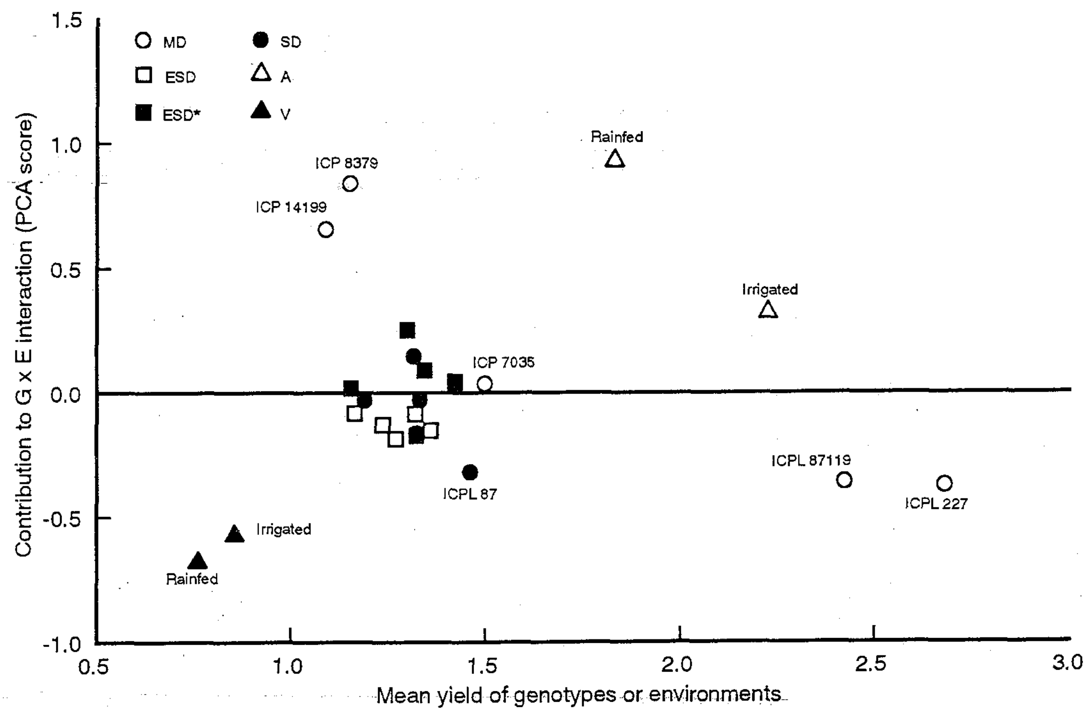


***Figure 9. Additive main effects and multiplicative interaction effects biplot of unadjusted mean yield (t ha$^{-1}$; x-axis) of five medium-duration (MD), five short-duration (SD), five extra-short duration (ESD), and five ESD genotypes (ESD*), with ICP 7035 as one of the parents, Vertisol (V) and Alfisol (A), rainfed and irrigated environments, and principal component axis 1 (square root of yield t ha$^{-1}$; y-axis).***

of similar sign have positive interaction effects, while a combination of PCA of opposite signs results in a negative interaction. Two medium-duration genotypes, ICP 8379 and ICP 14199, produced the lowest average yield and had the highest positive PCA score, as against the opposite score of the Vertisol, meaning these interacted negatively with this soil to produce lower yields than their respective mean. These genotypes turned out to be wilt susceptible, as a consequence of which their plant stand was decimated on a Vertisol. The highest-yielding genotypes, ICPL 227 and ICPL 87019, formed a separate group at the lower left side. These are wilt-resistant lines. These genotypes, with their negative PCA scores, multiplied with the negative PCA score of the Vertisol produced greater positive effect on yield than the other genotypes. All the extra-short-duration and short-duration genotypes, with the exception of ICPL 87, formed a separate group with a waterlogging-susceptible cultivar ICP 7035 and had a very low or zero PCA score, and their mean yield ranged between 1.0 and 1.5 t $ha^{-1}$. ICP 7035 was extensively used to enhance the seed size of short-duration genotypes. ICPL 87 tended to be separate from this group, with a high negative PCA score indicating its better adaptation to Vertisol than the other short-duration genotypes. Wilt was not a major problem for extra-short- and short-duration genotypes; nevertheless, they suffered from waterlogging on Vertisols due to rainfall and irrigation. The response to irrigation on both soils was small due to such interactive effects.

### Performance of ICPL 86012 in farmer's field

ICPL 86012, a short-duration genotype, has previously been reported to show good ratoonability (ICRISAT Legumes Program Annual Report 1990, p. 51). Anticipating this trait to also assist in recovery from insect damage, this genotype was compared with three other genotypes of very similar time to 50% flowering in a field experiment with and without insecticide sprays (CV = 12.9%). ICPL 86012 gave 1.19 t $ha^{-1}$ compared with 0.72 t $ha^{-1}$ by UPAS 120, 0.82 t $ha^{-1}$ by ICPL 85045, and 0.47 t $ha^{-1}$ by ICPL 87, the differences being highly significant at $P \leq 0.01$, and attributable to pod borer (*H. armigera*) damage. Under protected conditions, ICPL 86012 gave 2.53 t $ha^{-1}$ compared with 2.13 t $ha^{-1}$ by UPAS 120, 2.45 t $ha^{-1}$ by ICPL 85045, and 2.62 t $ha^{-1}$ by ICPL 87. The chances that ICPL 86012 might have escaped the pod borer were small, as in all the genotypes, floral bud initiation occurred between 44 and 46 days, and time to 50% flowering between 70 and 75 days.

In the 1994 rainy season, we gave 1 kg seed each of ICPL 86012 and ICPL 87 to a farmer, on his request, in a village adjoining IAC. The farmer applied two insecticide sprays of monocrotophos and harvested 1.37 t $ha^{-1}$ from ICPL 86012 from about 0.13 ha, compared with negligible yield from ICPL 87. Obviously the sprays were ineffective as a protectant for ICPL 87. When the trials were monitored at the podding stage, a good pod set was apparent in ICPL 86012 and pods were much less damaged than those of ICPL 87. Further studies are in progress to confirm the better adaptation of ICPL 86012 under limited or no protection from pod-boring insects.

## Groundnut

### Screening for drought tolerance

During the 1993/94 postrainy season, 226 genotypes, comprising 162 spanish and 64 valencia types were screened for tolerance to mid- and end-of-season drought. Response of genotypes to mid-season drought was assessed by examining crop growth rates (CGR) and partitioning of dry matter to pods ($p$) during the drought and recovery period, following alleviation of drought. Genotypes with tolerance to end-of-season drought were identified, based on the dry matter and yield, relative to the experimental mean yield. ICG 10042, ICGVs 89259, 89280, 92003, and 92114 belonging to bunch type, and ICGVs 92050, 92130, 91063, 92186, and 91234 belonging to virginia types showed superior performance under midseason drought. Seven spanish and valencia genotypes (ICGs 1901, 2036, ICGVs 90013, 91216, 91030, 91035, and 91040) and four virginia types (ICGVs 90116, 91224, 91060, and 91063) were identified as tolerant to end-of-season drought conditions.

## Selection for high water-use efficiency

As a part of an Australian Centre for International Agricultural Research (ACIAR)-Indian Council of Agricultural Research (ICAR)-ICRISAT collaborative project on selection for water use efficiency (WUE) in groundnut, the effect of genotype and environment interaction on WUE, and partitioning of dry matter to pods was examined in 50 selected genotypes in a multilocational trial conducted at seven locations in India during the 1993 rainy season (ICRISAT Legumes Program Annual Report 1993, p. 94–95). Results from this experiment indicated that the pod yield was strongly influenced by genotype and environment, which also influenced specific leaf area (an indicator of WUE) and partitioning. There was a negative association between WUE and partitioning at nearly all sites, confirming earlier results (ICRISAT Legumes Program Annual Report 1991, pp. 79–81). Multilocational analysis of the $^{13}C$ discrimination ($\Delta$, as a measure of WUE) revealed a significant ($P \leq 0.01$) variation among genotypes, and the relation between $\Delta$ and specific leaf area (SLA) was significant at all locations except at Durgapura (Table 8). It is suspected that sample contamination might be the reason for lack of relationship between $\Delta$ and SLA at Durgapura.

Results from this experiment were utilized to describe yield in terms of a simple physiological model, i.e., $Y = T \times WUE \times HI$, where Y = pod yield, T = transpiration, WUE = water-use efficiency, and HI = harvest index. The WUE and HI were estimated through simple crop measurements on SLA, final vegetative and pod dry matter. T was computed from the final biomass and WUE estimates. The analysis indicated that the pod yield was strongly influenced by the G×E interactions for T, WUE (measured via SLA) and HI. The analysis also indicated that significant G×E for, as well as negative associations among yield determining traits such as WUE and HI, occur widely in groundnut. The simple physiological model approach proposed should enable a more thorough understanding of the potential occurrence and of the interactions in variable environments, thus allowing the selection of genotypes with high levels of each trait to improve adaptation of genotypes in a given environment.

***Table 8. Correlation between Δ and specific leaf area in 18 groundnut genotypes grown at different locations in India, during the 1993 rainy season.***

| Location | Regression coefficients | Regression[1] ($R^2$) |
|---|---|---|
| Vriddhachalam (Tamil Nadu) | $\Delta = 17.50 + 0.011 \times SLA$ | 0.630** |
| Tirupati (Andhra Pradesh) | $\Delta = 18.46 + 0.011 \times SLA$ | 0.557** |
| Bangalore (Karnataka) | $\Delta = 17.23 + 0.012 \times SLA$ | 0.570** |
| IAC (Andhra Pradesh) | $\Delta = 16.95 + 0.013 \times SLA$ | 0.470* |
| Jalgoan (Maharashtra) | $\Delta = 14.71 + 0.023 \times SLA$ | 0.480* |
| Junagadh (Gujarat) | $\Delta = 16.56 + 0.013 \times SLA$ | 0.530** |
| Durgapura (Rajasthan) | $\Delta = 14.73 + 0.036 \times SLA$ | 0.320NS |

NS = not significant; * = $P \leq 0.05$; ** = $P \leq 0.01$.

In collaboration with the Genetic Resource Division (GRD), 167 groundnut accessions (81 virginia bunch and 86 virginia runner types) were assessed for WUE, using SLA as a screening tool (ICRISAT Legumes Program Annual Report 1991, pp. 79–81) during the 1993/94 postrainy season. Genotypes were grown under irrigated conditions in a replicated trial. The third and fourth leaves were sampled at three stages (66, 97, and 129 days after sowing) for SLA. Virginia runner types, in general, had lower SLA than virginia bunch types, indicating higher WUE. Genotypic variation for SLA was significant and time of sampling also had a significant effect on SLA, but genotype × time of sampling interaction was nonsignificant. Genotypes with low SLA (high WUE) were identified from virginia bunch (e.g., ICGs 1643, 618, 570, and 4434) and virginia runner types (ICGs 1069, 1031, 849, 880, and 945). These genotypes will be further evaluated for their performance under drought conditions.

## Physiological and anatomical basis of genotypic variation in specific leaf area

Earlier studies have shown that SLA is correlated with Δ and WUE in groundnut, and that the cause for genotypic variation in WUE is mostly due to photosynthetic capacity per unit leaf area (ICRISAT Legumes Program Annual Report 1993, pp. 94–95). Earlier studies also indicated a negative association between SLA (WUE) and partitioning (ICRISAT Legumes Program Annual Report 1991, pp. 79–81). The anatomical basis for variation in SLA and partitioning has been examined in selected genotypes during the 1994 rainy season. Rate of photosynthesis was measured on second or third leaves (from the apex) three or four times during the season, and the leaves were sampled for chlorophyll estimation and leaf anatomical studies.

There was a strong correlation of SLA with photosynthetic rate ($r^2 = 0.78^{**}$) and chlorophyll ($r^2 = 0.81^{**}$) per unit leaf area, suggesting more chlorophyll and higher rates of photosynthesis per unit leaf area in low SLA types. Interestingly, leaf anatomical studies have shown a significantly positive relationship between SLA and physical thickness of leaf lamina ($r^2 = 0.62^{**}$, Fig. 10), suggesting that low SLA types, in fact, are thinner by physical measurement. Preliminary observations suggest that the genotypes varied in the arrangement of various structural components. For example, high SLA types appear to have more air spaces and less denser mesophyll, compared with low SLA types. There was also genotypic variation in structure and frequency of vascular bundles. Studies are continuing to quantify the density of various structural components, i.e., mesophyll, bundlesheath, cortex, etc., and relate these to function. The observations made so far suggest that the variation in SLA seem to be caused more by the weight of elements (mainly nitrogen and carbon) per unit leaf area rather than by structural variations.

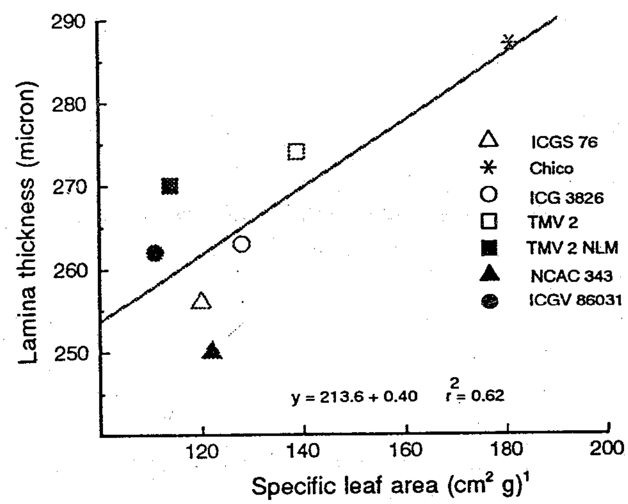


*Figure 10. Relationship between lamina thickness and specific leaf area (SLA) in seven groundnut genotypes grown at ICRISAT Asia Center during the 1994 rainy season.*

## Influence of soil temperatures on partitioning of dry matter to pods and seed quality

Information on influence of soil temperature on partitioning of assimilates to pods and seed quality is vital to understand the G×E interactions for yield and quality traits. The influence of soil temperatures on partitioning of dry matter to pods and seed quality was examined in three selected genotypes, i.e., TMV 2, Comet, and AH 6179, in a greenhouse experiment. The three genotypes were grown in a sand and Alfisol mixture in pots. The potting medium was maintained at four day/night temperature regimes, 20/14 °C (T1), 26/20 °C (T2), 32/26 °C (T3), and 38/32 °C (T4) by keeping the pots in temperature-controlled water baths.

The leaf area and SLA increased, and the root dry matter declined as soil temperature increased from T1 to T3. However, the specific root length increased at high soil temperatures (T3 and T4). Plants in T1 produced more number of pods but their seed growth rate was lower, compared with T2 and T3. At T4 also, the seed size was smaller compared with T2 and T3, mainly because of reduced assimilate translocation to the seeds during the seed-filling phase. The oil content increased from T1 to T3, but there was no change from T3 to T4. While the starch content declined as the temperature increased from TI to T4, protein content was greater at warmer (T3 and T4) compared with cooler soil temperatures (T1 and T2). Among fatty acids, oleic acid increased and linoleic acid decreased with a rise in soil temperature from T1 to T3.

# Cropping Systems

## Effect of Amount and Frequency of Planting Rains on Sorghum Establishment

The semi-arid tropics are characterized by pronounced seasonal variability in rainfall intensity. Coefficients of variation in weekly rainfall are particularly high at the commencement of the rainy season. Throughout much of the SAT, farmers begin sowing dryland crops after receipt of the first major rainfall event of the growing season. In some locations, farmers have little choice of when to sow due to the short length of the rainy season. After sowing, seedlings are particularly vulnerable to drought stress due to their small and shallow root systems, and as only the surface layers of the soil are moist. This situation is aggravated by high incident solar radiation and potential rate of evaporation, resulting in rapid drying of the surface layers of the soil. Seedlings often have to survive between protracted breaks between rainfall events. Farmers are sometimes forced to resow fields due to low survival of seedlings, as a result of drought stress at the seedling stage.

Poor crop establishment continues to contribute to low yields of many dryland crops of the SAT. This is particularly the case for sorghum and groundnut in ICRISAT-defined production systems 9, 14, and 20 and pearl millet in production systems 1, 13, and 21. Crop establishment is also a major constraint to the establishment of legumes in rice-fallows in production system 5.

This study aimed to examine historical weather records for IAC, for variability in size and duration between rainfall events at sowing. The mean commencement of rainy season at IAC is 15 Jun. Farmers begin sowing their rainfed crops after this date, when rainfall has moistened the surface layers of the soil profile. Using the historical weather records for IAC (1974–94), the size of the planting rains was calculated as the first substantial (>20 mm) rainfall event after 15 Jun. Using these criteria, the mean size of the planting rains was 43.8 mm, with values ranging from 20 to 108 mm. The coefficient of variation in the size of the planting rain was 53%. Using a simple water balance model, the duration between rainfall events was calculated. The time from sowing till the next rainfall event, that raised the storage of moisture in the surface (0–15 cm) soil layer to 20 mm, was calculated. In this calculation, runoff from the soil profile was assumed to be negligible. The mean duration between rainfall events was 20 days, with data ranging from 5 to 41 days. The coefficient of variation in the duration between rainfall events was 54%.

If sowing was delayed till the first major rainfall event after 1 Jul, then there was little effect on the size of the planting rains, which was 48.5 mm (range 20–21 mm). The main difference is that the later sowing resulted in the mean duration between rainfall events decreasing from 20.2 to 10.2 days (range 2–38 days). Consequently, earlier sowing was associated with increased risks associated with poor crop establishment. In much of the SAT, delayed sowing of sorghum is unfortunately associated with an increased incidence of shoot fly damage. Further, delayed sowing is associated with a reduced period of agricultural productivity and a lower rainfall use-efficiency, as a result of increased soil evaporation and runoff.

A field study was also conducted to examine the relationship between the amount and frequency of planting rains on sorghum establishment. An experiment was conducted before the 1994 rainy season on an Alfisol at IAC.

The experiment was a split-split plot design with the amount of planting rain as the main plot, time of rewatering as the subplot, and sorghum lines as the sub-subplots. Planting rain was simulated by irrigating plots with 15, 30, 45, and 75 mm of water depending on the treatment. The rewatering treatment was implemented by bunding the plots and flood irrigating at 8, 15, and 22 days after sowing. The sorghum cultivars chosen were CSH 9, a released hybrid, and IS 17605, a landrace, selected for superior crop establishment at IAC.

The volumetric moisture content of the surface layer decreased in an exponential manner in all plots (Fig.11). Plots receiving 15 mm of irrigation had an initial moisture content of 0.1 $m^3$ $m^{-3}$. By comparison, plots receiving 75 mm or irrigation had an initial moisture content of 0.17 $m^3$ $m^{-3}$. In this treatment, much of the moisture had moved to deeper layers beyond the rooting depth of sorghum seedlings. The effect of the larger planting rains was to delay the occurrence of low soil moisture contents. To emphasize this fact, the inset in Figure 11 presents the same data except that 1.6 and 4.5 days have been added to the abscissa for treatments receiving 39 and 15 mm of irrigation. Data from all treatments then fell on one curve.

Seedling survival was linearly related to the soil moisture content below a given level (Fig. 12). This relationship was independent of the amount of planting rain. Therefore, it was concluded that it is not the amount of rain per se that is important but the amount stored in the surface layer. Larger planting rains delayed the occurrence of low surface moisture contents, and hence prolonged the survival of seedlings. The death of sorghum seedlings began to occur at a higher moisture content for CSH 9 than for IS 17506. At lower moisture contents a greater number of IS 17605 seedlings survived than was the case for CSH 9. For CSH 9, seedling survival was reduced to 50% at 11.6 days when sown after receiving 15 mm of rain. This period was only extended to 16.2 if crops were sown after receiving 75 mm of rain. This difference is small in relation to the differences in rainfall. This emphasizes that it is not the amount of planting rain that is critical, but the duration between rainfall events.

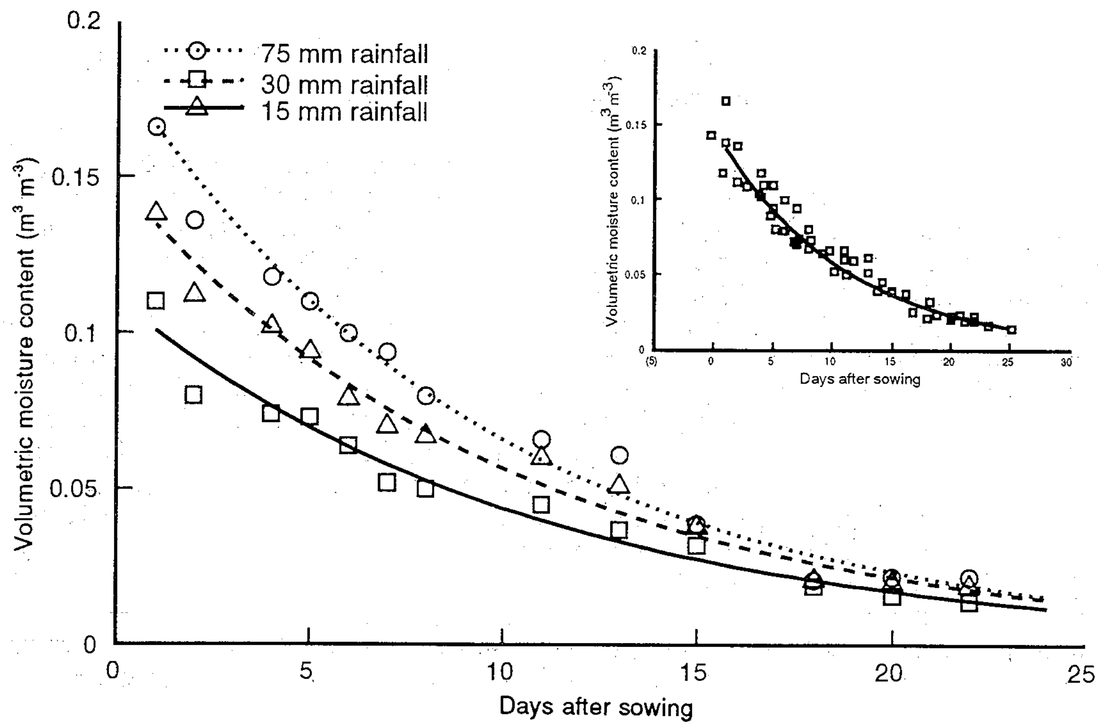


*Figure 11. Changes in the volumetric moisture content of an Alfisol with time after sowing, and the relationship for treatments receiving the equivalent of 75, 30, and 15 mm of rainfall. The inset contains the same data, with an adjustment of the abscissa (see text).*

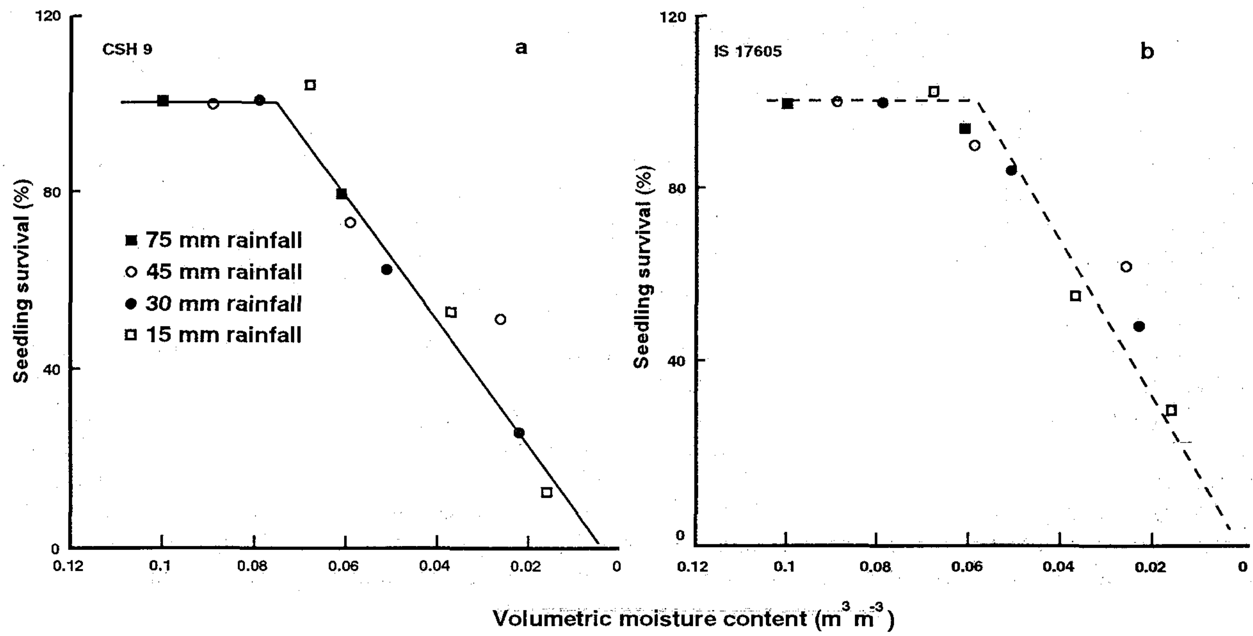


***Figure 12. The relationship between the percentage of surviving seedings and the volumetric moisture content of the surface soil layer (0–15 cm). The solid squares, open circles, solid circle, and open squares are data from treatments receiving 75,45, 30, 15 mm of rainfall.***

## Simulation of Root System Development of Component Crops in Pigeonpea-based Intercropping Systems (Government of Japan Special Project)

Crop growth models are now used to predict many agronomic processes, but are still in the early stages of development for many crops. Limited information is as yet available on crop growth for pigeonpea, a grain legume important to resource-poor farmers of the SAT, and known to have a deep rooting characteristic, which is a key factor for the exploitation of soil resources. In our earlier report, the applicability of a root model for maize established by Jones et al. 1991 (ICRISAT Legumes Annual Report 1993, pp. 59–61), was tested with short-duration pigeonpeas as a first step to simulate interaction of roots from different crops in intercropping. The results showed that the model adequately simulated the rooting profile for sorghum. However, for pigeonpea, regressions between measured and simulated root growth were highly significant, but root length and mass tended to be underestimated by the model; the model could, with a few modifications, predict root system development of pigeonpea.

During the 1994 rainy season, we validated the model for the simulation of root growth and distribution of the individual five major component crops (pigeonpea, cowpea, groundnut, sorghum, and pearl millet) used for intercropping in the semi-arid tropics using weather data, soil properties, and crop parameters. A medium-duration pigeonpea (*Cajanus cajan* L. Millsp.cv ICP 1–6), cowpea (*Vigna sinensis* Endl. cv IT 82D-7), groundnut (*Arachis hypogaea* L. cv ICGS 11), sorghum (*Sorghum bicolor* cv CSH 5), and pearl millet (*Pennisetum glaucum* L. R.Br. cv ICMV 221) were grown as sole crops on an Alfisol. Monolith sampling method was applied to measure root distribution at different soil depths in terms of root length and mass. Characterization of root system development among crops was then carried out, based on model outputs such as profile distribution, rooting depth, and root senescence.

Since a growth model has not yet been developed for pigeonpea, a logistic equation was used to fit the observed dry matter of roots. Daily dry matter allocation to roots, a major input to the model, was computed as the difference in the simulated root mass between two successive days.

The simulated daily dry matter allocated to the roots of cereals followed a similar trend, whereas among the legumes, variability was observed (Fig. 13). Dry matter allocation to pigeonpea roots was low at the initial stage and then increased remarkably during the late vegetative period. In contrast, groundnut maintained a lower rate of dry matter allocation to roots throughout the growth period.

Root growth in terms of root length density simulated by the model for two soil layers (0–10 and 20–30 cm depth) is shown in Figures 14 and 15. In cereals, root length density was higher in the surface layers and decreased with the soil depth. In legumes, the root length density was relatively lower (0.3–0.4 cm $cm^{-3}$) at the surface with an equivalent amount of root in the lower layers. For pigeonpea in particular, the root length density in the lower layers was underestimated by the model at the later growth stage (Fig. 15).

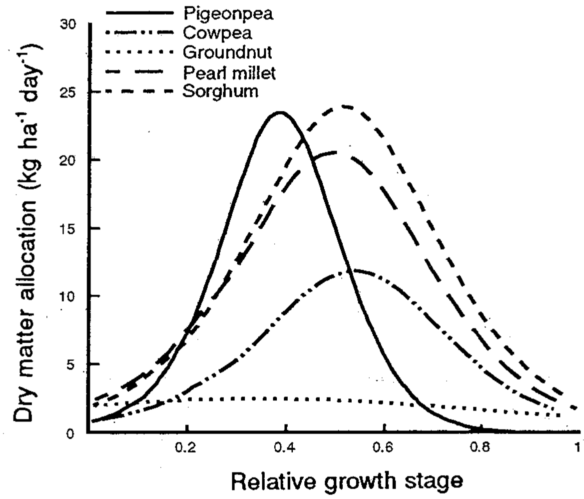


***Figure 13. Dry matter allocation to roots as obtained by the difference in root mass between two consecutive days. Data on root dry mass fitted with a logistic equation.***

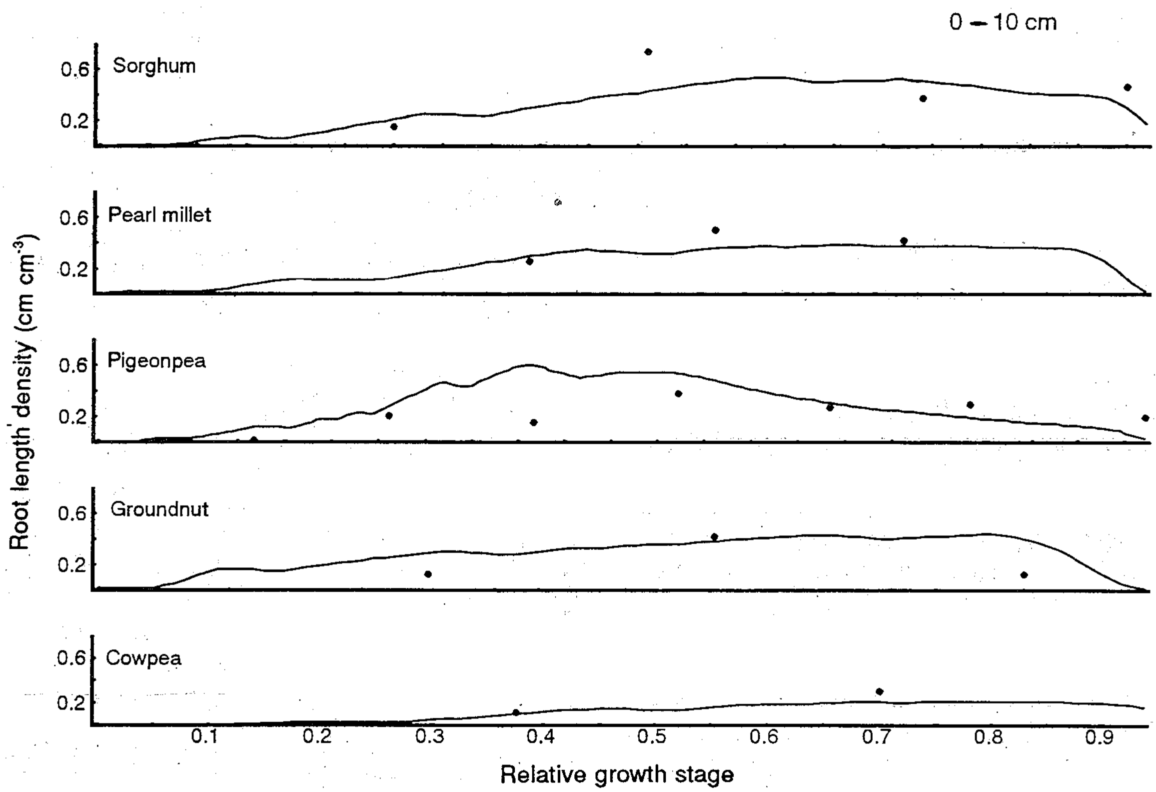


***Figure 14. Measured and simulated root length density at 0–10 cm for sorghum, pearl millet, pigeonpea, groundnut, and cowpea crops.***

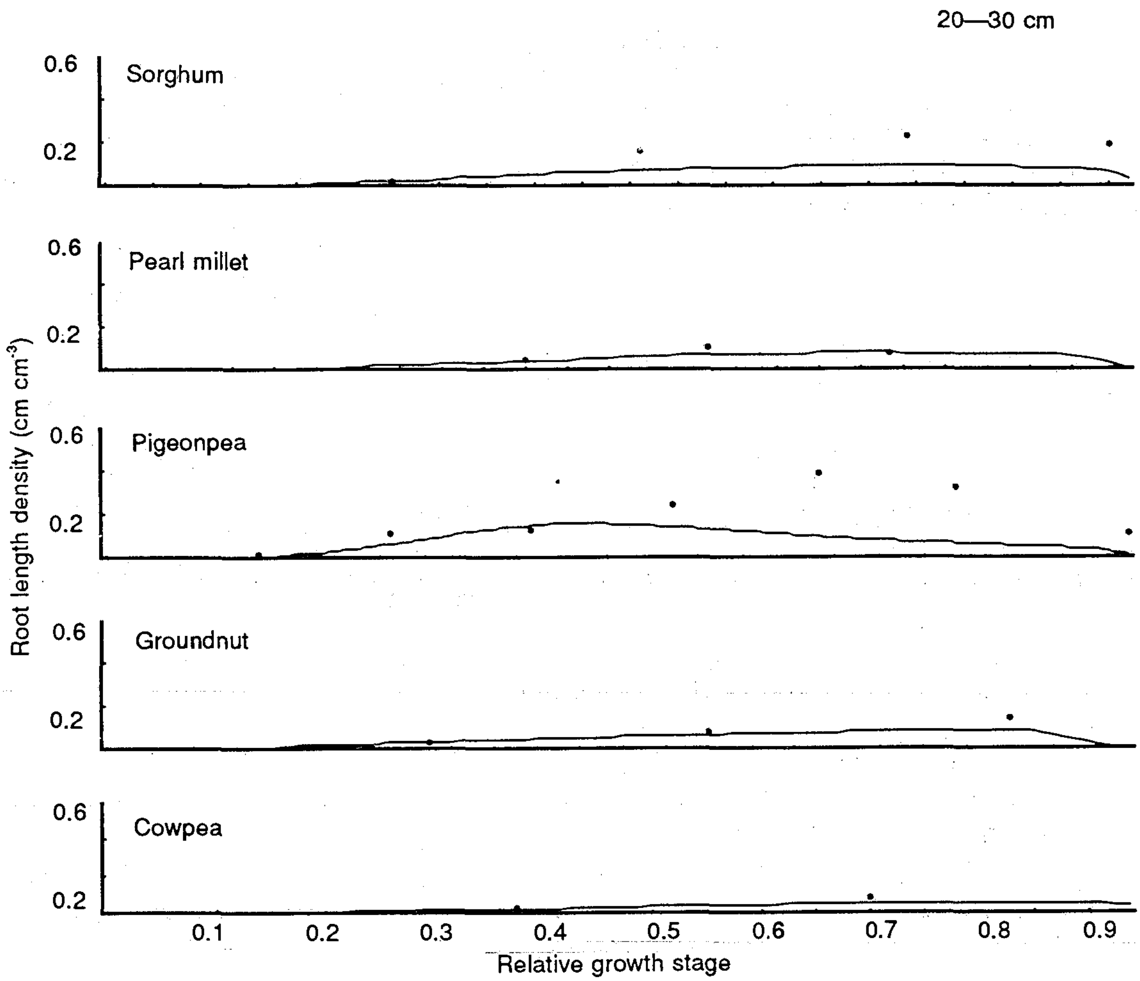


***Figure 15. Measured and simulated root length density at 20–30 cm for sorghum, pearl millet, pigeonpea, groundnut, and cowpea crops.***

Comparing the rooting depth among the crops used in this study using the growth stage relative to an entire growth period (referred to as relative growth stage, RGS), the rate of advance of the rooting front was fastest in pigeonpea at the early growth stage, followed by cowpea (data not shown). Pigeonpea and groundnut initially distributed more roots to the surface layer and then rapidly attained a deeper rooting depth, whereas the root development in cowpea was directed vertically downward in the soil profile at the initial growth stage. The cereals showed a slower rate of gain in the rooting depth compared with the legumes. The daily loss of root mass, expressed in kg $ha^{-1}$ $day^{-1}$, was highest in pigeonpea followed by pearl millet and cowpea (Fig. 16). The amount of root senescence was lowest in sorghum.

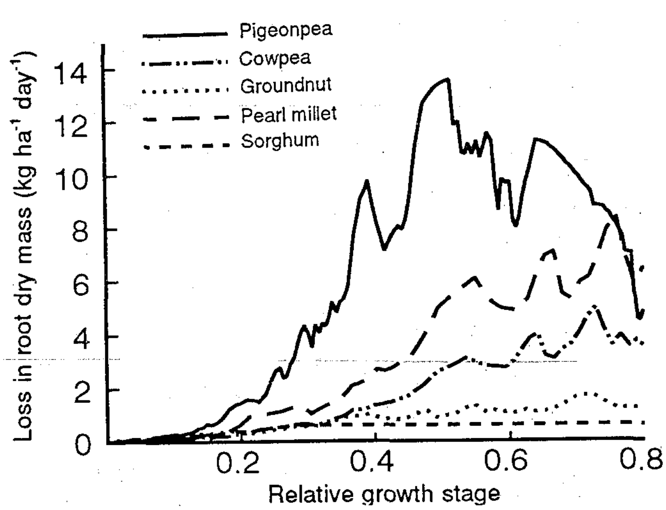


***Figure 16. Loss in root dry mass simulated by the model.***

The root distribution in terms of root length density in the surface layer was higher in cereals compared with any of the legumes. Among the legumes, pigeonpea and cowpea tended to develop more root length in the middle and lower layers than in the surface layer, as growth proceeded.

To adequately predict root system development and resource utilization of pigeonpea under intercropping situations, the following are needed. Firstly, the model needs to be adjusted to consider the structure of the pigeonpea root system, if adequate simulation is to be achieved. This is because pigeonpea has a tap root system with considerable branching and the tap root contributes to the root mass in the surface layers of the soil, while the lateral roots contribute mainly to the root length, but very little root mass due to their fine structure. Secondly, more data on roots from multilocational field experiments are essential.

## Root Activities and Function in Intercropping (Government of Japan Special Project)

Among various root traits, length and mass are most commonly measured both in the laboratory and field, as they are closely related to carbon allocation to roots and uptake of nutrients and water, which is a major function of roots. Although profile distribution of these traits in soil layers is greatly affected by physico-chemical properties of soils, considerable differences exist in root system architecture among plant species and genotypes. Characterization of root systems will become a more reliable source of information for better utilization of water and nutrients, if certain physiological activities of roots are measured together with length and mass.

Root respiration is one of the physiological traits relatively easy to measure even in the field, and approximates activities of functions such as growth, maintenance, and ion uptake. In this report, respiration was used as an indicator of root activity and was correlated with the major function of nitrogen uptake, using data from field experiments of pigeonpea-based intercropping with sorghum, pearl millet, cowpea, and groundnut.

Soil blocks were taken from the field by a monolith sampling method to obtain a rough measurement of root respiration after removal of soils by washing with tap water. Total root respiration was positively correlated with root fresh mass, the slope being respiration rate (mass basis) of whole root system (Fig. 17). Pigeonpea showed a higher rate than sorghum and the intercrop had a higher rate than the sole crop (Fig. 18).

To correlate respiratory activities with major physiological function, respiration was separated into two or three components such as growth, maintenance, and uptake, based in a simple first-order equation.

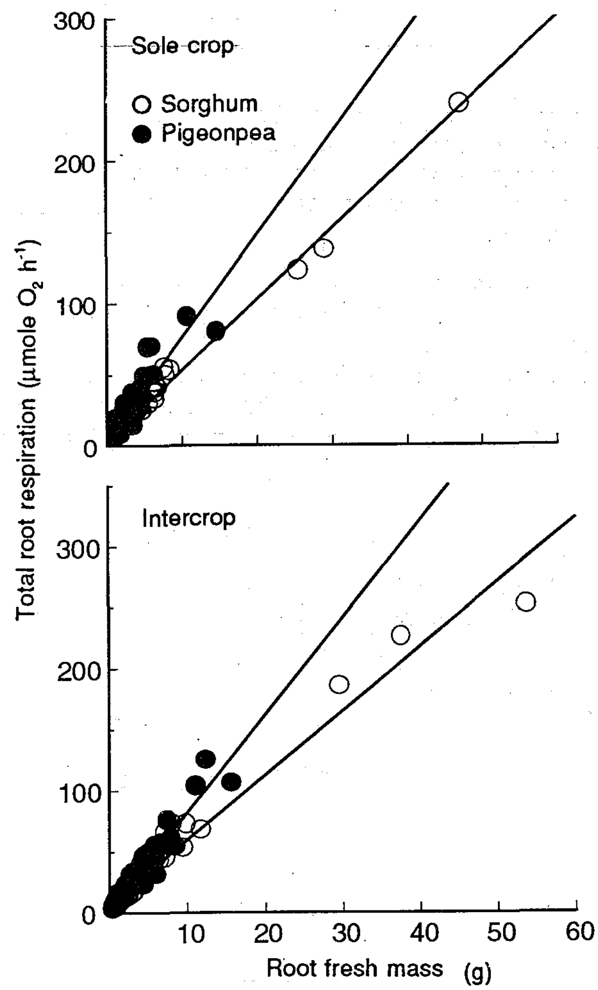


***Figure 17. Total root respiration and root fresh mass, measured in a soil block (10 x 10 x 5 cm) taken from the field of pigeonpea and sorghum in sole cropping and intercropping. The slope of regression lines gives respiration rate on a fresh mass basis.***

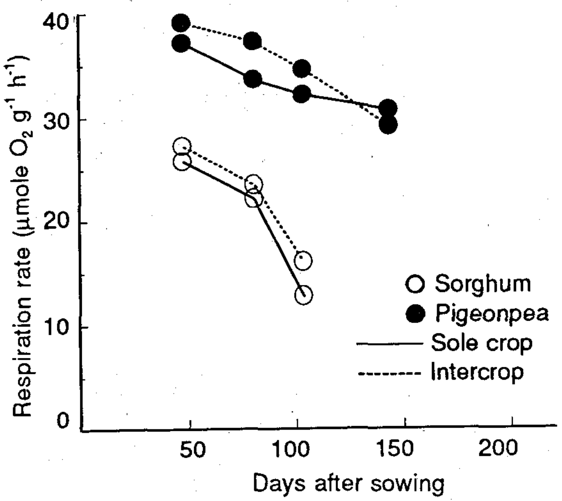


***Figure 18. Respiration rate (dry mass basis) of a whole root system obtained by the regression analysis presented in Figure 17 in pigeonpea and sorghum, under sole cropping and intercropping situations.***

R = aP + bW (1), where
R = rate of respiration,
P = rate of gross photosynthesis,
W = dry mass, and a and b are constants.

For much easier separation of respiration, the equation (1) was modified as:

R/W = g[(dW/dt)/W] + m (2), where
R/W = specific respiration rate,
(dW/dt)/W = relative growth rate,
g = growth coefficient, and
m = maintenance coefficient.

The g and m values were obtained from the slope and Y intercept, of the linear regression between relative growth rate and specific respiration rate. The g is converted to Yg, growth conversion efficiency, which describes an increase in the mass of plant material per unit mass of substrate used, by:

Yg = 1/(1 + g), (3)

Data obtained from our field experiments were analyzed following this approach (Fig. 19), and Yg and m calculated using reported values. Respiration rates obtained from two different experiments satisfactorily fitted the linear regression.

Our results showed that in order to achieve the same growth rate, legumes including pigeonpea, groundnut, and cowpea would require a much higher rate of root respiration than do cereals, including sorghum and pearl millet (Fig. 19). The rate of N accumulation including N uptake and $N_2$ fixation was calculated from the difference between

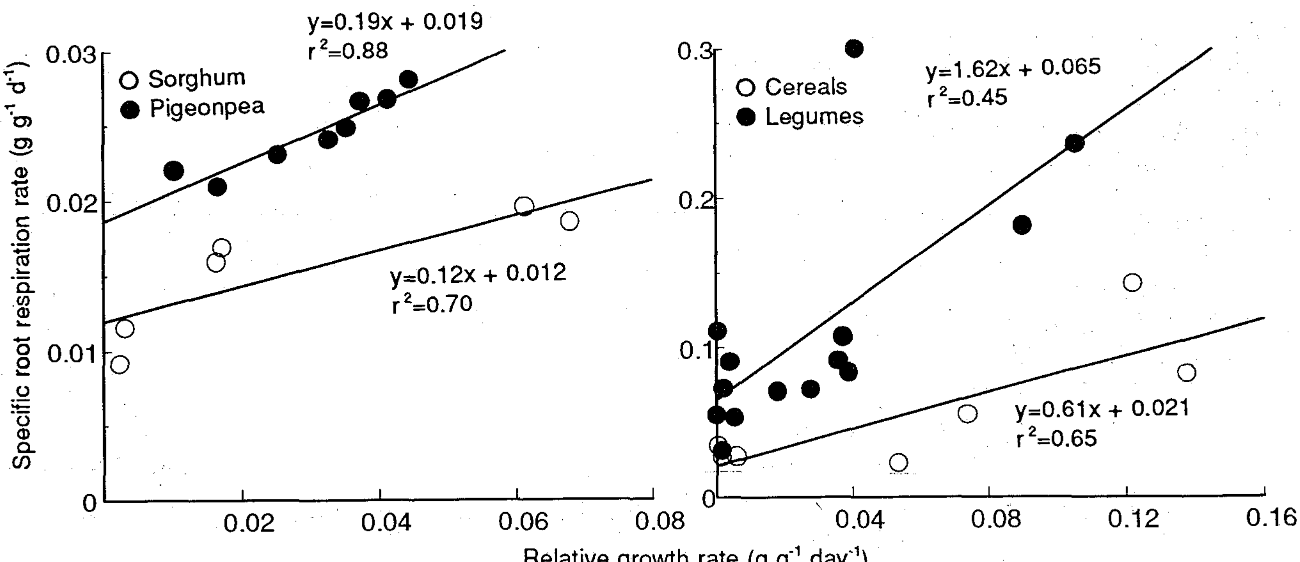


***Figure 19. Specific root respiration rate (dry mass basis) with relative growth rate of (a) pigeonpea and sorghum and (b) three legumes (pigeonpea, cowpea, and groundnut) and two cereals (sorghum and pearl millet), in sole cropping and intercropping. Conversion factors of $O_2$ to $CO_2$ is assumed to be 1 and that of $CO_2$ to $CH_2O$ is assumed to be 0.68.***

two consecutive sampling points and plotted against RGR (Fig. 20). Legumes and cereals fitted different relationships. The result clearly indicates that at the same rate of N accumulation, cereals can achieve much higher growth rate than legumes.

Respiratory cost for N accumulation was calculated for each individual crop used in this experiment. Pigeonpea had the highest respiratory cost, indicating that pigeonpea requires more respiratory activities to accumulate the same amount of nitrogen. The other four crops including two legumes and two cereals, show similar values and a seasonal trend. This suggests that a higher respiratory requirement for N accumulation in pigeonpea may not be due to biological $N_2$ fixation.

We observed that legumes and cereals differ in respiratory activities for growth and maintenance of roots. It should be further investigated whether the higher respiratory burden for growth and maintenance in legume roots would be related with formation and function of nodules or morphological differentiation of tap roots. Pigeonpea showed the lowest respiratory efficiency for N accumulation; in other words, pigeonpea may oxidize more carbohydrates to take up the same amount of N than do other crops. Pigeonpea has been considered as a promising component crop in cropping systems of the semi-arid tropics, especially from a view point of adaptability to water- and nutrient-limited conditions, and soil fertility maintenance. The higher respiratory requirement for N accumulation by pigeonpea might be a physiological adaptation to stressed environments. Intercropping causes a slight increase of root respiration, probably through alteration in patterns of dry matter accumulation.

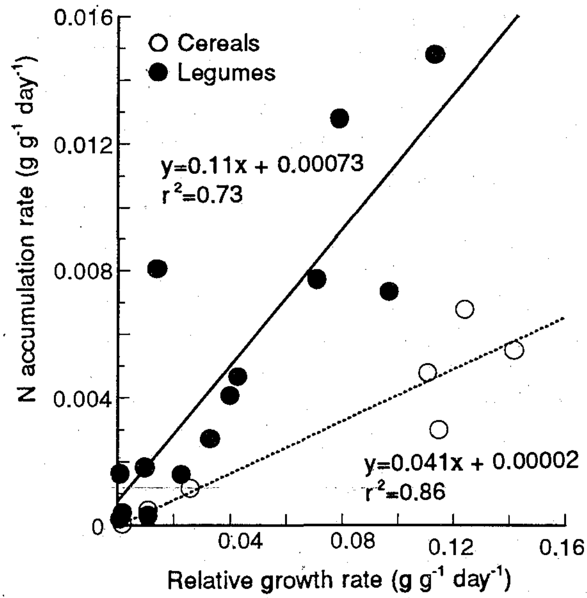


***Figure 20. Nitrogen accumulation rate in plants on the basis of root dry mass with relative growth rate of three legumes (pigeonpea, cowpea, and groundnut) and two cereals (sorghum and pearl millet).***

## Relationship Between Root Length Density and Soil Moisture Content Simultaneously Measured with Mini-rhizotron (Government of Japan Special Project)

Root development can be observed through a transparent observatory tube with a micro-video camera (popularly known as mini-rhizotron method). Similarly, soil moisture content (SMC) can be estimated through an aluminum tube with a neutron probe. Both methods are nondestructive and allow continuous observations from the same spot at different soil depths. Thus, the inherent variation due to soil heterogeneity in the field can be minimized for the time-course observation of root and water dynamics, although a considerable number of observations is still required for generalization of findings. In most cases, the measurements of root and water dynamics using both methods are carried out at separate spots in the same field. A more accurate picture of the quantitative relationship between root development and moisture status could be drawn if the measurements are possible through the same tube. In this study, we verified the possibility of using the same transparent tube for both measurements and then this was applied to a field experiment where five crops were grown under water-limiting conditions.

An acrylic tube and an aluminum tube were installed at a 45° angle to the soil horizon side by side. Soil moisture measurements were carried out with a neutron moisture meter (Model 3332, from Troxler Electronic Laboratories Inc., N.C., USA) from 0 to 90 cm soil depth at 1, 4, 8, 12, 15, and 22 days after irrigation. Three leguminous crops, pigeonpea (*Cajanus cajan* L. Moench), groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna sinensis* Endl.), and two cereals, hybrid grain sorghum (*Sorghum bicolor* L. Moench), and pearl millet (*Penninsetum glaucum* L.R. Br.) were grown on a broadbed in an Alfisol at IAC during the 1993 rainy season. Root length was measured with a mini-rhizotron apparatus (CIRCON MV9011 agriculture system with a color CCD micro video camera, MV9390) at 31, 46, 60, 74, 84, 105, 143, and 169 days after sowing. Root length at 10-cm intervals up to 60 cm depth was calculated from the number of roots observed on the surface of the tube. Soil moisture was measured simultaneously through the acrylic mini-rhizotron tube as described above at 15 cm intervals, up to 60 cm depth with the neutron probe. Soil moisture in the top 0–10 cm was estimated gravimetrically. The neutron counts through the acrylic tube were closely correlated with values measured through the aluminum tube (Fig. 21), clearly indicating that SMC can be properly estimated through the acrylic tube used for the mini-rhizotron observation with minor calibration.

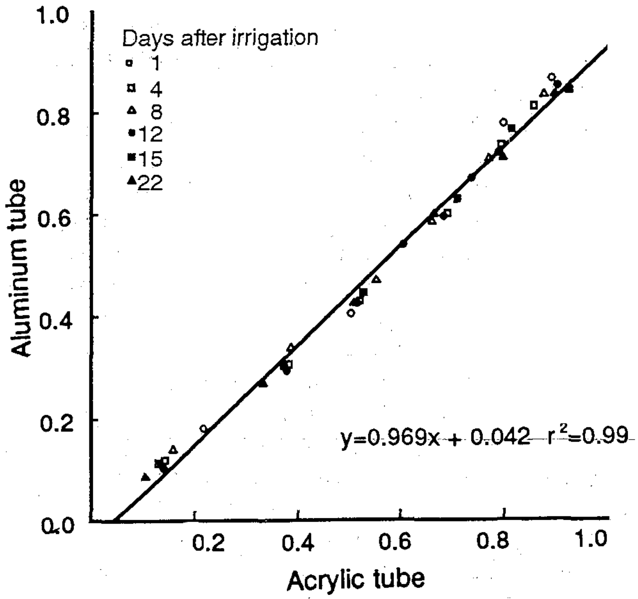


***Figure 21. Neutron counting for soil moisture measurement through acrylic and aluminum tubes.***

There was a significant negative correlation between SMC and root length density (RLD) of both cereals and legumes which resulted in the different regression lines. The difference in RLD between cereals and legumes became larger as water receded from soils, suggesting that cereals have a higher ability to develop more roots under water-limiting conditions than do legumes. This may be a desirable characteristic for survival in a moisture-deficient environment. The results confirm that acrylic tubes used to monitor root growth through the mini-rhizotron method can also be used for simultaneous monitoring of water dynamics under field conditions.

## Income-generating Cropping Systems

The main purpose of this study was to identify promising pigeonpea-based income-generating systems suitable for an Alfisol in Production System 9 and Vertisols in Production System 7 under rainfed conditions. An on-station study was conducted from 1990 to 1994. In this study, a medium-duration pigeonpea cv ICPL 87119 was strip-intercropped with several cash crops (green gram, sunflower, soybean, safflower, and cotton) independently in five replacement series of four strip widths (1,5,3,4.5, and 6-m strip) under three land configuration systems (flat; ridge and furrow (RF) at 0.75 m; and broadbed and furrow (BBF) at 1.5 m). Each crop was rotated with an associated intercrop in a 2-year rotation cycle.

Results indicated that all strip intercropping systems were more productive and profitable than sole pigeonpea or sole green gram + sunflower sequential systems. However, the sole cotton or sole soybean + safflower sequential system were the most profitable systems compared with any of the strip intercropping combinations. Land configuration or cropping system by land configuration interaction effects on individual crop yields or cropping systems economic returns were nonsignificant during all the 4 years. Sole cotton gave the maximum gross (Rs 19 870 $ha^{-1}$) and net returns (Rs 9970 $ha^{-1}$) with the lowest gross (Rs 10 480 $ha^{-1}$) and net returns (Rs 6250 $ha^{-1}$) obtained in the sole green gram + sunflower sequential system. Benefit/cost ratio varied widely among cropping systems and between years. A combination of 1.5-m pigeonpea and 4.5-m soybean + safflower strip intercropping gave the maximum benefit/cost ratio of 2.65, followed by a sole cotton or sole soybean + safflower sequential system with a benefit/cost ratio of 2.57 in each system. The lowest benefit/cost ratio of 1.57 was obtained in the sole green gram + sole sunflower sequential system.

CMBD

# Cellular and Molecular Biology Division

*A major activity of the Cellular and Molecular Biology Division is to make available to other divisions, mostly Genetic Enhancement Division, genetic material which cannot be accessed by conventional means.*

*The techniques used to achieve these objectives are wide hybridization, wherein useful genes from wild species of crop plants are transferred to cultivated crops using embryo rescue and tissue culture techniques; and the newer discipline of transformation, whereby genes from a totally unrelated source can be introduced into plants. The latter technique has considerably increased our chances of overcoming some of the longstanding problems in crop improvement.*

*The other activity in the division is to improve the efficiency of crop improvement by the production of haploid plants by anther culture.*

*Another technique to improve the efficiency of selection is the development of markers for agronomic characteristics. These markers can be scored in the laboratory, and relate to the presence of the desired gene. There are many advantages to the use of markers. Their accuracy can reduce the size of the population needed, and by detecting the presence of the gene, it is not necessary to expose the plant to pests and pathogens to assess the degree of resistance. Therefore, selection can be done at the seedling stage, and susceptible plants can be eradicated. Markers have an added advantage in that they are also very useful in assessing the range of diversity present in a selected group of plants, for example, a collection of germplasm.*

*The Cellular and Molecular Biology Division is also involved with the end products of genetic enhancement, in relation to the eventual utilization by the consumer. This work involves the analysis of nutritional value, protein content, and other dietary factors which are the ultimate measure of the value of the products.*

*Cellular and Molecular Biology Division scientists are members of 13 projects, with emphasis on genetic enhancement, and pest- and disease-resistance activities, but are also involved in aspects of farmer and consumer preferences.*

### Downy mildew pathogen

Downy mildew [*Sclerospora graminicola* (Sacc) Schroet] is an economically important disease of pearl millet [*Pennisetum glaucum* (L.) R. Br]. The crop is cultivated in about 26 million ha in the arid and semi-arid tropical and subtropical environments of Asia and Africa for forage and food. *Sclerospora graminicola* induces systemic infection in pearl millet, apparent as foliar symptoms and on panicle, as a green-ear disease. The disease is a serious threat to the full exploitation of the high yield potential of $F_1$ hybrids because of their high susceptibility. The pathogen is both seed- and soilborne, and it renders crop rotation less effective in controlling the disease. Like its host, the pathogen is also highly variable and isolates from different locations in a region show varying virulence patterns. To develop strategies to breed cultivars with durable and stable host resistance to downy mildew, it is important to generate information about pathogen populations; and six pathotypes were characterized at the molecular level.

We used DNA fingerprinting to characterize the genetic variability in six host genotype-specific pathotypes of *S. graminicola*: path-1 (from host NHB 3), path-2 (BJ 104), path-3 (MBH 110), path-4 (852 B), path-5 (700651), and path-6 (7042 S). These pathotypes were maintained on the respective host genotypes by repeated inoculation with asexual spores in isolation chambers in a greenhouse. Our results indicated that microsatellites $(GAA)_6$, $(GACA)_4$, and especially $(GATA)_4$, revealed a high level of polymorphism among the pathotypes with the specific restriction endonucleases. The six pathotypes were classified into five groups, based on cluster analysis of their genetic similarities, confirming the existence of host genotype-specific pathotypes of *S. graminicola*. The heterogeneity observed in the oospore- and zoospore-derived isolates of the pathogen was also evident in the DNA fingerprinting patterns, and showed differences from the host-specific pathotypes. Thus, the genetic variation *S. graminicola* was demonstrated for the first time by the DNA fingerprinting technique. These fingerprint profiles of the different pathotypes could serve as diagnostic tools to formulate breeding strategies and to monitor the emergence of new virulent races. This technique can be further used to study population structure and clonal dynamics of the fungus.

### Transformation

Preliminary experiments on sorghum gene transfer were conducted in collaboration with the International Centre for Genetic Engineering and Biotechnology, New Delhi. The target gene ß-glucoronidase (GUS) and a herbicide-resistant gene bar were bombarded into excised sorghum embryos and embryonic calli, using a microprojectile particle bombardment gun. Transient assay for GUS gene expression was positive, indicating transfer of genes, and the possibility of incorporating external genes into sorghum.

# Pearl Millet

## Production of dihaploids to expedite breeding

In pearl millet [*Pennisetum glaucum* (L.) R.Br.], to develop a new variety, the chosen attributes of two parental lines are combined, and the desirable plants are selected during the succeeding generations, before agronomically uniform lines can be derived. Pearl millet is a highly heterozygous cross-pollinated crop, and it takes more than 12 generations of selection to produce uniform lines that breed true. This causes a serious delay in breeding new varieties and hybrids. However, the process of deriving uniform lines can be hastened if haploid plants can be produced by the culture of microspores and then their chromosome number doubled to produce homozygous true breeding diploids.

Our results showed that a cold pretreatment of harvested panicles was necessary to induce the development of microspores. Incubating harvested panicles at 14°C rather than the commonly used 4°C pretreatment was better for inducing androgenic response. Among the different culture media tested, Yu-Pei medium was the most effective. It was found that incubating anthers in darkness was better than doing so under red light. Although the red light promoted the formation of proembryoids, placing cultures in the dark promoted the further development of embryoids. A higher temperature of 27°C was more favorable than 20°C to induce androgenesis under culture. Androgenesis in pearl millet involves the formation of the embryoid by the symmetrical division of the microspore. Among the different sugars tested, sucrose was most effective to induce divisions in the microspores, followed by maltose. Mannitol and sorbitol were not useful. The percentage of viable microspores was remarkably high in anthers even after three months in culture. Genotypic differences were also noted.

The knowledge obtained from the above studies is helpful to develop a successful protocol for the production of pearl millet dihaploids.

# Chickpea

## Wide Hybridization

The biggest constraint to the improvement of chickpea (*Cicer arietinum* L.), in spite of decades of active research, is limited genetic variation available in the chickpea germplasm. A major need is durable resistance to Ascochyta blight, especially in the winter-grown chickpeas in the WANA region.

*Cicer pinnatifidum* ICPW 38, a wild species incompatible with cultivated chickpea, has been identified as having good levels of resistance to Ascochyta blight.

Crossing *C. arietinum* cv GL-769 with *C. pinnatifidum* ICPW 38 resulted in pod set at a low frequency, but the seeds were shriveled and were 5 × 2 mm in size. By developing appropriate embryo rescue and tissue culture techniques for chickpea, hybrids between *C. arietinum* and *C. pinnatifidum* were produced and were propagated in vitro. Esterase isozyme analysis of the parents and the hybrid confirmed the hybridity of the progeny.

Initially the hybrid shoots lacked chlorophyll and were pale yellow. After a few subcultures, green shoots were observed. Transmission electron microscopy (TEM) of leaf sections from pale yellow plants showed abnormal chloroplast structure with poorly developed thylakoids containing few and disorganised grana. Transmission electron microscopy studies of green shoots showed normal chloroplasts with organised grana.

Interspecific derivatives obtained by crossing chickpea with *C.reticulatum* and *C. echinospermum* were sown in the field. The population showed a wide range of segregation for vegetative characters, duration, and yield parameters. Selections were made for further studies.

## Tissue Culture

To develop methods suitable for genetic transformation of chickpea, experiments were carried out to obtain shoot organogenesis and/or somatic embryogenesis from diverse seedling explants including cotyledons, leaves, roots, and embryo axis. Embryo axis from presoaked seeds and leaflets from 7-day-old seedlings produced globular embryo-like structures when cultured on a medium containing a high concentration of Auxin. However, these structures turned brown and necrosed after transfer to various media tested for embryo maturation. Attempts are underway to further optimize culture conditions for the recovery of mature and morphologically normal somatic embryos.

## Transformation

Embryo axes were used for the introduction of hygromycin phosphotransferase (HPT) and ß-glucuronidase (GUS) as marker genes. Decapitated embryo axes from presoaked seeds were incubated with *Agrobacterium* strain carrying the marker genes, before their culture on embryo culture medium containing 500 µg $L^{-1}$ carbenicillin. After 2 weeks, the embryo axis explants germinated. They were transferred to a selection medium containing 15 mg $L^{-1}$ hygromycin, where 90% of the shoots necrosed. So far it has not been possible to obtain putative transformants using this system.

## Crop Quality

### Functional properties

Functional properties of chickpea seeds are assuming significance in view of the increasing emphasis on the utilization of grain legumes in the cereal-based composite flours. We examined the functional properties of five genotypes each of desi (ICCV 10, ICCC 37, ICCV 88202, ICCV 92502, and Annigeri) and kabuli (ICCV 2, ICCV 3, ICCV 6, ICCV 16, and L 550) types. Emulsification capacity, gel consistency, and viscoamylographic properties were examined in detail. Results indicated that the starch component of kabulis was more viscous than those of the desis, confirming our earlier results. Also, the results of this study confirmed that the emulsification capacity of desi chickpea flours was higher than that from the kabuli types. This was further confirmed by the emulsification values of the isolated protein fractions of these two types of genotypes examined in a similar way. Emulsification capacity has been reported to be associated with product stability during storage.

## Monitoring Newly Developed Genotypes

It is essential to monitor newly developed genotypes for various grain quality components. We evaluated the dhal yield, cooking quality, and protein content of two newly developed genotypes: ICCV 88201 and ICCV 88202. The cooking time of dhal of ICCV 88202 was higher (27.7 min) than that of ICCV 88201 (22.7 min). There were no noticeable differences in dhal yield and protein content of these genotypes. In addition, we determined protein content in many germplasm accessions and breeding lines and found large variations among the samples.

# Pigeonpea

## Wide Hybridization

$F_1$ hybrids between *Cajanus platycarpus* Bentho and *Cajanus cajan* (L.) Millsp. were successfully obtained by rescuing aborting embryos (ICRISAT Legumes Program, Annual Report 1993).

The $F_1$ hybrids grew normally and flowered profusely, but the plants were completely pollen sterile. In order to obtain fertile $F_1$ hybrids, these plants were treated with colchicine to double their chromosome number. Only 2% of plants had doubled their chromosome number and had fertile pollen grains.

The fertile $F_1$ plants were selfed, and a large number of $F_2$ plants were obtained. The $F_2$ plants grew normally, and resembled the $F_1$ hybrids in their morphological characteristics, but were pollen fertile. A large number of shrunken and a few bold seeds were obtained. Though the seeds were bold, most of them did not reach maturity, and had to be germinated in vitro. The $F_2$ seeds resembled those of *C. platycarpus* in having a prominent strophiole and a black seed coat. The shape of the seed resembled that of cv ICPL 87, the female parent used in the original cross (*C. platycarpus* × *C. cajan* cv. ICPL 87).

## Tissue Culture

Tissue culture methods leading to somaclonal variation have been used to generate enhanced and heritable genetic variability. The $R_1$ plants that were regenerated without any selection pressure in culture, showed floral alterations which were absent in the sexual progeny, and are thus assumed to be epigenetic manifestations of tissue culture (ICRISAT Legumes Program, Annual Report 1993). Preliminary observations of $R_2$ plants showed segregation for flower color, plant height, leaf shape, and flowering habit. Statistical analysis of the $OR_2$ data on various yield parameters such as plant height, *Helicoverpa* damage, seed size, biomass, and harvest index has shown significant variations for these characteristics within the progenies from individual plants as well as among the different $R_1$ plants. The average frequency of variant phenotypes such as presence of strophiole, seed shape, seed coat color, and pattern, color and flowering habit recorded in all the plants arising from individual explants ranged from 0.25 to 4.0 variants per regenerated plant. Chi-square analysis showed that these characteristics segregated according to Mendelian ratios and were heterozygous in the $R_1$. Based on the cluster analysis of summary statistics, somaclonal segregants were selected for high yield, seed size, white seed coat color, and low *Helicoverpa* damage.

Molecular analysis based on RAPD was carried out using the leaf material from $R_3$ progeny. The plants used were those selected for desirable characteristics such as *Helicoverpa* resistance, white seed coat color, high harvest index, reduced plant height, and high 100-seed mass. Total genomic DNA was extracted, and RAPD analysis done using the polymerase chain reaction with 19 primers of arbitrary sequence of 10 nucleotides each. Eighteen of the primers amplified the template DNA, while 16 showed polymorphisms for different characteristics.

## Transformation

Since the nontransformed pigeonpea shoots can grow in the presence of very high levels of kanamycin (up to 150 mg $L^{-1}$), hygromycin was tested as an alternative selection agent. Hygromycin concentration of 20 mg $L^{-1}$ was found to be adequate to suppress regeneration of shoot buds from nontransformed cotyledon explants. An *Agrobacterium tumefaciens* strain carrying hpt and GUS genes was used to cocultivate the cotyledon explants. After 3 weeks of shoot induction, the shoot buds were transferred to the selection medium containing 20 mg $L^{-1}$ hygromycin. The surviving shoots (about 45% of the regenerated shoots) were transferred to the shoot elongation and multiplication medium. At this stage, histochemical analysis of the putative transformants showed a positive reaction for activity of the GUS gene. Work on the elongation of the regenerated shoots is going on.

## Crop Quality

### Nutritive value of food products

The method of food preparation in legumes includes such treatments as soaking, boiling, sprouting, fermentation, and extrusion processes. These treatments influence the nutritive value of the food products. We continued to examine the nutritive value of Asian and African food products of pigeonpea. Eighteen food products earlier prepared and freeze dried were analyzed for the calorific value (energy content) and mineral composition. The calorific value was highest (958.9 k cal 100 $g^{-1}$) for *masallam*, a Latin American food product made from green seeds of pigeonpea, and lowest (216.7 k cal 100 $g^{-1}$) for *isyo*, a Kenyan mixed food product of pigeonpea, maize, and potato. This indicated large differences in calorific value of food products of pigeonpea. Pigeonpea sprouts, *masallam*, *bongko*, and noodles were observed to be good sources of calcium, which varied from 120.7 to 219.9 mg 100 $g^{-1}$, for these products. Such food products as *empanadas*, *tempeh*, and stuffed *puri* contained low amount of calcium, ranging between 47.9 and 65.4 mg 100 $g^{-1}$.

# Groundnut

## Wide Hybridization

One of the important diseases of groundnut (*Arachis hypogaea* L.) in many of the SAT countries is early leaf spot (ELS) caused by *Cercospora arachidicola* Hori. Levels of resistance to this disease are low in most groundnut germplasms. Wild species with resistance genes to ELS in section *Erectoides* have been identified. When a range of species of section *Arachis* were crossed with species of section *Erectoides*, mature pods with immature seeds were obtained. Embryo rescue resulted in production of hybrid plants, which were completely pollen sterile.

*Arachis* wild species *A. hoehnoi* (collection no. GK 30006) has been identified to have high levels of resistance to aphids. Only immature pods were obtained when *A. hypogaea* was crossed with *A. hoehnoi*. The pollination to pod formation efficiency was 18%. *Arachis helodes* (collection no. GK 30036) also in section *Arachis* has good levels of resistance to leaf miner. Both mature and immature pods were obtained when *A. hypogaea* was crossed with *A. helodes*. The pollination to pod formation efficiency was 21% mature and 9% immature pods.

## Tissue Culture

Besides the cotyledon explant system for shoot regeneration (ICRISAT Legumes Program, Annual Report 1993), an alternative system based on leaf explants from 2–10-day-old seedlings was developed. In our preliminary studies, leaves from 2-day-old germinated seeds produce multiple shoot buds in 100% of the cultures. Various parameters such as the type of hormone and quantity, duration of exposure to the hormones, and factors affecting elongation of these shoots are being optimized.

To obtain somatic embryogenesis, a system based on the production of somatic embryos from embryo axis and immature leaves from mature seeds was developed. In our preliminary studies, it was possible to obtain at least 15–20 somatic embryos from each of these explants. However, about 70% of the embryos were morphologically abnormal, while 5–8% germinated normally. Histological studies with these systems are being carried out to ascertain the anatomical and temporal events associated with de novo shoot regeneration and somatic embryogenesis.

## Transformation

Genetic transformation experiments were carried out using split cotyledon and leaflet explants. *Agrobacterium* strains containing hpt and npt II genes were used for cocultivation experiments. The shoot buds produced after cocultivation were selected on 15–20 mg $L^{-1}$ hygromycin, where 70% of the treated explants produced shoot buds on selection medium. While the shoot buds from cotyledon explants produced shoots, those from leaflets did not. The shoots are being maintained on selection medium.

From the previous studies (ICRISAT Legumes Program, Annual Report 1993), the putative transformants containing GUS and npt II genes were transferred to the greenhouse where they grew normally and produced viable seeds. Some of the selected $T_1$ plants randomly tested positively for the GUS gene based on histochemical analysis, PCR amplification of the GUS and npt II genes and southern blot hybridization. These tests confirmed our groundnut transformation protocols, and this method is now suitable for the transfer of economically important genes.

## Crop Quality

### Effect of soil temperature on grain quality

Grain quality is considerably influenced by environmental factors. Soil factors such as fertility, moisture, and temperature are very critical for the growth and maturity of groundnuts, and hence affect the yield and quality components. We examined the effects of soil temperature on grain quality of groundnut by conducting an experiment in collaboration with the Agronomy Division. Oil, protein, starch, total soluble sugars, and fatty acid composition were determined in three groundnut cultivars (COMET, TMV 2, and AH 6179) grown at soil temperatures varying between day/midnight temperatures: 20°C/14°C ($T_1$), 26°C/20°C ($T_2$), 32°C/26°C ($T_3$), and 38°C/32°C ($T_4$). From $T_1$ to $T_2$, the oil concentration increased and the starch concentration decreased remarkably, but only slightly to $T_3$. The protein concentration was higher in the warmer soil temperatures than in the colder temperatures. There was no difference between $T_3$ and $T_4$ for oil, starch, and protein concentration. The total soluble sugar concentration was higher in both extreme temperature regimes than in the intermediate treatments. The oleic/linoleic acid ratio increased from $T_1$ to $T_3$. The results show that soil temperature has a marked effect on the proximate composition and fatty acid profile of these groundnut cultivars.

## Evaluation of blanching quality

Having standardized the laboratory method to evaluate blanching quality, we continue to monitor the blanching quality of confectionery types. Blanching quality of 54 bulk groundnut seed samples obtained from the 1993 rainy season yield trials were determined. Total blanchability percentage was higher in spanish than in virginia varieties, in both the advanced and elite confectionery varietal trials. Nonblanched kernel percentage was higher in virginia varieties. These samples were also analyzed for total soluble sugars which varied from 10.0 to 15.9%, indicating a large variation among the confectionery types.

CPD

# Crop Protection Division

*This is the first annual report produced by the ICRISAT Asia Center (IAC) after ICRISAT's restructuring during 1994, and a brief summary of the newly formed Crop Protection Division (CPD) follows. The Division is one of seven global divisions, with 26 scientists working in six different locations in the semi-arid tropics (SAT). The majority of them (19) are based at IAC; and the rest are based in Niger (3), northern Nigeria (1), Kenya (1), Zimbabwe (1), and Malawi (1). Crop Protection Division covers five important disciplines including pathology (12 scientists), entomology (9), virology (2), nematology (1), and microclimatology (2). Crop protection scientists are presently involved in 21 of ICRISAT's projects. CPD is therefore a diverse, widely distributed division that is well-integrated with other divisions, especially Genetic Enhancement Division (GED) and Cellular and Molecular Biology Division (CMBD), and within projects.*

*Crop Protection Division is involved in basic, strategic, applied, and adaptive research depending on the problem, the needs, and the stage of each research subproject and activity. The main research themes include host-plant resistance, cultural control, microclimatology in relation to diseases, strategic use of chemicals and natural control products, biological control, and insecticide resistance management. Increasingly, results from these themes are being assembled into integrated pest management strategies, some of which are now being tested on farm, in collaboration with the National Agricultural Research Systems (NARS), Nongovernmental Organizations (NGOs), and farmers.*

*During 1994, CPD carried out research on management of diseases, pests, and nematodes of all ICRISAT mandate crops in 12 major production systems in Asia, with the principal aim of improving the production and productivity of sorghum, pearl millet, groundnut, chickpea, and pigeonpea. Applied and adaptive research in southern, southeast and eastern Asia was facilitated by the Cereals and Legumes Asia Network (CLAN) which is coordinated from IAC. Collaborative research on chickpea in the West Asia and North Africa region was ongoing through the ICRISAT/International Center for Agricultural Research in the Dry Areas (ICARDA) Joint Kabuli Chickpea Project.*

*In this section, we describe research done at IAC, information and technology exchange during 1994. Results of research on diseases, microclimatology in relation to diseases and insect pests are organized under each crop. Research from CPD in Africa is reported separately in the ICRISAT West Africa and Southern and Eastern Africa Annual Reports.*

# Chickpea

## Diseases

### Wilt and root rots

In a multilocational testing (13 locations in India) of 49 chickpea lines identified as resistant to wilt and root rots at IAC, only two lines (ICCX 830141-BH-BH-4H and ICCX 830203-BH-BH-11H) were found resistant at seven locations, with a wilt incidence of ≤10%. Eight other lines were found resistant at six locations. All the 300 new germplasm lines tested at IAC were susceptible to wilt and root rots.

### Ascochyta blight

**Screening for Resistance:** In the Chaudhary Charan Singh Haryana Agricultural University (CCSHAU)-ICRISAT Cooperative Ascochyta Blight Nursery, we screened breeding lines ($F_5$ progenies) and entries from the Advanced Yield Trials (AYTs) and Preliminary Yield Trials (PYTs). Several lines showed moderate levels of resistance to ascochyta blight. Five breeding lines showed high levels of resistance (rating 3 on 1–9 point scale). The susceptible control Pb-7 was killed in the disease nursery.

Twenty-five $F_6$ progenies were screened at Hisar, Ludhiana, and Sri Ganganagar. All the lines were found resistant-to-moderately resistant at all locations.

Twenty-one entries from the Ascochyta Blight Nursery 1993/94 (ABN) were screened at five locations in India, and one location in Pakistan. Four lines, NARC 9002, 9005, 9006, and ICCX 850622-25H-BH were found resistant in all the locations in India and eight lines NARC 9002, 9005, 9008, 9009, ICCX 860047-BP-9H-BHB, ICCX 850622-BH-BH-25H-BH, FLIP 83-13C K, and ICC 3996 were found resistant in Islamabad, Pakistan.

### Botrytis gray mold

**Field Screening.** Field experiments on botrytis gray mold of chickpea were carried out in the Cooperative Botrytis Screening Nursery at the Gobind Ballabh Pant University of Agriculture and Technology (GBPUAT), Pantnagar, Uttar Pradesh, India. We screened six $F_3$ populations, one $F_5$ bulk, and entries from PYTs and AYTs against botrytis gray mold. Single plant selections were made in $F_3$ populations.

**Integrated Disease Management.** High level of resistance to botrytis gray mold (BGM) is not available in chickpea. Field screening indicated that the erect and compact genotypes suffer less than the spreading and semierect genotypes. Field trials on the integrated disease management of BGM were conducted for the third year at Pantnagar (India) and Ishurdi (Bangladesh) in the 1993/94 postrainy season.

A tall, erect genotype, ICCL 87322, and botrytis-susceptible genotype, H 208, were sown at four different row spacings: single row spacings of 30 and 60 cm and paired row spacings of 45:15:45 and 60:40:60 cm. Interplant spacing was maintained at 10 cm. One set of plots was sprayed with 0.2% vinclozolin (Ronilan®).

ICCL 87322 had low disease levels in both sprayed and nonsprayed plots. H-208, semispreading and susceptible to BGM, had high disease levels in sprayed and nonsprayed plots. The wide spacing influenced the disease levels significantly in both cultivars in sprayed and nonsprayed plots. These results confirmed the previous findings that it is possible to manage BGM in chickpea by sowing erect, compact genotypes (moderately resistant) at wide spacing with judicious use of fungicides. A similar trend was observed at Ishurdi in Bangladesh (Table 1).

Effects of dates of sowing and growth habit of five chickpea genotypes on BGM were studied for the third year. The genotypes were sown on four dates at 2-week-intervals from 31 Oct 1993 to 15 Dec 1993 at Pantnagar, and from 11 Oct 1993 to 11 Dec 1993 at Ishurdi. Of the five genotypes, ICCL 87322 and ICCV 88510 were erect and compact, and moderately resistant to BGM. H-208 was semispreading and highly susceptible to BGM, Pant G-114 semispreading and late maturing, and K 850 semierect. The date of sowing influenced the disease severity in all the genotypes. Delayed sowing in November-December resulted in low levels of disease, even in susceptible cultivars (Table 2).

***Table 1. Effect of row spacing and fungicide-sprays on botrytis gray mold severity in chickpea at Pantnagar (India) and Ishurdi (Bangladesh) 1993/94.***

| | | | Disease rating (1–9 scale)[1] | |
|---|---|---|---|---|
| Treatment | Cultivar | Spacing | Pantnagar | Ishurdi |
| Sprayed | ICCL 87322 | 30 x 10 | 4.7 | 4.0 |
| | | 60 x 10 | 4.5 | 2.0 |
| | | 45:15:45 | 4.2 | 5.3 |
| | | 60:40:60 | 3.5 | 4.3 |
| | H 208 | 30 x 10 | 7.2 | 7.3 |
| | | 60 x 10 | 5.5 | 3.5 |
| | | 45:15:45 | 5.0 | 7.8 |
| | | 60:40:60 | 5.0 | 6.3 |
| Nonsprayed | ICCL 87322 | 30 x 10 | 6.0 | 5.3 |
| | | 60 x 10 | 5.7 | 2.5 |
| | | 45:15:45 | 5.2 | 5.3 |
| | | 60:40:60 | 4.7 | 4.5 |
| | H 208 | 30 x 10 | 8.7 | 8.5 |
| | | 60 x 10 | 7.7 | 4.5 |
| | | 45:15:45 | 6.7 | 8.3 |
| | | 60:40:60 | 7.0 | 7.0 |
| SE | Cultivars | | ±0.132 | ±0.158 |
| | Spacing | | ±0.187 | ±0.224 |
| | Sprayings | | ±0.132 | ±0.158 |
| | Spacing x Spraying | | ±0.264 | ±0.316 |
| | Cultivar x Spacing | | ±0.187 | ±0.224 |
| | Cultivar x Spraying | | ±0.264 | ±0.316 |
| | Cultivar x Spraying x Spacing | ±0.373 | ±0.447 | |
| CV (%) | | | 13 | 16.6 |

1. Average of three replications on 1–9 scale, where 1=highly resistant, and 9=highly susceptible.

**Biocontrol of botrytis gray mold.** Several fungal isolates were screened in a growth room for their ability to suppress BGM of chickpea. Seedlings of the BGM-susceptible cultivar H 208 were grown in plastic trays. After 10 days, the trays were shifted to the growth room and inoculated with *B. cinerea.* Fungal isolates were multiplied on PDA plates; spores harvested with a camel brush, and their concentration adjusted to $10^8$ conidia $mL^{-1}$. The spore suspension was sprayed on seedlings one day before Botrytis inoculation. The disease observation recorded after 10 days indicated that only one of the isolates of *Trichoderma* (no. 15) was most effective in reducing the BGM incidence.

An experiment was conducted in the growth room to evaluate the effect of the time of application of *Trichoderma* or Ronilan®, and of the combination treatments. In general, when Ronilan® or *Trichoderma* was applied along with Botrytis (in the same suspension), the disease suppression was more than when they were applied before or after Botrytis application. Similarly, when Ronilan® was applied along with *Trichoderma,* 1 day before *Botrytis* application, disease suppression was less compared with the treatment combination when *Trichoderma* was applied immediately after the application of *Botrytis* and Ronilan® (Table 3). The biocontrol agent is now being tested in a field at Pantnagar.

***Table 2. Influence of dates of sowing and growth habit of chickpea genotypes on botrytis gray mold severity and yield at Pantnagar (India) and Ishurdi (Bangladesh) 1993/94.***

| | DS I | | | | DS II | | | | DS III | | | | DS IV | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pantnagar[1] | | Ishurdi[2] | | Pantnagar | | Ishurdi | | Pantnagar | | Ishurdi | | Pantnagar | | Ishurdi | |
| Cultivar | DR[3] | PY[4] | DR | PY | DR | PY | DR | PY | DR | PY | DR | PY | DR | PY | DR | PY |
| Pant G 114 | 5.5 | 0.5 | 6.3 | 0.4 | 5.7 | 0.6 | 6.5 | 0.5 | 5.7 | 0.5 | 2.5 | 0.4 | 4.0 | 0.2 | 2.3 | 0.4 |
| H 208 | 6.5 | 1.0 | 7.3 | 0.2 | 7.0 | 0.9 | 4.3 | 0.4 | 6.5 | 0.8 | 3.3 | 0.2 | 4.2 | 0.3 | 2.3 | 0.4 |
| K 850 | 6.4 | 0.2 | 7.0 | 0.3 | 5.7 | 0.7 | 5.3 | 0.4 | 4.5 | 0.8 | 2.5 | 0.3 | 4.0 | 0.3 | 2.2 | 0.3 |
| ICCL 87322 | 4.0 | 0.8 | 5.0 | 0.5 | 4.2 | 1.5 | 3.5 | 0.8 | 3.7 | 1.1 | 1.8 | 0.7 | 3.0 | 0.6 | 2.2 | 0.8 |
| ICCV 88510 | 6.5 | 0.6 | 6.0 | 0.1 | 5.7 | 1.1 | 6.3 | 0.4 | 6.3 | 0.5 | 2.3 | 0.4 | 3.0 | 0.3 | 2.9 | 0.3 |

| | Disease rating | | Yield (kg plot$^{-1}$) | |
|---|---|---|---|---|
| SE | Pantnagar | Ishurdi | Pantnagar | Ishurdi |
| Cultivar | ±0.20 | ±0.34 | ±95.5 | ±59.2 |
| Sowing | ±0.23 | ±0.32 | ±106.8 | ±53.0 |
| Cultivar x Sowing | ±0.45 | ±0.71 | ±213.5 | ±118.5 |
| CV (%) | 17.5 | 30.2 | 65.0 | 24.5 |

1. Dates of sowing: Pantnagar: DS I = 31 Nov 1993; DS II = 18 Nov 1993; DS III = 3 Dec 1993; DS IV = 15 Dec 1993.
2. Dates of sowing: Ishurdi : DS I = 11 Nov 1993; DS II = 21 Nov 1993; DS III = 1 Dec 1993; DS IV = 11 Dec 1993.
3. DR = Disease rating 1–9 scale (Average of four replications).
4. PY = Plot yield in kg (Average of four replications).

*Table 3. Integrated control of botrytis gray mold in the growth room.*

| Treatment[2] | Disease rating (1–9 scale)[1] 3 days | 5 days | 7 days | 9 days | 11 days | Mean |
|---|---|---|---|---|---|---|
| R→B | 3.2 | 4.0 | 4.7 | 5.2 | 5.5 | 4.5 |
| B→R | 2.7 | 3.7 | 4.2 | 5.0 | 5.2 | 4.2 |
| B+R | 2.2 | 2.7 | 4.2 | 4.2 | 4.5 | 3.6 |
| T→B | 1.5 | 2.0 | 2.7 | 3.2 | 3.5 | 2.6 |
| B→T | 3.0 | 3.5 | 4.5 | 4.5 | 4.7 | 4.0 |
| B+T | 1.2 | 1.5 | 1.7 | 2.2 | 2.5 | 1.8 |
| R→B→T | 2.5 | 3.0 | 4.7 | 4.7 | 4.7 | 3.9 |
| T→B→R | 1.2 | 1.5 | 1.7 | 2.2 | 3.0 | 1.9 |
| T+R→B | 2.0 | 2.7 | 3.0 | 3.5 | 4.2 | 3.1 |
| Control | 5.5 | 6.7 | 7.2 | 7.7 | 8.0 | 7.0 |
| Mean | 2.5 | 3.1 | 3.9 | 4.3 | 4.6 | |
| | | Treatment | Days | Treatment x days | | |
| CD (5%) | | 0.76 | 0.20 | 0.95 | | |
| CV (%) | | | | | | 12.00 |

1. Mean of four replications on 1–9 scale, where 1=highly resistant, and 9=highly susceptible.
2. R = Ronilan 0.01%; B = *Botrytis* 3 x $10^5$ spores $mL^{-1}$ from broth culture; T = *Trichoderma* $10^7$ spores $mL^{-1}$ from broth culture.

**Stunt Virus Disease.** Twenty chickpea lines were screened for resistance to stunt disease in a multilocational testing. None of the lines tested were free of stunt at both locations in Hisar (India) and Debre Zeit (Ethiopia). Five lines (ICCX 850568-BP-3H-BH, ICCX 850639-BH-BH-22H-BH, ICCV 90232, ICCX 800550-41BH-9H-BWR-BH-BH, and ICCC 10) had ≤10% incidence at Hisar (Table 4).

Surveys conducted during the 1993/94 postrainy season in collaboration with NARS for chickpea stunt in different locations in India showed that chickpea chlorotic dwarf geminivirus (CCDV) was predominant in Hisar (Haryana) and Sri Ganganagar (Rajasthan); luteovirus(es) were predominant in Akola and Amaravathi (Maharashtra), and at IAC. Both CCDV and luteoviruses were predominant in Khargone (Madhya Pradesh). From samples collected at Akola, another distinct luteovirus, hitherto not recorded on chickpeas, was observed.

On the basis of host range and chemical characterization, one of the luteoviruses (CpLV-IL1) associated with chickpea stunt disease (ICRISAT Legumes Program Annual Report, 1993, p.34) was identified as a strain of beet western yellows virus(BWYV). This is the first report of the occurrence of BWYV on chickpea in India.

In collaboration with the virologists at the Scottish Crop Research Institute (SCRI), UK, the coat protein (CP) sequence of luteoviruses were amplified by reverse transcription-polymerase chain reaction (RT-PCR) method and the nucleotide sequence determined. A comparison of the CP sequences obtained so far with the corresponding sequences of other luteoviruses revealed the presence of three luteoviruses. Two of them, tentatively named chickpea luteoviruses (CpLV) B9 and A24, appear to be distinct, not only from each other, but also from other luteoviruses such as bean leaf roll virus. The third one (CpLV-IL1) was found to be a strain of BWYV. These studies also revealed variation within CpLV-A24 isolate, indicating the presence of strains of this virus in chickpea. CpLV-A24 appears to be the most widespread of all the three luteoviruses. In field tests, CpLV-A24 could cause crop losses up to 90%, depending on the age when plants were infected.

***Table 4. Reaction of chickpea lines to stunt, from the 10th International Chickpea Stunt Disease Nursery (ICSDN) 1993/94, at Hisar (India) and Debre Zeit (Ethiopia).***

| | Stunt (%)[1] | |
|---|---|---|
| Entry | Hisar | Debre Zeit |
| ICCX 850504-BP-18H-BH K | 12 | 18 |
| ICCX 850568-BP-3H-BH K | 4 | 17 |
| ICCX 830150-BH-BH-3H-BH | 23 | 16 |
| ICCX 830198-BH-BH-10H-BH | 11 | 77 |
| ICCX 830273-BH-BH-44H-BH | 16 | 90 |
| ICCX 830276-BH-BH-6H-BH | 22 | 100 |
| ICCX 850637-BH-BH-22H-BH | 24 | 62 |
| ICCX 850639-BH-BH-28H-BH | 9 | 76 |
| ICCX 850622-BH-BH-34H-BH | 37 | 99 |
| ICCV 90212 | 18 | 15 |
| ICCV 90228 | 21 | 92 |
| ICCV 90231 | 39 | 71 |
| ICCV 90232 | 5 | 25 |
| ICCV 90250 | 16 | 15 |
| ICCV 88507 | 40 | 20 |
| ICCV 89437 | 12 | 14 |
| ICCX 830740-8H-BH-BH-BH-BH | 24 | 19 |
| ICCX 800550-41BH-9H-BWR-BH-BH | 4 | 22 |
| ICCC 10 | 10 | 81 |
| ICCX 830739-6HUY-3H-2H-BH | 23 | 13 |
| ICC 11322 (WR 315) (Range) | 17–50 | 22–77 |
| SE | ±13.4 | |

1. Average of two replications.

## Microclimatology in Relation to Diseases

### Effect of weather on ascochyta blight of chickpea

Experiments were carried out to investigate the effect of leaf wetness on ascochyta blight infection on chickpea . The minimum period for infection at the optimum temperature (21°C) was about 4 h, and more than 50% disease severity resulted from exposure to leaf wetness for 24 h.

A published report of a substantial increase in infection when leaves were dried for 6 h after inoculation before exposure to 24 h wetness, compared with the same wetness period without drying, was not supported. We found continued reduction in infection with an increasing dry period. The pathogen was able to withstand drying for 8–10 h, but this never resulted in increased disease severity.

### Nematode diseases: root-knot nematode

Two-hundred-and-twenty-seven germplasm lines were screened for resistance to root-knot nematode, *Meloidogyne javanica*, in the greenhouse. All the accessions were found susceptible.

## Insect Pests

The main areas of chickpea entomology work during 1994 were the evaluation of component technologies, which could be used as part of an integrated approach to pest management on chickpea and the identification of the mechanisms of resistance to *H. armigera*.

An evaluation of component technologies was carried out at IAC. This involved a study of the effectiveness of an insect pathogen [(*Helicoverpa* Nuclear Polyhedrosis Virus (NPV)] when used in conjunction with *Helicoverpa*-resistant chickpea, and a study of the effect of intercropping on populations of *H. armigera* and its natural enemies.

Results from the study of the effectiveness of NPV have shown that the virus, which is highly specific and not harmful to humans, can provide control of *H. armigera,* similar to that provided by a correctly used synthetic insecticide. However, the NPV and the synthetic insecticide were both less effective in controlling the pest on *Helicoverpa*-resistant genotypes than on susceptible genotypes. The highest yields were recorded from a combination of susceptible genotype + NPV (1.27 t $ha^{-1}$) compared with 0.62 t $ha^{-1}$ in the nonsprayed control. The study identified NPV as a promising new management option for *H. armigera.* However, surveys of NPV formulations available in India have shown large differences in the quality of the products. Many of the products contained less than 5% of the stated amount of virus. This lack of quality control will limit the successful widespread use of NPV for *H. armigera* management in the immediate future.

Results of the study of the effect of intercropping on pest populations did not show any benefits in terms of increased parasitism of *Helicoverpa* larvae in plots of intercropped chickpea compared with sole chickpea plots. However, there were significantly more *H. armigera* larvae in the sole chickpea plots than in plots of chickpea intercropped with linseed. Further studies are now required, to examine the mechanisms responsible for these differences.

### *Helicoverpa* resistance

The chemical basis of the resistance mechanism to *Helicoverpa armigera* in chickpea was investigated. The larval growth of *H. armigera* was retarded on ICC 506, ICCV 7, ICCL 86101, and ICCL 86102, the genotypes which have been identified as resistant to *H. armigera*, compared with Annigeri and ICCX 730266, the susceptible controls, in a feeding test using fresh leaves. A feeding test using unwashed and washed leaves of ICC 506 and Annigeri revealed that the substance responsible for the larval growth inhibition is water soluble and is present on the surface of the leaves. These results are consistent with previous reports that acidic exudate from trichomes on chickpea plant surfaces is correlated with the reduced pod damage in the resistant genotypes. Acid components of the leaf exudate were analyzed by high performance liquid chromatography. Oxalic acid and malic acid were detected as major components in all four genotypes which were analyzed. The genotypes resistant to *H. armigera,* ICC 506 and ICCL 86102, accumulated more oxalic acid on the leaves than did Annigeri and ICCX 730266, the susceptible controls. Oxalic acid caused significant growth inhibition of *H. armigera* larvae, when included in a semiartificial diet. The accumulation of oxalic acid on the leaves is considered to be one of the mechanisms of *H. armigera* resistance in chickpea. Results of a paper feeding test showed that the larval growth inhibition by oxalic acid is not due to an anti-feedant effect. It is more probably due to antibiosis. Malic acid had no effect on the larval growth.

# Pigeonpea

## Diseases

**Influence of cropping systems on soilborne pathogens and antagonists.** Soil samples from farmers' fields in Andhra Pradesh representing seven different cropping systems were collected during February-April. They were analyzed for populations of plant pathogenic fungi—*Fusarium* spp, *Rhizoctonia* spp, and *Sclerotium* spp, and antagonistic fungi—*Aspergillus* spp, *Penicillium* spp, and *Trichoderma* spp. Of the seven cropping systems studied, two were from Alfisol [pigeonpea (PP)/maize, PP/groundnut], and five were from Vertisol [PP/sorghum, PP/sunflower, PP/green gram(GG)/black gram (BG), PP monocrop, and PP/cotton].

In all the cropping systems studied, the population of *Fusarium* spp. was higher than those of *Rhizoctonia* spp and *Sclerotium* spp. *Fusarium* spp populations in the two cropping systems on Alfisols were lower than in the five cropping systems on Vertisols. On Vertisols, the *Fusarium* spp population was comparatively higher in pigeonpea monocrop, PP-sorghum, and PP-GG/BG systems than in the others (Table 5).

*Table 5. Populations of* Fusarium *spp and four known antagonistic fungi, in seven different pigeonpea(PP)-based cropping systems in farmers' fields in Andhra Pradesh, March 1994.*

| | | | | Fungal population[1] [colony forming units (cfu) $g^{-1}$ soil] | | | | |
|---|---|---|---|---|---|---|---|---|
| Location/ district | Cropping systems[1] | Soil type | No. of fields studied | *Fusarium* spp | *Aspergillus* spp | *A. niger* | *Penicillium* spp | *Trichoderma* spp |
| Baswapur (Medak) | PP/maize | Alfisol | 10 | 567±124.1 (60–1210)[2] | 326±77.2 (0–780) | 1059±164.2 (260–1780) | 1004±233.1 (160–2360) | 880±361.1 (40–2560) |
| Tandur (Ranga Reddy) | PP/sorghum | Vertisol | 4 | 2040±369.3 (1320–3260) | 345±154.1 (0–840) | 1240±296.3 (440–1820) | 0 (0) | 935±410.0 (0–1920) |
| Tandur (Ranga Reddy) | PP/sunflower | Vertisol | 2 | 965±208.5 (670–1260) | 0 (0) | 3270±813.2 (2120–4420) | 70±49.5 (0–140) | 30±21.2 (0–60) |
| Tandur (Ranga Reddy) | PP/greengram/ black gram | Vertisol | 3 | 1897±111.1 (1650–2120) | 433±89.6 (240–620) | 2067±94.4 (1840–2220) | 0 (0) | 520±258.6 (0–1560) |
| Tandur (Ranga Reddy) | PP monocrop | Vertisol | 1 | 2820 (-)[3] | 1600 (-) | 3540 (-) | 0 (-) | 260 (-) |
| Nirmal (Adilabad) | PP/cotton | Vertisol | 10 | 1452±119.1 (900–2100) | 1190±461.9 (360–5220) | 6004±1159.7 2220–15880) | 982±388.9 (0–3440) | 4080±1140.9 (0–11960) |
| Anantapur (Kurnool) | PP/groundnut | Alfisol | 10 | 718±132.3 (40–1290) | 1390±184.9 (480–2260) | 1652±278.1 (280–3020) | 8±6.1 (0–60) | 10±8.0 (0–80) |

1. Populations of *Rhizoctonia* spp and *Sclerotium* spp were also estimated, but their populations in all the cropping systems were very low.
2. Figures in parentheses indicate range.
3. Range is not given as there was only one field of pigeonpea monocrop.

Populations of four antagonistic fungi were different in various cropping systems. Populations of *Aspergillus* spp were generally higher than those of *Penicillium* spp and *Trichoderma* spp. While a negative relationship was observed between *Fusarium* spp and *Penicillium* spp populations, no clear trend was noted between *Fusarium* spp and other antagonistic fungi. Pigeonpea/cotton system favored relatively higher populations of all the antagonistic fungi.

**Influence of cropping systems on *Fusarium* spp population.** Seven pigeonpea-based cropping systems (prevalent in Asia and southeast Asia) were sown in a pot experiment at IAC in both Alfisols and Vertisols, to study their effects on wilt incidence and *Fusarium* spp population in soil. These cropping systems were: PP/maize, PP/sorghum, PP/groundnut, PP/cotton, PP/green gram, sole PP, and fallow. These systems were tested at two levels of *Fusarium* spp populations in both diluted and wilt-sick Vertisols and Alfisols; with about 2225 colony forming units (cfu) $g^{-1}$ soil *Fusarium* spp population in wilt-sick Vertisols, and 1623 cfu $g^{-1}$ soil *Fusarium* spp population in wilt-sick Alfisols. The soil was then diluted to bring the populations to threshold level, i.e., approximately 1000 cfu $g^{-1}$ soil. Soil samples were analyzed from all the treatments for *Fusarium* spp populations after 4 and 6 months of sowing.

In general, in both Alfisols and Vertisols, and in wilt-sick and diluted soils, there was an increase in *Fusarium* spp populations from the time of sowing to 4 months after sowing (MAS), and a decrease from 4 MAS to 6 MAS. Also, the increase in *Fusarium* spp populations was more in the diluted soil than in wilt-sick soil. At 6 MAS, in both the soils and dilutions, there was a significant decrease in *Fusarium* spp populations in fallow compared with all the cropping systems. In the diluted soil, in both types of soils, there was a significant increase in *Fusarium* spp populations from the time of sowing to 6 MAS in all the cropping systems. However, in the wilt-sick soil (both Alfisols and Vertisols), there was a significant increase in *Fusarium* spp populations only in groundnut/PP systems from the time of sowing to 6 MAS. In Vertisols, the increase in population was also significant in PP/sorghum and sole PP.

**Effect of PP/castor intercropping on pigeonpea wilt incidence and *Fusarium* spp populations.** The effect of this system on pigeonpea wilt incidence, biomass, and *Fusarium* spp population in soil was studied in Vertisols in a greenhouse experiment. Pigeonpea/castor intercropping reduced the pigeonpea wilt incidence as well as *Fusarium* spp population in soil, 3–4 MAS. Wilt incidence in pigeonpea was significantly less (31%) in PP/castor intercrop compared with 93% in sole PP, 6 MAS. Similar results were obtained in 1993.

**Effect of root exudates of different crops on conidial germination of *Fusarium udum*.** Effect of root exudates of castor, sorghum (yellow local), cotton, maize, and pigeonpea on conidial germination of *Fusarium udum* was studied. Castor and maize root exudates were found highly inhibitory to conidial germination. Conidial germination was significantly less in castor (17%) and maize (41%) root exudates than in the control (water) (80%). Sorghum root exudate was less inhibitory (72%) to conidial germination of *F. udum*. Germination of conidia was significantly higher in cotton and pigeonpea root exudates than in the control (Table 6).

*Table 6. Effect of root exudates on the germination of the conidia of* Fusarium udum.

| Root exudates | Germination (%) |
|---|---|
| Control (water) | 80 |
| Sorghum | 72 |
| Maize | 41 |
| Cotton | 94 |
| Castor | 17 |
| Pigeonpea | 90 |
| SE | ±1.11 |
| LSD (at $P$ <0.05) | 3.5 |

## Nematode diseases

**Reniform nematode.** One-thousand-three-hundred-and-thirty-three germplasm accessions of pigeonpea were screened in a greenhouse for resistance to the reniform nematode, *Rotylenchulus reniformis*. Results indicated that nine accessions (ICPs 4220, 4221, 4240, 4281, 4286, 4317, 4680, 4881, and 4886) were moderately resistant to this nematode.

Of the 13 accessions of *Cajanus platycarpa* screened for resistance to the reniform nematode, four accessions (ICPWs 62, 68, 70, and 72) were found to be resistant. However, variable reactions of these accessions to the nematode were noted. Hence, these lines are now being purified.

**Cyst nematode.** All the 272 germplasm accessions screened in the greenhouse for resistance to pigeonpea cyst nematode, *Heterodera cajani*, were found susceptible. The *C. platycarpa* lines ICPWs 62, 69, and 70 identified as resistant, also showed variable reactions to the cyst nematode. These are also purified through single-plant selections based on zero cysts among the artificially inoculated plants.

**Root-knot nematode.** All the 13 accessions of *C. platycarpa* were found to be susceptible to root-knot nematode, *Meloidogyne javanica*.

# Insect Pests

## On-farm research

The focus of our pigeonpea entomology work during 1994 was on-farm research. This multi-disciplinary project involved staff from the Indian Council of Agricultural Research (ICAR)—Transfer of Technology program, Andhra Pradesh Agricultural University (APAU), and The Centre for World Solidarity, a local nongovernmental organization, in addition to IAC staff. The goal was to understand farmers' pest management practices and perceptions, and to involve farmers themselves in the evaluation of pest management technology in Marepalle village, Andhra Pradesh.

During 1994, we completed an extensive household survey, summarized findings from the first year's trials, and implemented the second year's trials, which evaluated both cultivars and two improved management practices. Several problems were highlighted in the household survey. Pesticides are widely used to control insect pests of pigeonpea, though farmers doubt their effectiveness. Overuse and inappropriate application are common. Part of this problem is due to farmers' lack of pertinent and unbiased information; fewer than 20% of farmers receive any pesticide-related information from extension agents. Shop-keepers are the main source of information, and also provide loans to most farmers to purchase pesticides. During the first season, we evaluated three *Helicoverpa armigera*-tolerant ICRISAT pigeonpea genotypes. Farmers participated in the evaluation through individual and group interviews, and based on their recommendation, two genotypes were selected for use in the second year. In the second year, in addition to the improved pigeonpea genotypes, we evaluated two management tactics, improved pesticide application, and a nonchemical approach. The former tactic involved advising farmers on correct mixing procedures, application rates and times, and on how to identify the most susceptible stage of the pest. For the nonchemical approach, we asked farmers to replace their synthetic pesticides with Nuclear Polyhedrosis Virus (NPV) (a highly specific insect pathogen), produced by a collaborating agency (Central Integrated Pest Management Centre, an ICAR organization). Our on-farm research also included collaborating with scientists at a nearby APAU research station. In the first year, we sowed the same three *H. armigera*-tolerant genotypes at the research station as were sown in farmers' fields at Marepalle. We limited pesticide applications to three sprays, as against the five to six applications that farmers make, and maintained effective control and good yields. During the second year, we evaluated 17 medium-duration pest-and disease-tolerant genotypes in a replicated trial. Yields and pod damage of the 17 genotypes, which included both ICRISAT and APAU material, as well as traditionally grown cultivars and standard controls, are given in Table 7.

***Table 7. Evaluation of pigeonpea genotypes against insect pests at the Andhra Pradesh Agricultural University Research Station, Tandur, rainy season 1994/95.***

| | Pod damage (%) (mean of five plants) | | | |
|---|---|---|---|---|
| Genotype | Borer | Podfly | Total | Yield ($t\ ha^{-1}$) |
| 850179-WE3-WEB-WH2-WHB[1]-HN49[1] | 52.6 | 2.1 | 55.1 | 1.09 |
| 860109-WE84-WH3-WHB[1]-HN46[1] | 43.1 | 1.4 | 44.6 | 1.38 |
| 860109-WE84-WH3-WHB[1]-HN3[1] | 37.9 | 1.0 | 39.2 | 0.78 |
| 860109-WE84-WH3-WHB[1]-HN13[1] | 38.5 | 1.4 | 40.1 | 1.05 |
| 860109-WE84-WH4-WHB[1]-HN29[1] | 36.7 | 1.2 | 38.4 | 1.31 |
| 860109-WE84-WH84-WHB[1]-HN31[1] | 37.0 | 1.1 | 38.5 | 1.31 |
| ICPL 332 | 47.9 | 1.2 | 49.6 | 1.14 |
| ICP 1691-E1 | 50.1 | 1.3 | 51.5 | 1.34 |
| ICP 8863 | 61.9 | 3.0 | 65.4 | 0.95 |
| C 11 (control) | 51.3 | 4.0 | 55.6 | 1.25 |
| ICPL 84060 | 43.1 | 0.9 | 44.2 | 1.23 |
| ICPL 87119 | 50.3 | 7.3 | 57.4 | 1.90 |
| ICPL 87088 | 42.9 | 1.4 | 44.9 | 1.04 |
| ICPL 87089 | 40.1 | 1.2 | 41.8 | 0.91 |
| PRG 88 | 54.9 | 9.2 | 63.7 | 0.94 |
| PRG 100 | 59.0 | 1.8 | 61.2 | 0.79 |
| Local | 55.1 | 11.4 | 66.5 | 0.97 |
| Trial mean | 47.2 | 2.98 | 50.45 | 1141 |
| SE | ±3.19 | ±1.147 | ±3.053 | ±110.4 |

1. Seed used from selfed plants.

## Egg parasite of *Helicoverpa*

We also initiated work under a special project [Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)/ ICRISAT] investigating the impact of cropping systems and host plants on the searching and parasitization behavior of *Trichogramma chilonis*. This parasite is an important natural enemy of *H. armigera* on many plants, but only rarely (<1%) attacks *H. armigera* eggs on pigeonpea. The reason for this has not been investigated. A field trial was sown this year to try and duplicate earlier results which showed that parasitism levels could be enhanced by intercropping sorghum and pigeonpea cultivars which flower at nearly the same time. On sorghum panicles, up to 50% of the *H. armigera* eggs were parasitized by *Trichogramma* spp. Parasitism of eggs collected from both pigeonpea cultivars was low, 1.4% (n=138) on ICPL 87 and 12% (n=59) on ICPL 84052. In contrast to earlier work, the interval between sorghum and pigeonpea flowering times did not appear to have an effect on the abundance of *Trichogramma* spp in the pigeonpea. We also began studying the role of pigeonpea surface chemicals on the behavior of *T. chilonis*. Three different extracts of the plant surface (water, acetone, and hexane) were evaluated by washing leaves and pods, and placing the extract on filter paper. Trichogramma wasps were repelled by hexane extracts of pigeonpea leaves and pods. The repellant effect of the pods was stronger, probably because of the higher concentration of these chemicals on pods compared with those on leaves.

## Host-plant resistance

Insect damage to pigeonpea is often extensive, with losses up to 100% being reported. Wild relatives of pigeonpea are rarely damaged, though the same insects will, under no-choice conditions, feed on these plants. We also began studies to understand the host-plant resistance mechanisms in the wild relatives of pigeonpea. We evaluated 166 accessions of 16 species in the field: 6 species of *Cajanus* and 10 species of *Rhynchosia*. Most of these accessions suffered less *H. armigera*-caused pod damage than pods on adjacent pigeonpea plants. Both physical and biochemical factors may contribute to the lower levels of damage observed in the wild species. A more critical assessment of two species, *Cajanus scarabaeoides* and *C. platycarpus*, was undertaken using the cultivated *C. cajan* as a control. The survival rate for neonate *H. armigera* larvae after 3 days on the pods of the three species was 16% on *C. scarabaeoides*, 46% on *C. platycarpus*, and 70% on *C. cajan*. Larval and pupal mortality were significantly higher, and larval development time was significantly longer when larvae were reared on *C. scarabaeoides* compared with *C. platycarpus* or *C. cajan*. We are also investigating biochemical factors in these two wild species which inhibit growth and development of *H. armigera* larvae. Acetone extracts of macerated *C. scarabaeoides* and pigeonpea pods were used in a filter paper feeding test and compared separately with a nontreated control, to calculate an Antifeedant Index. Extracts from both *C. scarabaeoides* and pigeonpea showed a feeding stimulant effect, though it was much stronger in the pigeonpea. Thus, it may be that part of the resistance of *C. scarabaeoides* to *H. armigera* is due to reduced feeding stimulation relative to pigeonpea.

## Insecticide resistance management

In collaboration with the Natural Resources Institute (NRI), UK, and the ICAR, six laboratories have been established with NARS, at the Andhra Pradesh Agricultural University, Regional Research Station, Guntur, and the Central Institute for Cotton Research—Coimbatore, Nagpur, and Sirsa; Tamil Nadu agricultural University—Coimbatore, Madurai. To monitor the dynamics of insecticide resistance in *Helicoverpa armigera* and to undertake research to develop improved control practices for this pest on cotton and pulses. Resistance to pyrethroid insecticides in Indian populations of *H. armigera* was first reported in the late 1980s, when farmers were unable to control this pest with insecticides on cotton crops in coastal Andhra Pradesh. Since that time, the situation has deteriorated, and reports of failures to control *H. armigera* on field crops have increased to the extent that they are commonplace throughout the Indian subcontinent. Systematic monitoring has revealed that pyrethroid resistance frequencies in *H. armigera* are high throughout India, and also in Pakistan and Nepal. Variable levels of resistance have also been reported to carbamate, cyclodiene and organophosphate insecticides in many regions of the subcontinent. As insecticides are still the mainstay for bollworm control in India, farmers have resorted to applying increased doses of insecticides at more frequent intervals in an attempt to control resistant *H. armigera* (termed the pesticide treadmill). In addition to the economic costs of resistance, must be added the unquantified, though almost certainly significant, costs of environmental contamination and human toxicity caused by the increased applications. Systematic resistance monitoring has provided the basic information needed to determine the extent of the problem and to model seasonal resistance trends. A field trial program is now underway at IAC and at NARS locations to develop practical strategies for improved management of insecticide-resistant cotton and pulse pests. The aim is to reduce the number of applications applied to a crop during the season by ensuring that maximum benefit is achieved from sprays through careful timing of applications, choice of chemical, and correct pest identification. Incorporation of biorational insecticides (NPV, Bt, and neem) into spray scheduling is also being researched.

# Groundnut

## Diseases

### Rust and late leaf spot

**Screening of germplasm/breeding lines.** Thirty selected breeding lines (including three resistant and three susceptible control cultivars) were evaluated for resistance to rust and/or late leaf spot (LLS) during the 1994 rainy season. Rust resistance was confirmed in 12 genotypes (medium duration, confectionery, and pest resistant). Two lines (ICGV 92163 and ICGV 890142) showed resistance to LLS.

Of the 212 breeding lines evaluated for resistance to rust and LLS, many were found resistant to rust; some (e.g., ICGV 93222 and 94165) had rust scores of 2–3 on a 1–9 scale. None of these lines showed resistance to LLS.

Of the 310 breeding lines evaluated for rust and LLS in pest resistance screening trials, five lines (ICGVs 86606, 87864, 87341, 87350, and 86707) were found resistant to rust. Resistance to LLS was not found in any of these lines.

Several hundred interspecific-derived lines were also evaluated for rust and/or LLS resistance. Many of them were highly resistant to rust, but only a few (330, 330-2, CS6xCS39-8, CS26xCS5-2, CS49xCS49(NLM, and 941) were found resistant to LLS (2–3 scores on 1–9 scale). These derivatives should be useful for LLS resistance breeding programs as we do not have high levels of resistance to LLS in released groundnut cultivars.

**Components of resistance to late leaf spot.** Components of LLS resistance were studied in 20 resistant genotypes, using the detached-leaf technique. Significant differences among genotypes were observed for components of resistance studied [infection frequency (IF), percentage of leaf area damage (LAD), incubation period (IP), lesion diameter (LD), and sporulation index (SI)]. A few genotypes [e.g., ICG 10890, BPZ 691, and EC 76446 (292)] had low SI (≤ 2.0) and long IP (13–14.5 days). Two of these genotypes (ICG 10890 and BPZ 691) also showed low IF (1.2–2.1), LD (0.9–1.1 mm), and LAD (3.7–7.2%). The susceptible control cultivars (JL 24, ICGS 11, and TMV 2) had high levels of these five components (SI 3.50–5.0; IP 9.7–10.3; IF 3.8–5.3; LD 2.3–3.5; LAD 45.8–72.5%). All components of resistance were not complementary in resistant genotypes.

### Variability in the late leaf spot pathogen

Preliminary studies indicated variability in morphological and germination characteristics of conidia among several isolates of the late leaf spot pathogen, *Phaeoisariopsis personata*, obtained from some locations in India. The percentage of conidial germination and length were significantly ($P$ <0.05) higher in the Hyderabad isolate than in the isolates from Aliyarnagar, Bapatla, and Jalgaon (all in India).

### Use of partial resistance in the management of foliar diseases

A field experiment with seven genotypes having different levels of foliar diseases (LLS and rust) resistance, was conducted at IAC during the 1992–94 rainy seasons, to integrate partial levels of resistance with judicious chemical control. All the seven genotypes were protected either with intensive, moderate, or minimum levels of fungicide (Chlorothalonil) application. In intensive disease control, genotypes were sprayed six times each at 30, 45, 60, 75, 90, and 105 days after sowing (DAS). In moderate level of control, genotypes received four sprays each at 45, 60, 75, and 90 DAS, while in the minimum level of protection, genotypes were given two sprays each at 45 and 75 DAS. Water-sprayed plots served as controls. The fungicide application reduced LLS and rust severities in all genotypes tested. There were no significant differences in LLS, rust severities and defoliation in the four- and six-spray regimes.

The percentage of leaf area damage by LLS in control plots of the resistant genotype ICGV 86699 was 2.3. The partially resistant genotypes ICG (FDRS) 10, ICGS 76, ICGV 86564, and ICGV 86590 showed 12–13% LAD in control plots. The susceptible genotype Robut 33-1 showed >13% LAD, and the highly susceptible genotype TMV 2 showed >19% LAD (Table 8).

The resistant genotype showed resistance to rust, and had only 0.8% LAD in control plots. Of the four partially resistant genotypes, ICGS 76 showed >13% LAD, but the other three showed <6% in control plots. The susceptible genotypes showed 13% LAD and the highly susceptible genotypes showed >9% LAD due to rust. The low rust pressure in the highly susceptible TMV 2 was due to heavy defoliation caused by LLS.

Defoliation in the control plots of resistant genotypes was $\leq 45$, in the partially resistant genotypes $\geq 75$, in the susceptible genotypes $\geq 85$, and in the highly susceptible genotypes it was $\geq 90\%$ As the number of sprays increased, the percentage of defoliation decreased (Table 8).

The resistant cultivar yielded 2 t $ha^{-1}$ without any chemical protection. Partially resistant genotypes required two sprays to achieve $\geq 2$ t $ha^{-1}$, and the susceptible genotypes required four sprays, and the highly susceptible genotypes six sprays, to yield 2 t $ha^{-1}$.

This study clearly demonstrates that when partially resistant genotypes are protected with judicious chemical control, yields and economic returns are higher than the chemical control of susceptible genotypes. For small farmers, the use of resistant genotypes is advisable for managing foliar diseases of groundnut.

### *Aspergillus flavus*/aflatoxin

Studies on the effects of farmyard manure and vermiculture compost on *Aspergillus flavus*/aflatoxin contamination in groundnuts were initiated during the 1994 rainy season. Very low levels of *A. flavus* seed infection occurred in all treatments, as rains were well distributed in the cropping season, and environmental conditions were not conducive to the development of the aflatoxigenic fungus.

In all resistance screening trials on *A. flavus* in the 1994 rainy season, levels of fungal infection were also very low even in the susceptible control cultivars.

## Microclimatology in Relation to Diseases

### Controlled environment studies

Sporulation studies on the LLS disease of groundnut showed that, with constant humidity and temperature, the majority of conidia were produced at night. We therefore investigated the effect of light on conidial production (with constant temperature and humidity).

We found significantly more conidia in the (light-day)/(dark-night) treatment than in any other treatment; more than 75% of the conidia were produced during the night (Fig. 1). There were also more conidia produced at night (but less total production) with the continuous dark treatment, indicating a biological rhythm. This was overcome by the (dark-day)/(light-night) treatment where the majority of conidia were produced in the dark. The large number of conidia produced with the (light-day)/(dark-night) regime could be explained by the promotion of conidiophore growth in the light and conidia development in the dark. Similar stimuli have been observed with other fungal pathogens.

*Table 8. Effect of Chlorothalonil (Kavach) spray schedules[1] on leaf area damaged by late leaf spot and rust, defoliation, haulm and pod yields, ICRISAT Asia Center, rainy season, 1992–94.*

| | Leaf area damaged (%)[2] by | | | | | | | | Defoliation (%)[2] | | | | Yield (t $ha^{-1}$)[2] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | late leaf spot | | | | rust | | | | | | | | Haulm | | | | Pod | | | |
| Cultivar | 6SP[3] | 4SP | 2SP | WSP | 6SP | 4SP | 2SP | WSP | 6SP | 4SP | 2SP | WSP | 6SP | 4SP | 2SP | WSP | 6SP | 4SP | 2SP | WSP |
| ICG(FDRS)10 | 3.8 | 5.8 | 8.7 | 12.3 | 2.6 | 2.4 | 3.2 | 2.5 | 39.0 | 51.8 | 62.6 | 80.5 | 2.82 | 2.54 | 2.03 | 1.76 | 2.64 | 2.57 | 2.10 | 1.76 |
| ICGS 76 | 3.9 | 5.1 | 7.3 | 13.6 | 11.6 | 13.3 | 16.6 | 13.9 | 32.1 | 40.1 | 54.0 | 77.4 | 3.53 | 3.21 | 2.57 | 1.92 | 2.93 | 2.75 | 2.34 | 1.61 |
| ICGV 86564 | 3.0 | 3.6 | 7.8 | 11.2 | 5.6 | 6.9 | 8.4 | 6.9 | 30.6 | 40.5 | 47.8 | 63.0 | 3.82 | 3.31 | 3.05 | 3.01 | 2.40 | 2.25 | 2.01 | 1.44 |
| ICGV 86590 | 4.6 | 6.5 | 11.1 | 12.9 | 2.4 | 2.2 | 1.6 | 1.4 | 31.2 | 43.8 | 58.0 | 73.9 | 3.84 | 3.02 | 2.45 | 2.66 | 3.20 | 2.87 | 2.63 | 1.74 |
| ICGV 86699 | 0.7 | 0.7 | 0.9 | 2.3 | 0.4 | 0.4 | 0.6 | 0.8 | 21.4 | 25.2 | 36.6 | 45.7 | 4.71 | 4.36 | 3.84 | 3.66 | 2.79 | 2.56 | 2.37 | 2.28 |
| Robut 33-1 | 5.7 | 7.8 | 10.0 | 13.7 | 13.1 | 16.3 | 15.9 | 13.1 | 35.2 | 38.8 | 60.7 | 85.4 | 2.82 | 2.53 | 1.85 | 1.31 | 2.53 | 2.11 | 1.75 | 1.03 |
| TMV 2 | 6.6 | 8.4 | 12.6 | 19.7 | 12.2 | 12.9 | 14.1 | 9.7 | 43.8 | 51.1 | 69.0 | 89.5 | 3.15 | 2.93 | 2.35 | 2.03 | 1.65 | 1.53 | 1.18 | 0.95 |

| | SE | LSD at 1% | SE | LSD at 1% | SE | LSD at 1% | SE | LSD at 1% | SE | LSD at 1% |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | ±0.915 | 3.33 | ±0.711 | 2.58 | ±1.465 | 5.33 | ±0.029 | 0.10 | ±0.041 | 0.14 |
| Spray regimes (SP) | ±0.566 | 2.06 | ±0.474 | 1.72 | ±1.95 | 7.10 | ±0.048 | 0.17 | ±0.022 | 0.08 |
| Cultivar (CV) | ±0.448 | 1.63 | ±0.531 | 1.93 | ±1.449 | 5.27 | ±0.064 | 0.23 | ±0.032 | 0.11 |
| Year × SP | ±1.248 | 4.55 | ±1.005 | 3.66 | ±3.271 | 11.91 | ±0.066 | 0.24 | ±0.053 | 0.19 |
| Year × CV | ±1.164 | 4.24 | ±1.110 | 4.04 | ±2.746 | 10.0 | ±0.089 | 0.33 | ±0.067 | 0.24 |
| SP × CV | ±1.004 | 3.65 | ±1.092 | 3.97 | ±3.316 | 12.07 | ±0.129 | 0.47 | ±0.065 | 0.23 |
| Year × SP × CV | ±1.904 | 6.93 | ±1.978 | 7.2 | ±5.682 | 20.69 | ±0.182 | 0.67 | ±0.118 | 0.42 |

1. Chlorothalonil (Kavach) at 1.6 kg in 800 L water $ha^{-1}$
2. Average of three replications.
3. SP = Sprays; WSP = Water spray.

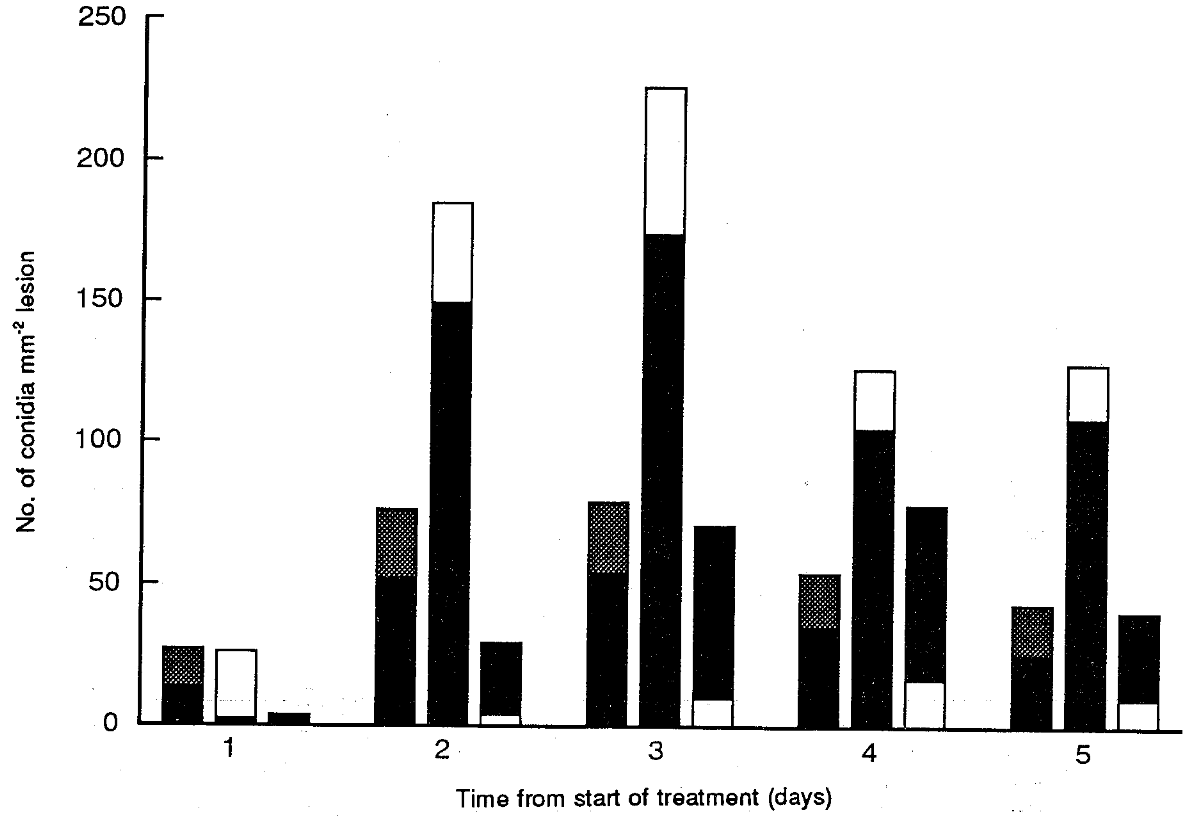


***Figure 1.*** ***Conidial production by*** **Phaeoisariopsis personata** ***with constant temperature and humidity and different light/dark regimes. For each 24 h period, the number conidia produced in 12 h dark (black) and 12 h light (white) are shown. With continuous darkness the night (black) is distinguished from the day (shaded).***

Experiments were carried out to investigate the effect of the quantity of dew on LLS infection. As the quantity of dew increased, the number of lesions per unit leaf area more than doubled. Similar results were confirmed with three experiments.

Experiments using single-plant chambers to control relative humidity (rh) were carried out with early leaf spot (ELS) of groundnut, examining spore production. The results showed that conidia are not released from sporulating lesions until the rh exceeds 95%, and a rapid increase in conidia number between 95 and 100%.

An initial dew chamber experiment was completed, with groundnut lines and wild species, previously thought to be resistant to ELS. The results showed a gradation of reactions for infection frequency, which can be exploited in nonconventional breeding techniques. Dew chambers appear to be ideally suited to screen small quantities of promising material where components of resistance should be assessed.

Experiments were carried out to investigate interactions between ELS, LLS, and rust on groundnut. When ELS and LLS were inoculated together, the infection frequency of LLS was about 30% of the value when LLS was inoculated by itself. Conversely, there appeared to be little or no effect of LLS on the infection frequency of ELS. Preliminary evidence was found that ELS and LLS reduced the incubation period of rust when they were inoculated 1 week after the rust. The equivalent effect of rust and ELS increased the incubation period of LLS, and rust and LLS also increased the incubation period of ELS. These interactions need confirmation, but if they are substantiated, they could be important to our understanding of the epidemiology of these foliar diseases.

**Soil resistance measurement for microclimate model.** Measurements using a locally assembled "soil porometer" yielded a high correlation between the diurnal variation of soil resistance $r_s$ to water vapor flux and that of the gradient of soil-surface temperature. The result is shown in Figure 2, where the diurnal variation of soil-temperature

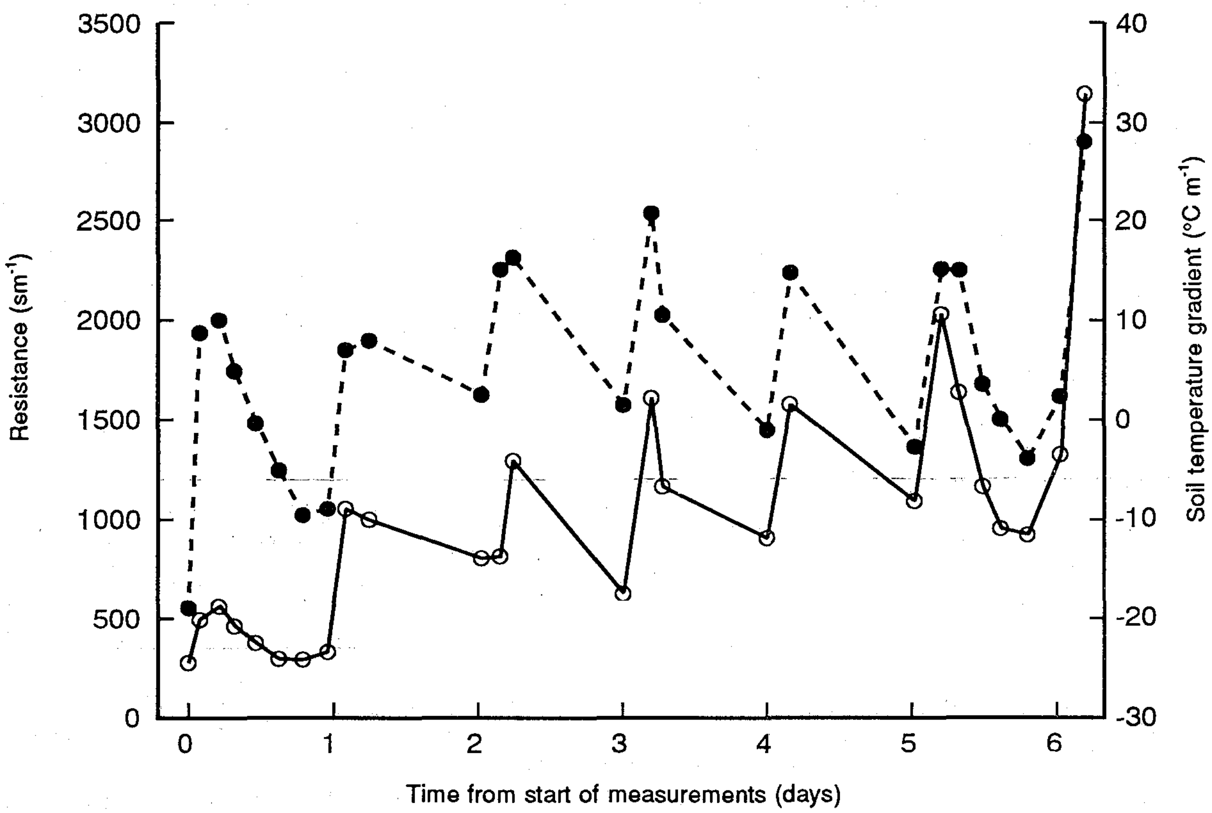


***Figure 2. Relationship between soil resistance and soil temperature gradient in a groundnut crop.***

gradient (solid circles) correlates highly with the diurnal variation of soil resistance (open circles). Similar resultswere obtained when the same measurements were repeated in the same field after the groundnut crop had been harvested.

Use of the results from our "soil porometer" measurements of soil resistance to water vapor flux has improved the ability of the microclimate model being developed for groundnut in simulating the weather variables in the crop canopy, such as relative humidity of the canopy air, and leaf temperature.

**Weather-based spray schedule.** A field experiment to test a weather-based scheme for the timing of fungicide to control leaf spot diseases of groundnut was harvested in October. We obtained significant effects on yield with three sprays (weather-based) and eight sprays (10-day intervals) (Table 9). The different responses of pod and haulm yields to fungicide highlights the need to consider the value of haulms for fodder when considering the economics of chemical control.

***Table 9. Effect of chlorothalonil (Kavach) on yields of TMV 2, a cultivar susceptible to foliar diseases, ICRISAT Asia Center, rainy season 1994.***

| Treatment | Pod yield ($t\ ha^{-1}$) | Seed yield ($t\ ha^{-1}$) | Haulm yield ($t\ ha^{-1}$) |
|---|---|---|---|
| $T_1$: No spray (control) | 0.63 | 0.35 | 1.61 |
| $T_2$: Spray at 10-day interval | 1.26 | 0.62 | 2.40 |
| $T_3$: Weather based[1] | 0.99 | 0.55 | 1.82 |
| $T_4$: Spray at 45, 60, 75 days after emergence | 0.96 | 0.56 | 1.91 |
| $SE_d$ | 0.10 | 0.076 | 0.20 |

1. $T_3$ = Fungicide spray depending on weather conditions.

## Use of weather-disease relationships in chemical control of foliar diseases in groundnut

**On-station trials.** Experiments at three sites, including at IAC, to test our weather-based scheme to advise on fungicide control of leaf spots were completed. The NARS sites are Dryland Farming Agricultural Research Stations (DFARS), Anantapur, and Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad.

**On-farm trials.** A collaborative on-farm experiment to evaluate the feasibility of our weather-based forecasting scheme to advise on fungicide control of leaf spots was completed. The NARS site is at Gudipadu National Watershed, Kurnool District, Andhra Pradesh, and the NARS partners are the staff of the Agricultural Research Station at Anantapur. Based on our weather-based scheme, no fungicide spray was needed, as the threshold wetness index was not reached at any time during the 1994 rainy season. Farmers at this site have not been using fungicide to control foliar diseases.

## Virus diseases

Limited surveys conducted in the 1994 rainy season crop on farmers' fields in parts of Andhra Pradesh and Karnataka states of India revealed a high incidence of peanut bud necrosis disease (PBND), often more than 40%. A method to isolate the nucleocapsids of peanut bud necrosis virus (PBNV), causal agent of PBND, was developed. Isolated nucleocapsids were used to obtain large quantities of small RNA (sRNA) of PBNV. Libraries of cloned cDNA were prepared for the sRNA. Sequencing of this genome is in progress in collaboration with scientists at the University of Georgia, with funding from Peanut Collaborative Research Support Program (Peanut CRSP).

Resistance to PBNV was identified in various advanced breeding lines. They include ICGVs 86031, 86388, and 86430. Resistance was due to restricted virus multiplication or virus movement, from the inoculated leaflets. Southern Runner, which was identified as field-resistant in USA, to tomato spotted wilt virus (TSWV; belonging to the same family as PBNV) was also found to be field-resistant to PBNV.

*Polymyxa graminis*, a suspected vector of Indian Peanut Clump Virus (IPCV), was observed in the roots of numerous plants under natural conditions. Several weeds, which are commonly found in groundnut fields, such as *Digitaria ciliaris*, *Cyanodon dactylon*, *Cyperus rotundus*, etc., were found to be infected by the fungus. With the exception of *Cyperus*, IPCV was detected in all these weeds. Plants such as *Cyperus*, which can support only the fungus multiplication, may render the fungus nonviruliferous. Groundnut was found to be a nonpreferred host for the fungus. Limited field experiments conducted at IAC showed that continuous cropping with groundnut could reduce clump disease incidence, while rotation with cereal crops such as sorghum and wheat increases the disease incidence. Facilities to multiply *Polymyxa* under laboratory conditions have been established. Utilizing modified enzyme-linked immunosorbent assay (ELISA) procedures and high quality polyclonal antisera, 100% correlation was established between growout tests and virus presence in groundnut seed. Therefore ELISA can be used in quarantine to detect the presence of IPCV.

Serological comparisons on IPCV isolates, collected from different parts of India, revealed the existence of at least three distinct serogroups: Group I comprising IPCV-Hyderabad (IPCV-H); Group II comprising IPCV-Ludhiana (IPCV-L); and Group III comprising IPCV-Telod (IPCV-T), IPCV-Durgapura (IPCV-D), and IPCV-Bapatla (IPCV-B) isolates. Nucleic acid hybridization studies, with coat protein (CP) of IPCV-H showed that isolates in serogroups I and III are related, and the isolate in serogroup II is a distinct virus. Further studies on the relationships among IPCV isolates are in progress.

Polyclonal antibodies prepared for cloned CP of IPCV-H expressed in *Escherichia coli*, were found to be superior to those produced for purified virus by conventional methods.

A 700 base pair cDNA clone, conserved at the 3' end of RNA 1 and RNA 2 of IPCV-H, was used to prepare a nonradioactive, labeled probe. This probe detected all currently known IPCV isolates. In addition, this probe was found to be suitable for virus detection in seed.

## Nematode diseases

**Root-knot nematode.** Three hundred groundnut germplasm lines were screened for resistance to root-knot nematode, *Meloidogyne javanica*, in the greenhouse. All of them were found susceptible.

## Insect Pests

During 1994, there was an epidemic of groundnut leaf miner at the IAC, with as many as 50 live larvae per plant, resulting in 100% foliage destruction. The leaf miner pheromone traps showed a good peak, with 7000 moths in the first week of January, followed by larval damage in the first half of February. Though other pests such as jassids, thrips, and *Spodoptera* were present, their populations were low and did not cause any problem to the crop. Data from the *Spodoptera* pheromone trap in the groundnut fields around Bapatla (India) indicated three clearcut peaks in the 1993/94 postrainy season. The population started increasing in the second week of December, with a small peak in the first week of January and further increased up to the second week of February, and later declined after the second week of March. The observations on other biological parameters such as oviposition and larval population showed a clearcut trend, with 7 and 14 days gap from the adult activity. This type of information is highly valuable to develop future forecasting systems.

### Surveys

Insect pest surveys carried out during the early part of the 1994 rainy season in Mahaboobnagar (Andhra Pradesh) and Raichur (Karnataka) in India clearly indicated the severity of red hairy caterpillars. This pest was in epidemic form in Nagarkurnool, Kolhapur, and Palem area of Mahaboobnagar, mainly attacking cotton, groundnut, sesemum, and castor. During the first week of August, the pest was at migratory phase, most probably in search of food and resting sites. Early-sown groundnut crop in Kolhapur area had a high influence of leaf miner and white grubs. Field visits in the second half of August around Raichur showed a drastic decline in red hairy caterpillar population. However, the samples collected from Raichur area revealed 100% parasitisation of red hairy caterpillar by braconid vasps. Farm surveys in October in Anantapur district (Andhra Pradesh) also indicated high incidence of red hairy caterpillars in the older groundnut crop. Generally, this type of incidence in the later part of the crop phase is not common. This could be due to poor rainfall in the early part of the season, followed by heavy rains in early October. This information stresses the need for further studies on the basic biology and ecology of red hairy caterpillars.

### Natural enemies of pests

Studies on larval parasites of groundnut leaf miner at IAC indicated 21% parasitisation during the second week of February, when the pest pressure was high. Later, by the second week of March, the parasitisation levels increased to 55%. Though the pest pressure was very high in February, the leaf miner population decreased drastically in March which was perhaps due to high parasitisation.

Observations on some predators at Kavur in Guntur (Andhra Pradesh) indicated 30 times higher coccinellid populations (60 adults per sample in nonsprayed fields). This resulted in 13% defoliation in nonsprayed fields, against 33% defoliation in sprayed fields. This is an indication that, by augmenting predators such as coccinellids, defoliator activity could be minimized.

Red hairy caterpillar samples collected during October from Anantapur (Andhra Pradesh) indicated 85% parasitisation by braconid wasps. This is another area of interest of Integrated Pest Management (IPM), where detailed studies are required to define the role of natural enemies in the population dynamics of red hairy caterpillars.

### Integrated pest management

Visits to farmers' fields during the 1993/94 postrainy season in coastal Andhra Pradesh indicated that leaf-eating caterpillars, particularly *Spodoptera* and *Helicoverpa*, are the key constraints to groundnut production. Farmers in some areas, especially in the coastal districts, were spending up to Rs.2500 $ha^{-1}$ on plant protection (pests and diseases). On-farm trials with trap crops for trapping *Spodoptera* egg masses and larvae using castor and sunflower suggested that sunflower is the best trap crop. The fast-growing habit of sunflower attracted a large number of *Spodoptera* for oviposition, which in turn enabled the farmers to collect and destroy the egg masses manually. Castor grows slowly and attracted moths for oviposition during the later phase of the crop. Since groundnut crop is vulnerable to defoliators at an early stage, sunflower seems to be the best trap crop for the management of *Spodoptera.* By effective monitoring using pheromone traps, following the thresholds, encouraging natural enemies, adopting trap crops and manually collecting egg masses, it became possible to achieve the target control of defoliators without insecticidal involvement. The contact villages in Guntur have been substantially benefited, through our collaborative effort with Agricultural Universities and nongovernmental organizations. The farmers in these villages have clearly understood the concept of integrated pest management and have realized the advantages of natural resources.

**Host-plant resistance.** High incidences of leaf miner populations during the postrainy season gave an opportunity to screen several lines against this pest. Observations on one set of 25 selected pest-resistant lines revealed 49–80% foliage destruction in different genotypes. Studies under sprayed and nonsprayed situations with different genotypes revealed that ICGVs 91185, 89281, 86590, and 86031 were promising against groundnut leaf miner.

Artificially reared *Spodoptera* populations were released in nonsprayed fields to evaluate the performance of the groundnut varieties against leaf-eating caterpillars. The release of five fourth-instar larvae per plant on 40 selected lines showed different levels of defoliation with a range of 12–47%.

The performance of 13 wild *Arachis* species against white grub damage was evaluated, using laboratory populations and field techniques developed during the previous season. Ten first instar white grub larvae released into 0.8 $m^2$ enclosures with different wild *Arachis* species reflected 0–39% plant mortality. The observations on larval mortality and larval mass gain are given in Table 10.

***Table 10. Interaction between white grubs and wild* Arachis *spp.***

| Wild *Arachis* spp | No. of replicates | Plant mortality (%) | Larval mortality (%) | Larval mass gain (g) | Larval dry mass (g) |
|---|---|---|---|---|---|
| HLK 409 | 4 | 2.3 (5.6)[1] | 77.5 | 3.09 | 0.72 |
| 30009 | 6 | 13.3(16.4) | 76.7 | 2.57 | 0.58 |
| 30085 | 7 | 2.4 (5.6) | 80.0 | 2.27 | 0.52 |
| 36034 | 4 | 38.7(37.8) | 72.5 | 2.29 | 0.47 |
| 30035 | 5 | 12.3(19.2) | 62.0 | 2.45 | 0.53 |
| RUS 6B | 8 | 10.0(15.9) | 61.3 | 2.94 | 0.72 |
| 553 | 3 | 0.7 (2.2) | 66.7 | 2.57 | 0.53 |
| 2A1 | 4 | 5.1(11.3) | 72.5 | 2.85 | 0.68 |
| 10120P2 | 3 | 0 | 83.3 | 2.49 | 0.62 |
| 9580 | 4 | 0 | 80.0 | 2.77 | 0.61 |
| 9882P246 | 3 | 0 | 83.3 | 2.38 | 0.51 |
| 486 | 4 | 0 | 82.5 | 2.21 | 0.36 |
| A52/120 | 3 | 0 | 86.7 | 2.46 | 0.50 |
| ICGS 44 | 10 | 17.0(21.0) | 66.0 | 2.8 | 0.72 |
| $SE_m$ | | (3.94) | 10.51 | 0.22 | 0.06 |

1. Arc-sine transformation.

**White grubs and their effect on sowing dates.** The artificial release of white grubs into experimental plots at different larval densities in both early and late groundnut sowings showed around 70% larval mortality induced by both biotic and abiotic factors. The release of 10, 20, and 30 larvae into experimental plots (0.8 $m^2$) induced 5, 21, and 47% plant mortality in early sowings and 34, 42, and 78% plant mortality in late sowings. This indicates that white grubs affect late sowings more than the early sowings. Because of these three levels of larval populations (10, 20, 30), there were 30, 54, and 78% reduction in matured pod yield in early sowings, and 63, 82, and 95% reduction in late sowings (Fig. 3).

A field trial using a foliar pest-susceptible (ICGS 44) and a pest-resistant (ICG 2271) groundnut variety was conducted at IAC, Dec 1993 to May 1994, to develop mathematical models to describe the effects of foliar pests and diseases on groundnut development and yield. The invasion of huge adult populations in late January resulted in high infestation in the early phase of the crop. Different levels of chemical control provided different levels of pest populations. Second and third generation densities were comparatively low. During this season, the incidence of other insect pests, such as thrips and jassids, and of diseases, were below the threshold levels. Plant growth was significantly influenced by the early leaf miner attack. Canopy masses and leaf areas were reduced; flowering and fruitset were retarded and reduced. The susceptible variety ICGS 44 was severely affected (up to almost 100% infested leaflets at early growth stages) than the multiple insect-resistant variety ICG 2271.

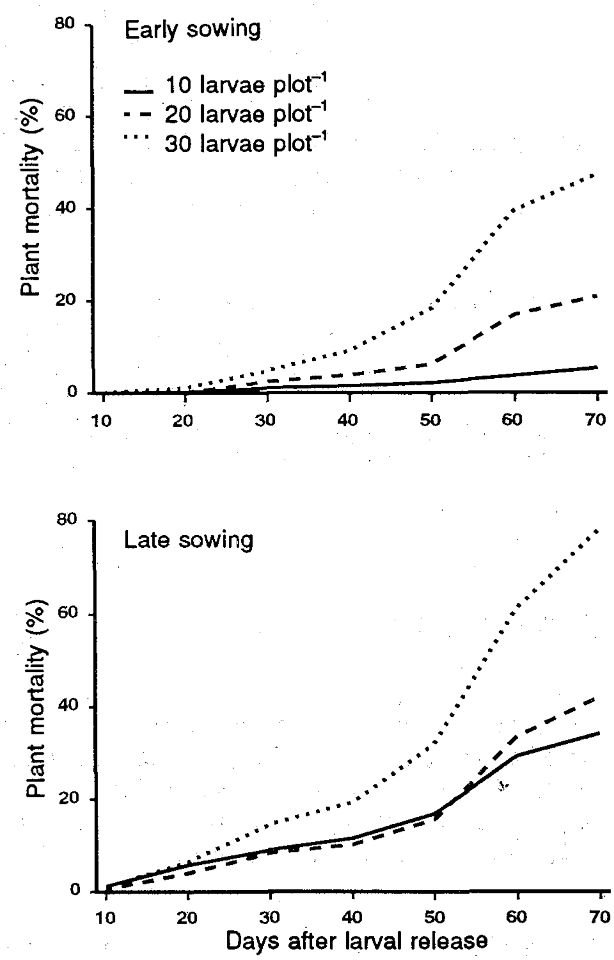


***Figure 3. Effect of sowing date and white grub larval density on groundnut plant mortality, ICRISAT Asia Center, rainy season 1994.***

# Pearl Millet

## Diseases

### Pathogenic variability in the downy mildew (DM) pathogen (*Sclerospora graminicola*)

We coordinate the evaluation of the International Pearl Millet Downy Mildew Virulence Nursery (IPMDMVN), to examine variability in the DM pathogen in Africa and India. The 1994 IPMDMVN was sent to eight locations in West Africa and four in India. Results are awaited. Analysis of the 1993 IPMDMVN data showed highly significant ($P$=≤0.001) effects of host genotype, pathotype (location), and host genotype x pathotype interaction. The DM pathotypes were least virulent on host genotype IP 18293, and most virulent on 7042S across locations. The pathotypes at Durgapura (India), Kamboinsé (Burkina Faso), and Nioro (Senegal) were more virulent on IP 18292 than those at other locations.

We employed a highly reliable and versatile technique of DNA fingerprinting, to study the extent of genetic variation in the DM pathogen. This technique is based on the use of microsatellites and minisatellites as DNA probes in the hybridization reaction. We analyzed the DNA fingerprints in six host genotypes-specific pathotypes of *S. graminicola*, and found that the polymorphic pattern was highly informative with the microsatellite (GATA)4. The four minisatellites (pV47, M13, rDNA, and R18) that we used, did not show any polymorphism among the pathotypes. The six pathotypes were classified into five different groups, based on the hybridization data. These results confirmed our earlier findings based on DNA RAPD markers.

**Effect of cultivar-mixtures on DM development.** It has been reported that cultivar mixtures show less disease compared with their components in monoculture in some host-pathogen systems. To test the hypothesis for DM, we mixed seeds of resistant (IP 18293) and susceptible (NHB 3) cultivars in different proportions (1:1, 1:2 and 1:3) and sowed the mixtures to achieve different proportions of resistant and susceptible plants. We found that there was no difference in disease incidence on the susceptible cultivar grown as a monoculture and as a mixture. For cultivar mixture strategy to be successful for DM management, the susceptible component in the cultivar mixture should be much less than 50%.

### Resistance screening

A total of 1635 entries from the All India Coordinated Pearl Millet Improvement Project (AICPMIP), ICRISAT breeding trials, and Genetic Resources Division were evaluated for downy mildew reaction. Of the 321 AICPMIP entries (involving hybrids, varieties, and lines), 67 remained DM-free in 30 days. Of 266 germplasm accessions (185 photoperiod-sensitive and 81 early genetic stock selected from earlier greenhouse screening), most lines were free from downy mildew in the first record.

**Disease survey.** Two surveys were conducted in Maharashtra, Karnataka, and Andhra Pradesh, during August and September, to record prevalence and severity of diseases. DM incidence ranged 0–50% on ICTP 8203, 0–40% on MLBH 104 and MLBH 267, and 20–70% on BK 560. About 15 samples of DM (oospores) were collected for use in the studies on variability in the population of the pathogen.

## Microclimatology in Relation to Diseases

**Pearl Millet (CSM-130).** Experiments were carried out to quantify the effects of temperature and leaf wetness periods on pearl millet infection by downy mildew sporangia. The optimum, maximum, and minimum temperatures for infection have been determined, but our experimental techniques need to be improved to draw firm conclusions about the response to leaf wetness periods. Infection in the control (zero hours of leaf wetness) suggests that guttation at the time of inoculation may be interfering with the treatments.

In the field, we carried out two experiments with shading treatments. These were open (no shade), 50% shade, and 75% shade. Areas of the crop were shaded for 2-week periods, to examine the effect on sporangial production. It appears that the effect of shade may be cumulative; increasingly reduced numbers of sporangia being found towards the end of the treatment period. An overriding effect of humidity on sporangial production was evident in the second experiment.

# Sorghum

## Diseases

### Sorghum grain molds

**Sources of grain mold resistance in white grain sorghum.** We tested 347 zera-zera lines converted from 12 photoperiod-sensitive accessions (IS 956, IS 2579, IS 3443, IS 6248, IS 6928, IS 18484, IS 18522, IS 18758, IS 18790, IS 18791, IS 24695, and IS 30469) using an in vitro screening technique in 1993. One-hundred-forty-three lines showed moderate to high level of grain mold resistance (grain mold ratings 1 to 5 on a 1–9 rating scale where 1=highly resistant and 9=highly susceptible). These lines were evaluated for three major fungi (*Fusarium moniliforme*, *F. pallidoroseum*, and *Curvularia lunata*) in a grain mold screening nursery at IAC during the 1993 rainy season. Seventeen lines showed grain mold ratings of 1 to 5. We made 82 single head selections from these lines. The selections were evaluated again in the field nursery during the 1994 rainy season. Eight selections, IS 30469C-140-2, 30469C-140-4, 18758C-618-2, 18758C-618-3, 18758C-710-4, 18758C-710-5, 30469C-1187-5, 30469C-1518T-2 showed a very high level of grain mold resistance (grain mold rating, 1.3 to 2.7). These selections will be evaluated again during the 1995 rainy season. These are useful sources of resistance to grain mold in white grain sorghum. Some of these accessions are agronomically good.

### Anthracnose

**Pathogenic variability in anthracnose (*Colletotrichum graminicola*):** In the greenhouse, we evaluated 17 isolates from eight states in India on a set of six sorghum lines with varied levels of resistance to anthracnose. All the isolates produced resistant/moderately resistant reaction on the two highly resistant lines A 2267-2 and IRAT 204, and variable reactions on other lines. This suggests that the 17 isolates were pathogenically variable, and the sorghum lines A 2267-2 and IRAT 204 were universally resistant to these isolates.

Efficient genetic characterization of pathogen isolates is possible thorough biotechnological methods. Among the 60 oligonucleotide primers tested for polymorphism, three primers could detect differences among 14 isolates of *C. graminicola* collected from different locations in India.

### Ergot

**Control of ergot (*Claviceps sorghi*).** We tested the efficacy of crude garlic extract for the control of ergot disease in sorghum. The extract in 8.3% concentration (1 part extract: 11 parts water) completely inhibited conidial germination. But the germination of pollen grain was not affected, even in concentration of 16.6% under controlled greenhouse conditions. Prophylactic sprays of crude garlic extract gave nearly 100% control of the disease. Under field conditions, the sprays gave up to 80% control of the disease during postrainy seasons or on nonrainy days during the rainy season. Garlic sprays were less effective on rainy days. An organosulphur compound, allicin, possessing antimicrobial properties, may be responsible for the control of ergot.

To prepare garlic extract, 500 g cleaned garlic cloves are crushed in 500 mL of water. The resultant suspension is filtered through a muslin cloth to remove fibrous material. The liquid is taken as 100% extract. The extract is diluted with water to 14–16%. Approximately 500 L extract is required to spray 1 ha sorghum crop. Economics of production of garlic extract would require some additional study. Garlic spray does not interfere with pollen germination, and seed set is normal. Neither does it present any toxicity hazard to the spray operator or to consumers or to the environment.

### Virus diseases

**Identification and characterization of potyviruses.** Two potyviruses (potyvirus-I, potyvirus-II) were isolated from sorghum crops grown adjacent to sugarcane/maize in Marathwada region of Maharashtra (India), and one (potyvirus-III) from IAC farm. Properties and methods to identify these potyviruses have been described in detail.

**Disease survey.** A survey was conducted in Maharashtra and Karnataka (India) in September 1994 to record disease prevalence and severity on sorghum diseases before grain maturity. The most striking disease was leaf blight on CSH 9 (100% incidence, 80% severity) and on fodder sorghum (10–100% incidence, 5–80% severity) in several fields in Maharashtra. Susceptibility of the hybrid CSH 9 to leaf blight is of concern, since it is widely grown in Maharashtra. The incidence of anthracnose ranged from 10 to 80% with 5–60% severity on fodder sorghum. Anthracnose-infected leaf samples were collected for use in studies on variability in the pathogen.

## Insect Pest Surveys

Nine survey tours were undertaken between February and December 1994 to monitor insect incidence/damage on sorghum in farmers' fields in India. These surveys covered 426 fields in over 400 villages in Andhra Pradesh (AP), Maharashtra (MH), and Tamil Nadu (TN) states. Mean shoot fly incidence was highest (28%) in Khammam (AP), followed by Wardha (23%) in MH. Stem borer infestation was highest in Nagpur (29%) in MH, followed by Medak (26%) in AP. The highest incidence of midge was recorded from Chidambaranar (59%) in TN, followed by Buldana (40%) in MH. The highest head bug incidence (90%) and damage score (3 on a 1–9 scale where 1=<10% damage and 9=>80% damage) was recorded from Buldana. Farmers interviewed recognized shoot fly and stem borer damage.

*Cotesia flavipes*, *Apanteles ruficrus*, *Xanthopimpala stemmator*, and *Sturmiopsis inferens* parasitoids were recorded on stem borer (*Chilo partellus*). *Apanteles ruficrus* recorded earlier on *Mythimna separata*, was recorded on *Chilo*. However, it needs further confirmation. Midge parasitoids included *Approstocetus gala*, *Eupelmus popa*, and an unidentified species. However, *A. gala* was the predominant species in all the districts surveyed.

## Host-Plant/Pest/Parasitoid Interactions in Sorghum Midge

A series of studies on the efficacy of parasitoids in reducing sorghum midge populations and other tritrophic interactions were undertaken. Three susceptible sorghum genotypes (Swarna, ACSV 112, and CSH 9) were sown on four dates (biweekly sowings) during the 1994 rainy and postrainy seasons. Parasitoid emergence started 1–2 weeks after initiation of midge emergence, and occurred mostly between 0700 and 1400).

We observed a complex of larval parasitoids (*Aprostocetus gala*, *A. coimbatorensis*, and *Eupelmus popa*), one predator (*Orius* sp), and a few unidentified species of hyperparasitoids on midge parasitoids. *Orius* sp was recorded early in the season, and was present throughout. *Aprostocetus gala* was predominant in both rainy and postrainy seasons.

## Host-plant/Insect/Parasitoid Interactions in Sorghum Stem Borer

We continued our studies on the efficacy of the parasitoids in discriminating sorghum genotypes to parasitize *C. partellus*. Results show that resistant genotypes recorded higher levels of parasitism than the susceptible ones, which is attributed to slower larval development and prolonged exposure to natural enemies. When the plants were infested artificially at a later stage [40 days after emergence (DAE)], the larval mortality was high due to poor establishment and predation of the young larvae, and the parasitization levels were low (Table 11). However, braconids and tachinids were more active than ichneumonids.

***Table 11. Parasitism levels of* Chilo partellus *infesting at three different stages of sorghum crop.***

| | Parasitization (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 20 DAE[1] | | 30 DAE | | 40 DAE | | |
| Genotype | AI[2] | NI[3] | AI | NI | AI | NI | Composition of parasitoids (%) |
| IS 2205 | 11.5 | 14.1 | 11.3 | 19.2 | 4.9 | 29.2 | 51.2[4] |
| ICSV 700 | 10.5 | 5.3 | 7.3 | 14.4 | 7.6 | 12.0 | 43.2[5] |
| ICSV 1 | 4.7 | 4.2 | 8.3 | 11.7 | 9.9 | 21.2 | 24.8[6] |
| CSH9 | 3.4 | 4.7 | 8.4 | 20.5 | 6.7 | 19.4 | 20.8[7] |
| Mean | 7.5 | 7.1 | 8.8 | 16.5 | 7.3 | 20.5 | – |
| SE | ±2.4 | ±4.3 | ±1.9 | ±6.7 | ±2.1 | ±10.2 | – |

1. DAE = Days after emergence.
2. Artificial Infestation.
3. Natural Infestation.
4. *Apanteles ruficrus.*
5. *Cotesia flavipes.*
6. *Sturmiopsis inferens.*
7. *Temelucha* sp.

## *Cotesia flavipes*: larval parasitoid of stem borers

*Cotesia flavipes* has been reported as the most common stem borer parasitoid in Asia. *Cotesia flavipes* may not be a monophyletic group, and may include cryptic and/or sibling species. Its impact on stem borer population suppression has not been studied in detail. International Center for Insect Physiology and Ecology (ICIPE) approached ICRISAT about the possibilities for collaborations on biological control of stem borers by *C. flavipes.* Nearly 600 cocoons from the Sugarcane Breeding Institute, Coimbatore, India, were shipped to ICIPE on request. ICIPE reported 100% cocoon emergence, and mixed broods were obtained from each cocoon mass. This was an indication of an excellent rearing technique and handling of the parasitoids.

## *Bracon albilineatus*: a larval parasitoid of sorghum stem borer

During the 1994 postrainy season, we observed that the peduncle damage was severe at crop maturity,. While sampling for stem borer parasitoids, we found some cocoons of *B. albilineatus* in the peduncle and brought them to the laboratory for parasitoid emergence. The parasitoids *Cotesia flavipes*, *Sturmiopsis inferens*, and *B. albilineatus* were very active during the season on the stem borer. However, *B. albilineatus* appears to be active during the end of the cropping season. The parasitoid activity coincides with the peduncle damage, which is mostly caused by the second generation of the *Chilo* larvae.

## Stability of resistance to sorghum midge

Resistance to sorghum midge in DJ 6514, and the lines derived from it, breaks down at Alupe, Kenya. We therefore studied the stability of resistance to midge in 10 lines across three sowing dates, and three insect densities. Under natural infestation, AF 28 suffered a damage rating (DR) (1=<10% damage, and 9=>80% damage) of 2–2.7 as compared with 7–8.3 in DJ 6514, 8.3–9.0 in ICSV 197, and 9.0 in the susceptible controls, KAT 369, Seredo, and Swarna, over three sowing dates. Under headcage screening, AF 28 suffered a DR of 2.4–2.9 compared with a DR of 4.1–7.0 in DJ 6514, 4.3–8.7 in ICSV 197, and 6.5–8.9 in KAT 369 and Swarna. The results indicate that AF 28 is stable in its resistance to midge, while DJ 6514 and the lines derived from it became susceptible at Alupe, Kenya. Thus, there is a possibility of the occurrence of a new biotype of this insect or the resistance genes in DJ 6514 becoming nonoperative at this location because of environmental factors.

## Shoot fly bioecology

Several greenhouse experiments were conducted on temporal and diurnal patterns of shoot fly ovipositional behavior, in relation to fly longevity and diurnal rhythm. The study reveals that the longevity of flies deprived of sorghum seedlings was drastically reduced, and after 11 days of host deprivation, no fertile eggs were laid, even when subsequently provided with host plants. However, with access to host plants after the pre-oviposition period, there were three distinct peaks in egg-laying for 30 days. Egg viability and successful development dropped considerably after the flies were 22 days old. Most eggs (60%) were laid between 0800 and 1200. This was associated with changes in temperature, and was optimum at 25°C. Egg laying vitality of shoot fly adult may partly account for the dramatic increase in shoot fly damage as the crop season advances, since there would be a geometric increase in active females with every new generation of flies.

The general combining ability (gca) effects of ICSA 42 were significant and positive, while those of the cytoplasmic male-sterile (CMS) lines (PM 7061A and PM 7068A) derived from DJ 6514 were negative, but nonsignificant. Restorers showing high levels of resistance to midge at Alupe did not combine with PM 76061 A and PM 7068A (which are resistant to midge at IAC but become susceptible at Alupe) to produce midge-resistant hybrids. Therefore, it is essential to utilize lines that are resistant to midge at Alupe to produce midge-resistant varieties and hybrids for this region.

## Characteristics associated with resistance to spotted stem borer

In our continuing efforts to quantify the relative contribution of various plant characteristics in genotypic resistance to stem borer, *Chilo partellus*, we studied various aspects of insect-plant relationships under artificial infestation during the 1993–94 postrainy season. Of the 13 plant characteristics studied, leaf glossiness (1=highly glossy, and 5=nonglossy) was significantly and positively associated with deadheart formation, indicating that nonglossy lines were more susceptible to the stem borer. Seedling vigor, plant height, and plant growth rates were negatively associated with stem borer damage. Moisture content of the central leaf was positively associated with leaf feeding and deadheart formation. These studies will lead to identification of lines with diverse mechanisms of resistance, and quantify the contribution of various characteristics associated with resistance to borers.

## Effects of time of borer infestation on genotypic resistance and grain yield

We studied the insect/host-plant interactions for spotted stem borer (*Chilo partellus*) across five infestation times (0, 15, 20, 25, and 30 days after seedling emergence, DAE) in a set of 20 stem borer-resistant and 5 stem-borer susceptible genotypes. The deadheart incidence was greater in the crop infested at 15 DAE than in the crops infested at 25 and 30 DAE. IS 12308 was stable in its resistance to stem borer across times of infestation. Grain yield across genotypes in plots infested at 15, 20, 25, and 30 DAE were 1.081, 1.056, 0.967, and 1.080 t $ha^{-1}$. Maximum reduction in grain yield was recorded in plots infested at 25 DAE. Grain yield of borer-resistant lines ICSV 714 (1.42 t $ha^{-1}$), IS 5604 (1.34 t), and IS 5469 (1.42 t) was greater than the commercial controls ICSV 1 (1.09 t $h^{-1}$) and ICSV 112 (1.30 t $ha^{-1}$), across infestation times.

## Midge-resistant varieties in multilocational trials and on-farm testing

In our continuing efforts to develop high-yielding midge-resistant cultivars, several lines were tested in multilocational trials, and on the farmers' fields. Midge-resistant varieties ICSV 93023 and ICSV 93073 were tested in 35 locations (22 in Asia and 13 in Africa) in the 1994 International Sorghum Variety and Hybrid Adaptation Trial. ICSV 88032 has been retained in the All India Coordinated Sorghum Improvement Project (AICSIP) Advanced Variety Trial for further testing. ICSV 88032 and ICSV 745 are also being tested on farmers' fields in the Kovilpatti area of Tamil Nadu, India. Breeder seed of the ICSV 745 has been requested by private seed companies, University of Agricultural Sciences, Dharwad; and State Seed Corporation, Karnataka, India, for multiplication, testing, and distribution to the farmers. One-hundred kilograms seed of ICSV 745, 500 g of ICSV 735, and 20 midge-resistant lines have been supplied to Sudan for testing, and on-farm trials. ICSV 735, ICSV 758, and ICSV 804 have been identified for large scale cultivation in Myanmar following on-farm trials during 1993.

ICSA and B 88019, and ICSA and B 88020 have been identified as midge-resistant, male-sterile lines. These lines are also less susceptible to leaf diseases. These male-sterile lines can be used to produce experimental midge-resistant hybrids involving midge-resistant restorers.

### Natural plant products in integrated pest management

We conducted studies on the field evaluation of pesticide formulations developed from neem (AF 20) and custard apple (ASF 16) for pest control on sorghum under field conditions, in collaboration with the Indian Institute of Chemical Technology, Hyderabad, India. Neem and custard apple extracts significantly reduced the damage by spotted stem borer, *Chilo partellus* and oriental armyworm, *Mythimna separata* (leaf damage rating <2 compared with 7.7 in the nontreated control). These plant products were comparable with endosulfan, and *Bacillus thuringiensis* with the nontreated control. At the milk stage, head bug, *Calocoris angustatus* numbers were <2 per panicle in plots treated with neem and custard apple extracts, compared with 20 bugs per panicle in plots treated with endosulfan, and 27 bugs per panicle in the nontreated control. Further studies are in progress to exploit these plant products for integrated pest management.

## Technology Exchange

Sorghum genotypes resistant to shoot fly and stem borer (25 lines; International Sorghum Shoot Pest Nursery), sorghum midge (25 lines; International Sorghum Midge Nursery), and head bug (International Sorghum Head bug Nursery) were supplied to scientists in Asia, Africa, Latin America, and Australia. Midge-resistant varieties ICSV 88032 and ICSV 745 were tested on farmers' fields in Kovilpatti region of Tamil Nadu. A progressive farmer multiplied the seed of ICSV 745 (supplied by ICRISAT) for further distribution to the farmers in this area. ICSV 745 and ICSV 735 were also tested widely in Andhra Pradesh through the Indo-Swiss Livestock Project. Breeder seed of ICSV 745 was supplied for further multiplication to Karnataka State Seed Corporation, and to several private seed companies in Maharashtra, India. One hundred kilograms ICSV 745, 500 g of ICSV 735, and 50 g of 20 midge-resistant lines were sent to Sudan for on-farm testing and multiplication.

Midge-resistant ICSV 735, ICSV 758, and ICSV 804 have been identified for largescale cultivation in Myanmar.

We also supplied egg masses of stem borer and armyworm to Indian Institute of Chemical Technology, Hyderabad; Maize Research Station, Amberpet; Central University of Hyderabad; Osmania University, Hyderabad; and the Sugarcane Breeding Institute, Coimbatore.

Information on resistance screening techniques, host-plant resistance to insects, and integrated pest management was supplied.

We supplied 1 kg seed of ICPL 87119, a medium-duration cultivar released as 'Asha' with resistance to wilt and sterility mosaic, to each of 12 farmers in four villages (Pati, Ghanpur, Yelimella, and Tellapur) in Medak, Andhra Pradesh, India. Farmers were advised to grow the crop in their existing cropping system in the 1994 season. Data were collected from eight farmers' fields where ICPL 87119 was grown. This cultivar was grown as a sole crop in two of the eight plots. The local variety was mixed or intercropped with sorghum in all the eight plots. Sorghum yields during 1994 were good, reaching up to 2.5 t $ha^{-1}$. The number of insecticide sprays in pigeonpea for *Helicoverpa armigera* ranged from 0 to 3.

Wilt incidence in the local cultivar in all the plots was very high (57%), but was negligible in ICPL 87119 plots (1.6%). ICPL 87119 outyielded the local cultivar in all eight trials, with an average yield of 783 kg $ha^{-1}$ compared with 93 kg $ha^{-1}$ for the local cultivar. Yield levels of ICPL 87119 were very high when it was grown as a sole crop (1.24–2.13 t $ha^{-1}$). Variation in yield across the trials was mainly due to variation in pigeonpea plant population and level of *H. armigera* management. ICPL 87119 was able to take advantage of late rains as it did not die from wilt and consequently produced a good second flush during the time when *H. armigera* activity was low.

We plan to continue these activities in 1995, with the addition of an extra-short duration pigoenpea cultivar (ICPL 85010) followed by postrainy-season sorghum, and ICPL 86012, a *H. armigera* tolerant short-duration cultivar (ICPL 87 group). An increase in pigeonpea plant population in inter-or mixed cropping and need-based use of pesticide for *H. armigera* management will also follow.

GED

# Genetic Enhancement Division

*Genetic Enhancement Division (GED) was created after amalgamating the erstwhile cereals and legumes breeding units in 1994. The creation of the GED has facilitated the increased disciplinary interaction among the breeders based at different ICRISAT locations. The Division serves as the hub of crop improvement activities and its scientists interact closely with scientists of other Divisions at ICRISAT and of NARS in their region. The input of the Division figures prominently in all commodity and integrated system based projects. In addition, significant efforts are also earmarked to study the impact of improved germplasm on NARS in collaboration with the scientists of the Socioeconomics and Policy Division. In future our breeding activities will be more focussed and collaborative in nature. NARS will be equal partners in our joint endeavor.*

# Sorghum

Great strides have been made in breeding tropically adapted sorghum with high productivity, especially for grain. However, the narrow genetic base of the elite gene pool causes concern over genetic vulnerability and limits opportunities for future gains. Also, there is limited resistance to major biotic and abiotic stresses, and under-representation of dual-purpose and forage types in the elite gene pool.

Sorghum breeding at ICRISAT Asia Center (IAC) endeavors to widen the genetic base in sorghums adapted to the semi-arid tropics. The breeding approaches being followed include population improvement, development of parental lines for resistance to the major pests, diseases, and *Striga*, development of alternative cytoplasmic seed parents, and development of materials and strategies for superior adaptation to postrainy-season environments.

## Rainy Season Adaptation

### Restorer lines/varieties

**Short-season, dual-purpose lines.** Both sorghum stover and grain are important economic products and must meet farmers' requirements to enable adoption of new varieties. Previous population improvement work had focussed on increasing grain yields alone, and had caused delayed maturity. Population improvement for short-season and dual-purpose sorghum was therefore undertaken.

Increasing yields of both grain and stover, while maintaining early maturity was the goal of two cycles of selection in the US/restorer sorghum population from 1991 to 1993. Evaluation of full sib progenies from the nonselected ($C_0$) and selected cycles ($C_1$ and $C_2$) was conducted in the 1994 rainy season. Results from this initial year of testing indicate that major gains for both grain and stover yields were achieved within a restricted growth duration (Table 1). The mean grain and stover yields of the Cycle 2 population were 20% and 16% higher than the original population under high-fertility, and 7% and 13% under low-fertility conditions.

The selected cycles were shown to possess individual progenies that were superior to the best progenies in the original population. This is important in a breeding program. Ranking the 180 progenies based on an index consisting of grain yield, stover yield, and days to anthesis indicated that 12 $C_1$ and 13 $C_2$ progenies were among the top 15% compared with only 3 $C_0$ progenies. Thus the realized gains for total biomass achieved within restricted growth duration through population improvement efforts offer national sorghum programs valuable source material for breeding short-duration, dual-purpose sorghums.

***Table 1. Cycle means (60 progenies each) and hybrid control from high- (HF)[1], and low-fertility (LF)[2] environments, ICRISAT Asia Center, rainy season 1994.***

| | Grain yield (t $ha^{-1}$) | | Stover yield (t $ha^{-1}$) | | Anthesis (days) | |
|---|---|---|---|---|---|---|
| Cycle/control | HF | LF | HF | LF | HF | LF |
| Cycle 0 | 3.3 | 3.1 | 4.8 | 4.7 | 52.9 | 59.6 |
| Cycle 1 | 3.9 | 3.3 | 5.7 | 5.5 | 53.5 | 61.3 |
| Cycle 2 | 4.0 | 3.3 | 5.5 | 5.3 | 52.4 | 60.6 |
| Control | | | | | | |
| CSH 6 | 3.0 | 3.4 | 3.6 | 4.0 | 54.8 | 63.0 |

1. High fertility = 80 kg N $ha^{-1}$.
2. Low fertility = 40 kg N $ha^{-1}$.

## Medium maturity, dual-purpose lines

**Grain mold resistance.** Earlier attempts to develop grain mold resistant white sorghums have had limited success, and grain molds remain a severe constraint to sorghum production. Resistant *guinea* sorghums have been produced, but these are generally low yielding, and their hard grain makes them unacceptable to many consumers. Flavan-4-ol pigmentation in the seed coat can complement grain hardness to confer grain mold resistance, but results in red seed which is again not acceptable in many food preparations. We are taking a two-pronged approach to genetic improvement of grain mold resistance by producing high-yielding, red-grained sorghums as a short-term objective, and improvement of white *guinea* sorghums as a long-term objective in combating grain molds.

Pedigree selection among crosses of elite lines and landraces identified as being resistant to grain molds has yielded several high yielding, agronomically desirable lines with good resistance to grain molds. Twenty-four advanced breeding lines—7 white grain, 10 red grain, and 7 brown grain without testa—were tested in a replicated yield trial for the first time in 1994. The control variety ICSV 112 yielded 6.1 t $ha^{-1}$ of grain, while the five best test lines yielded 5.5–5.7 t $ha^{-1}$. The threshed grain mold ratings (TGMR) of test lines (1–9 scale, where 1 = no mold, 9 = fully molded) ranged from 2.1 to 7.1, while ICSV 112 had a rating of 6.8. The TGMR of white-grained entries ranged from 5.1 to 7.1 with a mean of 5.7; brown-grained entries from 2.5 to 4.6 with a mean of 3.5; and red-grained entries from 2.1 to 4.2, with a mean of 3.5. Seven lines (5 red, 1 white, and 1 brown) which combined acceptable yield levels and grain mold resistance were selected for further use in breeding.

In a preliminary yield trial of 90 advanced breeding lines (56 with white grain, 28 with red grain, and 6 with brown grain), grain yields ranged from 2.1 to 5.9 t $ha^{-1}$ for the test entries, and 4.1 to 6.4 t $ha^{-1}$ for 5 control varieties and hybrids. Threshed grain mold ratings averaged 6.7 for the control cultivars, and 5.7 for the white-grained, 4.1 for the red-grained, and 3.5 for the brown-grained test entries. A total of 12 red-grained, 13 white-grained, and 2 brown-grained entries, with a combination of resistance to grain mold and good grain yield, were selected for further evaluation.

Pedigree breeding lines were advanced a generation during the postrainy season, and 615 $F_7$ lines were evaluated and selected for grain mold reaction under sprinkler irrigation to enhance mold pressure in rainy season. A total of 189 lines were selected for grain mold resistance. Of these, 42 were white-grained (TGMR <5), 99 red- and 48 brown-grained without testa (TGMR <4). A random mating population of *guinea* sorghums was mass selected for reduced height and white grain in both postrainy and rainy seasons.

**$A_2$ restorers.** Diversity among $A_2$ restorers is limited. Therefore, we studied landraces available from China, with IAC's Genetic Resource Division for restoration and agronomic desirability. We tested 104 lines for restoration efficiency on $A_2$ cytoplasm. Evaluation was carried out in the 1994 rainy season at IAC. We found 37 (36%) of them restoring fertility. Of these, 18 lines appeared to be productive for grain yield. These lines are generally early but susceptible to leaf diseases.

## Milo and nonmilo cytoplasm male-sterile lines

The majority of cytoplasmic male-sterile (cms) lines available at IAC and in national sorghum programs are based on $A_1$ cytoplasm. They are susceptible to most pests and diseases. The use of nonmilo cms lines is limited due to restricted diversity among the male-sterile lines that are available and lack of restorers.

**Milo-cytoplasm lines for resistance to biotic stresses.** As indicated in the ICRISAT Cereals Program Annual Report 1993, we continued selecting, testcrossing, and backcrossing male sterility maintainer lines in our efforts to breed milo cms lines with resistance to major yield-limiting factors (grain mold, anthracnose, leaf blight, rust, downy mildew, shoot fly, stem borer, midge, head bug, and *Striga* resistance). In addition, we evaluated the advanced resistant B-lines (grain mold, shoot fly, and midge) for their performance per se.

**Selection for resistance.** During 1994, we carried out one screening nursery with selection for each of the factors. The conversion process for selected lines was advanced by two further backcrosses. The information on the number of B-lines screened and selected, and their resistance levels for various factors is given in Table 2. Many of the selected B-lines had significantly superior resistance levels compared with the control(s) for all 10 stresses targeted in the program.

*Table 2. Sorghum seed parents evaluated and selected for resistance during 1994.*

| Stress/location | Test materials/ control | B-lines tested No. | B-lines tested Resistance levels Mean | Range | SE | B-lines selected No. | B-lines selected Resistance levels Mean | Range |
|---|---|---|---|---|---|---|---|---|
| Mold at IAC | | | | | | | | |
| Head[1] | B-lines | 118 | 3.7 | 2.1–7.0 | ±0.45 | 94 | 3.4 | 2.1–6.0 |
| Head[1] | 296B | | 8.8 | 7.8–9.0 | | | | |
| Grain[2] | B-lines | 94 | 4.9 | 2.5–6.3 | ±0.46 | 94 | 4.1 | 2.5–6.3 |
| Anthracnose | | | | | | | | |
| IAC | B-lines | 60 | 3.5 | 2.0–6.7 | ±1.10 | 37 | 3.4 | 2.0–6.0 |
| | IS 18442 | | 6.0 | 6.0–6.0 | | | | |
| Pantnagar | B-lines | 60 | 5.7 | 3.3–9.0 | ±1.50 | 37 | 4.8 | 3.2–6.0 |
| | IS 18442 | | 8.6 | 8.3–8.9 | | | | |
| Leaf blight | | | | | | | | |
| IAC | B-lines | 106 | 5.4 | 3.3–7.3 | ±1.33 | 50 | 4.6 | 3.3–5.3 |
| | IS 18442 | | 7.4 | 7.3–7.7 | | | | |
| Rust | | | | | | | | |
| IAC | B-lines | 106 | 4.1 | 1.7–5.3 | ±1.11 | 45 | 3.2 | 1.7–4.3 |
| | ICSR 119 | | 4.8 | 4.7–5.0 | | | | |
| Downy mildew[3] | | | | | | | | |
| IAC | Advanced lines | 77 | 9.9 | 0–96 | ±1.5 | 73 | 6.3 | 0–42 |
| | $F_3$ progenies | 37 | 22.6 | 0–96 | ±1.9 | 32 | 16.0 | 0–34 |
| | 296B | | 100.0 | 100–100 | | | | |
| Shoot fly[4] | | | | | | | | |
| IAC Rainy season | B-lines | 144 | 30.0 | 9–75 | ±6.70 | 79 | 27.0 | 9–43 |
| | CSH 1 | | 74.3 | 71–93 | | | | |
| Stem borer[4] | | | | | | | | |
| IAC Rainy season | B-lines | 119 | 63.9 | 32–93 | ±8.00 | 41 | 47.7 | 32–64 |
| | ICSV 1 | | 89.5 | 86–91 | | | | |
| Midge[1] | | | | | | | | |
| Kovilpatti | B-lines | 96 | 5.3 | 2.5–7.5 | ±0.60 | 75 | 4.7 | 2.5–6.0 |
| | CSH 1 | | 7.1 | 7.0–7.3 | | | | |
| IAC Postrainy | B-lines | 81 | 3.2 | 1.0–8.7 | ±0.98 | 75 | 2.7 | 1.0–4.7 |
| | CSH 1 | | 7.9 | 7.0–8.7 | | | | |
| Head bug[1] | | | | | | | | |
| IAC | B-lines | 27 | 4.7 | 3.3–5.7 | ±0.85 | 17 | 4.3 | 3.3–4.7 |
| | Malisor 84-7 | | 4.4 | 4.3–4.7 | | | | |
| *Striga*[5] | | | | | | | | |
| IAC | B-lines | 74 | 3.3 | 0–4.0 | ±0.51 | 50 | 0.3 | 0–2.0 |
| | CSH 1 | | 12.0 | 3–46 | | | | |

1. Ratings of the stress symptoms on a 1–9 scale where 1 = free from mold, and 9 = <50% of the grains molded in grain mold; 1 = no lesions and 9 = >75% leaf area covered with anthracnose lesions, and 1 = leaf lamina free from disease, and 9 = >80% area affected by leaf blight or rust diseases.
2. Threshed grain ratings as in head molds, taken for lines selected with head mold score of≤ 6.5.
3. Percentage of plants free from disease.
4. Percentage of deadhearts out of total plants.
5. Number of *Striga* plants.

**Grain yield potential in B-lines.** In sorghum, the performance of male-sterile lines per se is positively related to the performance of their hybrids. The performance per se of the B-lines selected for resistance to grain mold, shoot fly, and midge was evaluated in the 1994 rainy and postrainy seasons (Table 3). Many B-lines selected for resistance produced grain yields on par with the high-yielding susceptible control, 296B and many were significantly superior to their respective resistant controls.

**Nonmilo cytoplasm male-sterile lines.** Diversification of the cytoplasm of cms lines is a useful safeguard against the dangers of association of susceptibility to pests and diseases with any one cytoplasm. We continued conversion of a set of $A_1$ restorer lines selected for agronomic diversity or resistance to various yield-limiting factors into cms lines with $A_2$, $A_3$, and $A_4$ cytoplasms. They are at various stages of conversion into male sterility with $A_2$, $A_3$, and $A_4$ cytoplasms. They are: 5 lines in $BC_4$, 6 in $BC_3$, 30 in $BC_2$, and 45 in $BC_1$ in $A_2$, 10 in $BC_4$ and 2 in $BC_2$ in $A_3$, and 5 in $BC_4$ in $A_4$ cytoplasms at the end of the 1994 rainy season.

***Table 3. Grain yield (t ha$^{-1}$) of improved sorghum B-lines, ICRISAT Asia Center, 1994.***

| | | | B-lines tested | | | | Resistant B-lines selected for yield ≥ the control | |
|---|---|---|---|---|---|---|---|---|
| | | | | Grain yield (t ha$^{-1}$) | | | Grain yield (t ha$^{-1}$) | |
| Characteristic | 1994 season | Control | No. | Mean | Range | SE | No. | Range |
| Grain mold | Rainy | | 106 | 3.7 | 1.3–6.0 | ±0.36 | | |
| | | 296B | | 5.2 | | | 5 | 5.2–6.0 |
| | | IS 10475 | | 3.8 | | | 36 | 3.8–6.0 |
| | Postrainy | | 106 | 3.4 | 1.2–5.1 | | | |
| | | 296B | | 4.0 | | | 17 | 4.0–5.1 |
| | | IS 10475 | | 3.1 | | | 66 | 3.1–5.1 |
| Shoot fly - Trial I | Rainy | | 34 | 1.0 | 0.5–2.3 | ±0.19 | | |
| | | 296B | | 0.8 | | | 20 | 0.8–2.3 |
| | | IS 18551 | | 0.4 | | | 31 | 0.4–2.3 |
| Shoot fly - Trial II | Rainy | | 52 | 3.6 | 1.7–5.0 | ±0.55 | | |
| | | 296B | | 5.3 | Nil | | | |
| | | IS 18551 | | 5.2 | Nil | | | |
| | | | | | | | 12 | 4.0–5.0 |
| | Postrainy | | 67 | 1.9 | 0.4–2.9 | ±0.31 | | |
| | | 296B | | 1.2 | | | 61 | 1.2–2.9 |
| | | IS 18551 | | 1.8 | | | 31 | 1.8–2.9 |
| Midge | Rainy | | 79 | 4.3 | 2.6–6.9 | ±0.50 | | |
| | | 296B | | 5.5 | | | 8 | 5.5–6.9 |
| | | ICSV 745 | | 4.5 | | | 28 | 4.5–6.9 |
| | Postrainy[1] | | 79 | 4.1 | 2.5–6.6 | ±0.60 | | |
| | | 296B | | 3.7 | | | 49 | 3.7–6.6 |
| | | ICSV 745 | | 4.0 | | | 39 | 4.0–6.6 |
| | Postrainy[2] | | 81 | 2.6 | 0.7–3.9 | ±0.51 | | |
| | | ICSV 745 | | 3.5 | | | 12 | 3.5–3.9 |
| | | CSH 1 | | 2.8 | | | 31 | 2.8–3.9 |

1. Vertisol.
2. Alfisol.

### Hybrids

Strategic research, i.e., development of parental lines has been receiving major attention in the program. So, we gave lesser priority to developing hybrids and testing them for general purpose and grain yield assessment. However, a few hybrids were tested to enable us to select the parents for forage purposes.

We evaluated 29 single-cross and 118 three-way-cross forage hybrids and selected 5 single-cross and 13 three-way-cross forage hybrids. The parents of the selected hybrids include ICSAs 52, 85, 93, and 95, and GDs 28802A, 28804A, 28805A, 28825A, 28832A, 28842A, 28891A, 28898A, 25532A, 25534A, and 25536A, 296A, and (ICSA 95 × IS 646) female lines, and SSG 59–3, ICSRs 93023, 93025, 93020, 93019, and 93024 male lines. Selection was carried out for high green forage yield at soft dough stage, high sugar percentage, better plant agronomic score, tall plant height, and high tiller percentage in the main crop, and higher rejuvenation ability after the first cut of the main crop. The fresh forage yield ranged from 45.3 to 66.7 t $ha^{-1}$ in the selected hybrids. The control SSG 59-3 yielded 38.0 t $ha^{-1}$. The trial mean was 44.8 ± 4.81 t $ha^{-1}$. The selected hybrids varied for the selection criteria and these are shown in Table 4.

## Postrainy Season Adaptation

### Restorer lines

**Variability in landraces for restoration.** Fertility restoration is known to be influenced by low temperatures (when minimum temperatures go below 10°C for several days during flowering, as happens in the postrainy season), and some restorers show male sterility in hybrids, leading to partial to complete failure of seed setting under bagging. The restoration patterns on $A_1$ and $A_2$ cms lines of landrace sorghums adapted to postrainy season were studied during the 1993 and 1994 postrainy seasons and the results are summarized below.

In about 2000 testcrosses made from individual plants from 18 landraces and *caudatum*-derived $A_1$ and $A_2$ cms lines, restoration frequency in the 1993 postrainy season evaluation was similar on $A_1$ (65%) and $A_2$ (56%) sources. However, when *durra*-derived $A_1$ testcrosses were compared with *caudatum*-derived $A_2$ testcrosses, restoration frequency of landraces was significantly less in durra $A_1$ system (15%) than *caudatum* $A_2$ system (69%). Even within the $A_1$ system, *durra* supported less restoration (23%) than *caudatum* (62%).

Several of the most promising postrainy-season landraces (e.g., M 35-1, NTJ 2, IS 33166, IS 33751, and IS 33843) segregated for restoration, and sterility maintenance, indicating the opportunity to select for restoration.

***Table 4. Performance of selected sorghum forage hybrids and control variety (SSG 59–3) for forage characteristics, ICRISAT Asia Center, rainy season 1994.***

| Characteristic | Selected hybrids (range) | Control (SSG 59–3) | Trial mean[1] | SE |
|---|---|---|---|---|
| Fresh forage yield (t $ha^{-1}$) | 45.3–66.7 | 38.0 | 44.8 | ±4.81 |
| Sugar (%) | 10.9–14.2 | 11.2 | 10.8 | ±1.30 |
| Agronomic score[2] | 1.0–2.5 | 1.8 | 2.8 | ±0.42 |
| Plant height (m) | 2.9–3.7 | 3.0 | 2.9 | ±0.17 |
| Time to 50% flowering (days) | 63–78 | 77.0 | 67.0 | ±1.90 |
| Tiller (%) | 12–157 | 38.0 | 23.0 | ±7.90[3] |
| Rejuvenation[4] | 1.2–2.5 | 1.5 | 2.5 | ±0.42 |

1. n = 150 entries (118 three-way-cross hybrids, 29 hybrids, and 3 controls).
2. Scored on a 1–5 scale, where 1 = highly desirable, and 5 = least desirable.
3. Arc sine transformed values.
4. Scored on a 1–5 scale, where 1 = high rejuvenation, and 5 = poor rejuvenation.

We found highly significant positive correlation (r=0.34**) between minimum temperatures starting from 5 days before and 5 days after 50% flowering, and restoration, as indicated by percentage seed set under bagging.

The testcrosses made from the individual plant progenies (100 on $A_1$ and $A_2$ cytoplasms each) selected based on restoration in the testcrosses in the 1993 rainy season were again evaluated in the 1994 postrainy season. The night temperatures were sufficiently low (about 10°C) during flowering. The results confirmed that all selected single-plant progenies of Swathi, ISs 5631, 5476, and 18361 were restoring fully (≥80%) on $A_1$ cytoplasm and of M 35-1, Swathi, ISs 23509, 33844, 18372, 5631, 18361, and 5476 on $A_2$ cytoplasm.

## Male-sterile lines

We continued to select B-lines with postrainy season adaptation for resistance to shoot fly and stem borer and for stay-green or large grain characteristics. We completed one screening and two backcrosses. The details of selection and the effects of cms cytoplasms are presented below.

**Shoot fly resistant lines.** The postrainy-season adapted B-lines (44) selected for resistance to shoot fly in the 1993 postrainy season were screened under infester-row technique for resistance to shoot fly in the 1994 postrainy season in a replicated trial. All the B-lines showed significantly less deadhearts (%) than the susceptible control, CSH 1 (trial mean: 19.6, range: 4.0–36.7, SE ±4.8) which showed 60% deadhearts. The resistant control, IS 18551 showed 14% deadhearts. Seventeen B-lines selected for resistance produced grain yield ranging from 3.7 to 4.7 t $ha^{-1}$ (trial mean: 3.4 t $ha^{-1}$; SE ±0.4 t $ha^{-1}$).

**Stem borer resistant lines.** The postrainy-season adapted B-lines (40) and $F_3$s (32) were evaluated for resistance to stem borer under artificial infestation in the 1994 postrainy season, along with resistant (IS 2205) and susceptible (ICSV 1) controls. The trial mean for deadhearts (%) damage was 41. The mean deadhearts damage (%) in the resistant control, IS 2205 was 35 (range 28.0–43.0) while it was 57 (range 46.0–65.0) in the susceptible control, ICSV 1. The deadhearts damage (%) was 27 (range 17.0–34.0) in the selected B-lines (18) and 39 (range: 22.0–40.0) in the selected $F_3$ progenies (19).

**Stay-green lines.** We evaluated 20 B-lines under conversion for stay-green and grain yield under terminal drought conditions in the 1994 postrainy season in a replicated trial. The stay-green line, QL 101 scored 3.0–4.3 on a 1–5 scale where 1 = 90–100% leaf area green, and 5 = <60% leaf area green. Of the 16 lines selected for green leaf area, eight B-lines produced significantly higher grain yield (3.13–3.93 t $ha^{-1}$, SE ±0.36) than did QL 101(2.38 t $ha^{-1}$).

**Bold-grain lines.** From 183 bold-grain progenies, we selected 27 uniform lines, fully converted to male sterility and 112 lines needing further conversion in the 1994 rainy season. They were further evaluated and backcrossed in the 1994 postrainy season. At present, we have 41 large-grain lines, fully converted to male sterility and 45 lines which need further conversion. Their grain mass ranged from 2.8 to 5.3 g $100^{-1}$ grains.

**Effects of $A_1$ and $A_2$ cytoplasms.** In a study involving hybrids of four isonuclear cms lines of $A_1$ and $A_2$ cms systems, and 10 common restorers evaluated in the 1993 and 1994 postrainy seasons in a split-split plot design with restorers (R) as main plots, A-lines (A) as subplots, and cytoplasm (C) as sub-subplots. Data were collected on days to 50% flowering, plant height, grain mass, grain yield, and fertility restoration. Variance estimates due to season (S), R and A were highly significant for all characteristics except those of grain yield and restoration due to S. Variance due to C was highly significant only for restoration, but not for other characteristics. Variance estimates due to interaction of C with others were highly significant only in the following cases: grain mass: A × C and R × A × C; grain yield: S × C, R × C, A × C, R × A × C, and S × R × A × C; and fertility restoration: R × C, A × C, and R × A × C. On the other hand, most of the interactions variance estimates due to other factors, S, A, and R were highly significant for all the characteristics. Although $A_1$ and $A_2$ variance estimates differed significantly for restoration, the difference has little biological significance, as average restoration was higher than 80% in both the systems studied. Thus, the direct variances due to cytoplasm were not significant for agronomic characteristics. It is therefore concluded that the $A_2$ cms system can also be used in hybrid programs.

### Landrace hybrids

We found many desirable landrace characteristics (e.g., grain mass and shape, plant height, earliness, stalk-rot resistance, etc.) that confer adaptation to the postrainy-season environment. These are expressed in hybrids when landraces are used as pollinators. We evaluated 23 landrace hybrids from 13 male-sterile lines and 12 landraces in a replicated trial at one location in the 1993 postrainy season, and two locations in the 1994 postrainy season. The control hybrid, CSH 13R produced a grain yield of 3.73 t $ha^{-1}$ (SE ±0.18 t $ha^{-1}$). Eight hybrids produced grain yields (3.27–3.78 t $ha^{-1}$) on par with CSH 13R. They also showed plant height (2.2–2.6 m, SE ±0.05 m) similar to CSH 13R (2.3 m). However, the selected hybrids were early (59–66 days to 50% flowering, SE ±0.55 days) compared with CSH 13R (69 days), and had significantly higher 100-grain mass (3.13–3.55 g, SE ±0.08 g) than CSH 13R (2.84 g). Further, all the selected hybrids had significantly higher restoration (%) (85-97; SE ±3.44) compared with CSH 13R (67). The selected hybrids are: ICSHs 91222, 91225, 92252, 93123, 93124, 93125, 93126, and 93134. The parents involved are: ICSAs 15, 20, 30, 41, 88010, 91002, and 91003 (male-sterile lines); and ICSRs 91034, 92026, 93011, and 93034 (restorer lines).

### International trials

During 1994, we coordinated the International Sorghum Variety and Hybrid Adaptation Trial (ISVHAT) with an objective to provide elite sorghum cultivars and hybrids to national agricultural research systems (NARS) scientists. It contained 9 hybrids and 17 varieties, and was sent to 35 locations (22 in Asia and 13 in Africa). The data of ISVHAT 93 received from 27 locations (until September 1994) were analyzed and reported in the ICRISAT Cereals Program Annual Report 1993.

We started the retrospective analysis of earlier ISVHATs to understand the genotype × environment (G×E) interaction. The details of statistical methods used are given elsewhere in this report. Main results are: genotypes bred at different centers cultured differently, G×E interaction was mainly due to three genotypes originated from SEA and one from Indian NARS, mainly two environments from India and one from each of Indonesia and Iran, contributed to G×E interaction and maturity groups are the main sources of G×E interaction.

Genotypes ICSV 112, ICSH 110, and ICSH 89123 bred at IAC were identified as most stable and widely adapted cultivars, as they possessed principal component axis 1 values near to zero in the AMMI analysis, indicating the absence of G×E interaction.

## Seed Exchange

We distributed a total of 7258 sorghum seed samples to 12 countries in Asia (72.6%), 7 countries in Africa (25.5%), and 3 countries in Europe (0.3%) and in the Americas (1.3%). The 10 countries which received the maximum number of samples are: India (43.2%), Sudan (11.7%), Pakistan (6.4%), Myanmar (6.3%), Egypt (5.6%), Thailand (3.8%), Iran (3.1%), Ethiopia (3.0%), Kenya (2.5%) and Indonesia (2.2%).

# Pearl Millet

Genetic enhancement research on pearl millet moved further into strategic areas. In this report, we illustrate the extent of diversity among pollinator collection entries, and characteristics that make major contributions to this diversity. We report a new source of cytoplasmic-nuclear male sterility that could be immensely useful for breeding forage hybrids. Population improvement research evaluated the potential of selection indices in improving grain and fodder yield, and assessed the utility of IAC as a selection site to breed open-pollinated varieties for locations in northern India, Pakistan, and Nepal. A molecular mapping population for seedling heat tolerance has been developed, and identification of quantitative trait loci (QTLs) is underway. In the meantime, this population has been put to good use to identify QTLs for downy mildew resistance, flowering time and 1000-grain mass. Supply of breeder seed of released ICRISAT-bred open-pollinated varieties and hybrid parents continued to be our major service function, targeted to achieving the full impact of our previous applied research.

## Pollinator Collection Diversity

A large number of inbred pearl millet pollinators—male parents of hybrid cultivars—are maintained in the ICRISAT Pollinator Collection. Many are related by pedigree or origin, while others are derived from random-mated bulks, and hence have unknown relationships. To create new variability, crosses among diverse parents must be made. Therefore, an investigation was initiated to identify genetically diverse pollinators from a subset of elite entries in the collection.

Sixteen elite inbred pollinators were selected for this study, based on their good combining ability for grain yield and downy mildew resistance. They were evaluated in two environments at IAC—1992 rainy season and 1994 summer. Twelve characteristics with significant phenotypic differences and with broad-sense heritabilities >0.80 were used to analyze genetic diversity among these 16 pollinators using the $D^2$ statistic. Pollinators were also clustered using Ward's minimum variance method.

As expected, considerable diversity was detected among the 16 elite inbred pollinators. Groupings were consistent and largely independent of environment (Fig. 1). Among 12 characteristics considered, only four—time to maturity, panicle length, panicle girth, and plant height—made major contributions to the diversity detected in this set of inbreds. Four elite pollinators—IPC 0098, IPC 0107, IPC 0736, and IPC 1470—were identified as diverse parents for future crosses.

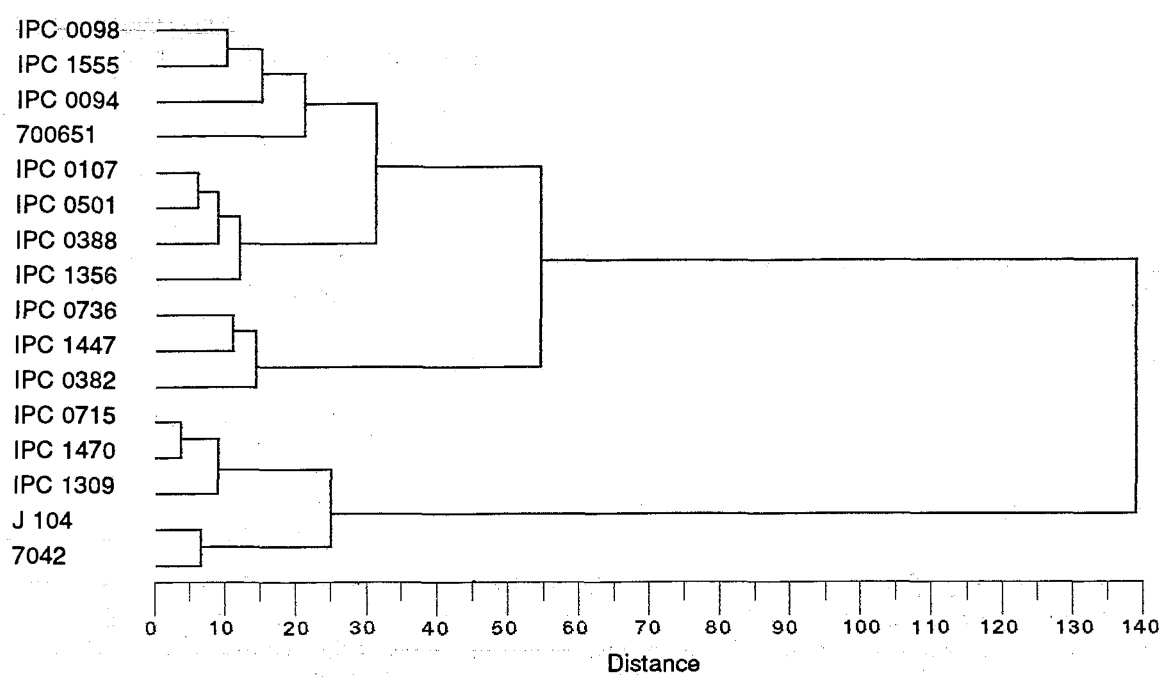


***Figure 1. Dendrogram of 16 elite pearl millet inbred pollinators across rainy season 1992 and summer 1994 at ICRISAT Asia Center.***

## New Source of Cytoplasmic-Nuclear Male Sterility

All commercial pearl millet hybrids bred to date in India and the USA are based on female parents having a single source of cytoplasmic-nuclear male sterility (CMS)—the $A_1$ cytoplasm of Tift 23A. Cytoplasmic diversification of female hybrid parents is a major objective of pearl millet seed parents breeding at IAC. Search for, and characterization of, new sources of CMS is ongoing. This effort recently resulted in the identification of 67 male-sterile plants from the Large-Seeded Gene Pool (LSGP), constituted jointly by the Genetic Enhancement and Genetic Resources Divisions at IAC. Open-pollinated seeds from one of these plants produced only male-sterile hybrids. Since no other CMS source gives this high level of sterility in its hybrids, this LSGP cytoplasm appeared to represent a new CMS system.

Among CMS systems previously reported in this crop, the $A_m$ cytoplasm, identified at the Coastal Plain Experiment Station, Tifton, Georgia, USA, produces the highest frequency of male-sterile hybrids. We compared the male sterility of near-isogenic hybrids made on the new CMS source and the $A_m$ cytoplasm. Thirteen diverse restorers of the $A_m$ CMS system produced highly male-fertile hybrids (68–92% selfed seed-set) when crossed onto $81A_m$. However, they all produced highly male-sterile hybrids (0–3% selfed seed-set) when crossed onto a near-isonuclear line ($81A_L$) having the new male-sterile cytoplasm from the LSGP. Four diverse composites crossed onto $81A_m$ produced topcross hybrids with 10–35% plants having good male fertility (>50% selfed seed-set). When crossed onto $81A_L$, all topcross hybrid plants produced by these composites were male-sterile. Results suggest the CMS system of $A_L$ is different from that of $A_m$ and other sources. Utility of this new CMS system in breeding male-sterile parents of grain hybrids requires discovery of its restorer genes in a more extensive survey of the germplasm. However, $A_L$ provides a good opportunity to diversify the nuclear and cytoplasmic base of seed parents for pearl millet forage hybrids.

## Regional Pearl Millet Trials

For the first time in several years, in 1994, data were returned from a uniform trial of advanced pearl millet open-pollinated varieties and population bulks (PMEPAT-94) sent to cooperators in countries across the Indo-Gangetic Plain. Trials were successfully conducted at one site in Nepal, three sites in northern India, and four sites in Pakistan. Although genotype × environment interactions were statistically significant, relative performance of most trial entries was comparable across the eight sites (Table 5). The trial was topped by entries based on progenies selected for yield and agronomic score at IAC in the Large Grain Population (ICMV 94135), or selected visually at IAC from Medium Composite 91 (ICMV 94475). Other top performers included a topcross pollinator developed from the Bold Seeded Early Composite (ICMV 31293) at IAC, and the second random-mating bulk from the newly formed Medium Composite 94. Forty percent of trial entries had mean yields 10% above the mean of the four controls. It appears that even for these relatively high-latitude Asian locations—which did not include sites in the drier regions of Rajasthan and Gujarat—selection at IAC can provide materials worthy of further evaluation and refinement by breeders in local and national programs.

## Downy Mildew Resistance in Seedling Heat Tolerance Mapping Populations

Joint efforts of IAC and the Institute of Grassland and Environmental Research (IGER), UK, have produced two pearl millet mapping populations to tag genes controlling seedling heat tolerance of elite inbred pollinator H 77/833-2. The restriction fragment length polymorphism (RFLP)-based skeleton map of the first of these populations (derived from a cross with ICMP 451) was completed in 1994. Field data on downy mildew reaction (Patancheru isolate), flowering time, and 1000-grain mass from a replicated trial conducted in the 1994 dry season downy mildew nursery at IAC were used to evaluate this map for its ability to detect QTLs. Two QTLs for downy mildew resistance were detected from ICMP 451, including one in linkage group 1 (LG1) at a location similar to QTLs previously detected for this characteristic from P 7-3 and ICMP 85410. Together, these two QTLs accounted for nearly 90% of the

*Table 5. Grain yield (t ha$^{-1}$) of the top five test entries and controls in the 1994 Pearl Millet Early Population Advanced Trial, conducted at eight locations across the Indo-Gangetic Plain, rainy season 1994.*

| | | India | | | Nepal | Pakistan | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Entry | Overall rank | Gwalior | Hisar | Madhu-rikund | Nepal-gunj | Dadu | Isla-mabad | DI Khan | Yousuf-wala | Overall mean |
| ICMV 94475 | 1 | 3.42 | 2.75 | 1.65 | 1.94 | 2.33 | 4.29 | 3.67 | 3.41 | 2.66 |
| ICMV 94135 | 2 | 4.30 | 2.67 | 2.64 | 1.87 | 1.44 | 1.96 | 3.04 | 2.62 | 2.57 |
| MC 94 II RM | 3 | 3.40 | 2.35 | 2.21 | 1.53 | 2.44 | 2.51 | 2.47 | 2.90 | 2.48 |
| ICMV 31293 | 4 | 3.59 | 2.30 | 1.63 | 1.46 | 1.56 | 2.64 | 3.25 | 3.21 | 2.45 |
| ICMV 94132 | 5 | 3.89 | 2.02 | 2.43 | 1.53 | 1.94 | 1.73 | 3.08 | 2.24 | 2.36 |
| Controls | | | | | | | | | | |
| ICMV 221 | 13 | 3.58 | 2.48 | 1.56 | 1.04 | 1.17 | 1.51 | 2.50 | 2.91 | 2.09 |
| WC-C75 | 19 | 3.19 | 2.48 | 2.63 | 0.97 | 0.78 | 1.62 | 2.29 | 2.42 | 2.04 |
| ICTP 8203 | 23 | 3.28 | 1.54 | 1.98 | 1.32 | 0.61 | 1.73 | 2.79 | 2.45 | 1.96 |
| Local | 26 | 3.49 | 2.23 | 1.56 | 1.49 | 0.94 | 0.78 | 2.33 | 1.91 | 1.84 |
| Mean (28 entries) | | 3.48 | 2.29 | 1.68 | 1.39 | 1.41 | 1.85 | 2.56 | 2.50 | 2.13 |
| SE | | ±0.25 | ±0.12 | ±0.09 | ±0.26 | ±0.20 | ±0.56 | ±0.33 | ±0.23 | |
| CV (%) | | 13 | 9 | 9 | 33 | 20 | 52 | 18 | 16 | |

variation for downy mildew reaction detected in this mapping population in this trial. Three QTLs of large effect were detected for 1000-grain mass—one in LG2 and two in LG4. For flowering time, one QTL of large effect (accounting for 35% of detected variation) was identified on LG6, along with another of smaller effect on LG1. Late flowering of ICMP 451 was tightly linked to its downy mildew resistance QTL in LG1. This skeleton map appears suitable to identify QTLs for characteristics having high heritabilities. Success in mapping QTLs for seedling heat tolerance—the primary target characteristic for this mapping population—will be possible if heat tolerance screening heritabilities are improved.

## Heritability of Selection Indices Used in Pearl Millet Population Improvement

Selection indices are used in pearl millet population improvement work to integrate multiple selection criteria, such as grain yield (GY), effective grain setting score (GSS), stover yield (SY), fodder quality score (FQS), and time to 50% flowering (TF).

Although individual characteristics in an index show significant genetic variation, undesirable relationships among component characteristics would reduce the effective variation of the index, and may result in unacceptable changes in particular characteristics. Likewise, when combining index values over locations, genotype by location interaction would further reduce the expected effectiveness of the index. Therefore, before committing to selection with a particular index, we examine selection differentials and heritabilities of the proposed indices.

Improvement of the Early High-Tillering Population (EHiTiP 92) in 1994 via full-sib progeny evaluation is taken as an example. The objectives are to increase grain yield, earliness, and fodder quality of this population without sacrificing stover yield. Selection indices chosen for each target environment (Jodhpur and Fatehpur, India) showed moderately high heritabilities (Table 6). The combined indices across locations had lower heritabilities, yet were sufficient to justify proceeding with selection. Selection differentials in the two target environments obtained from applying the across-location index of Jodhpur + Fatehpur + IAC predict that index selection would provide simultaneous gains for grain yield, earliness, and fodder quality without reducing stover yields (Table 7).

**Table 6. Heritabilities on entry mean basis ($h^2$) of individual location selection indices and across-location selection indices in 1994.**

| Location | Index[1] | Mean squares | | |
|---|---|---|---|---|
| | | Entry | Error[2] | $h^2$ |
| Fatehpur | GY–GSS–FQS–TF | 7.8 | 2.8 | 0.61 |
| Jodhpur | GY–0.5GSS+SY–0.5FQS–TF | 6.2 | 3.1 | 0.50 |
| ICRISAT Asia Center | GY–0.5GSS+SY–0.8FQS–0.5TF | –[3] | – | – |
| Across two locations | I (Fatehpur)+I (Jodhpur) | 1.2 | 0.8 | 0.35 |
| Across three locations | I (Fatehpur)+I (Jodhpur)+I (IAC) | 1.5 | 0.8 | 0.48 |

1. GY = grain yield, GSS = grain setting score, FQS = fodder quality score, TF = time to 50% flowering, and SY = stover yield.
2. Genotype × location interaction mean square for across-location selection index and error mean square for individual location selection index.
3. – = Not available.

## Seed Distribution

During 1994, 10163 pearl millet seed samples were supplied in response to requests from various institutions and national programs (Table 8). Asia received 65% of these samples, followed by Europe (31%), and Africa (3%). Only 1% of samples provided were sent to the Americas this year. The large number of samples sent to Europe were associated with seed color inheritance studies (The Netherlands) and research of Overseas Development Agency-funded collaborators in the UK on seedling heat tolerance and downy mildew resistance. In addition, we supplied 547 freeze-dried tissue samples for DNA extraction by the UK collaborators who are developing molecular maps of the pearl millet genome.

Included among the 517 pearl millet Breeder Seed samples supplied to 68 seed-producing agencies in India during 1994 were 0.7 t of six open-pollinated varieties and 1.0 t of 16 hybrid parental lines (Table 9). Parental lines of ICMH 451 (i.e., ICMA 1, ICMB 1, and ICMP 451) comprised 43% of the hybrid parents Breeder Seed supplied, while seed parents of popular hybrids Pusa 23 (ICMA 841 and ICMB 841) and HHB 67 (ICMA 2 and ICMB 2) accounted for another 37%. Among the open-pollinated varieties, ICTP 8203 (20%) and WC-C75 (22%) continued to be popular, but recent releases—ICMV 155 (16%) and ICMV 221 (31%)—could replace them in future. The seed parents Breeder Seed distributed in 1994 is sufficient to produce hybrid Certified Seed to sow 6 m ha, assuming two generations of multiplication, 200-fold multiplication per generation, and a hybrid seed sowing rate of 4 kg $ha^{-1}$. Open-pollinated variety Breeder Seed distributed is sufficient to produce Certified Seed to sow 7 m ha based on similar assumptions.

**Table 7. Selection differentials as percentages of population means for EHiTiP 92 in 1994 at target locations from selection with the across-location index, Fatehpur + Jodhpur + ICRISAT Asia Center, India.**

| Characteristic | Location | |
|---|---|---|
| | Jodhpur | Fatehpur |
| Time to 50% flowering | –1.8 | –2.2 |
| Grain yield | 14.3 | 20.6 |
| Grain set score | –14.2 | –17.1 |
| Stover yield | 4.3 | – |
| Fodder quality score | –12.0 | –14.5 |

*Table 8. Pearl millet seed samples supplied from Genetic Enhancement Division at ICRISAT Asia Center to national programs and other organizations worldwide during 1994.*

| Region/country | No. of samples | | | | |
|---|---|---|---|---|---|
| | Breeder Seed | Breeding lines | Trials and nurseries | | Total |
| | | | Sets | Entries | |
| **Southern and Eastern Asia** | | | | | |
| Bangladesh | 0 | 6 | 0 | 0 | 6 |
| India | 517 | 4547 | 62 | 1219 | 6283 |
| Nepal | 0 | 0 | 1 | 28 | 28 |
| Pakistan | 0 | 0 | 7 | 199 | 199 |
| Republic of Korea | 0 | 41 | 0 | 0 | 41 |
| Yemen | 0 | 16 | 0 | 0 | 16 |
| Subtotal | 517 | 4610 | 70 | 1446 | 6573 |
| **Eastern Africa** | | | | | |
| Ethiopia | 0 | 11 | 3 | 75 | 86 |
| Kenya | 0 | 79 | 1 | 28 | 107 |
| Sudan | 0 | 21 | 0 | 0 | 21 |
| Subtotal | 0 | 111 | 4 | 103 | 214 |
| **Northern Africa** | | | | | |
| Egypt | 0 | 14 | 2 | 51 | 65 |
| **Southern Africa** | | | | | |
| Zimbabwe | 0 | 4 | 0 | 0 | 4 |
| **Western and Central Africa** | | | | | |
| Niger | 0 | 39 | 0 | 0 | 39 |
| **Americas** | | | | | |
| Colombia | 0 | 42 | 0 | 0 | 42 |
| Paraguay | 0 | 30 | 0 | 0 | 30 |
| USA | 0 | 4 | 0 | 0 | 4 |
| Subtotal | 0 | 76 | 0 | 0 | 76 |
| **Europe** | | | | | |
| The Netherlands | 0 | 1857 | 0 | 0 | 1857 |
| UK | 0 | 1335 | 0 | 0 | 1335 |
| Subtotal | 0 | 3192 | 0 | 0 | 3192 |
| **Grand total** | 517 | 8046 | 76 | 1600 | 10 163 |

*Table 9. Breeder Seed of pearl millet hybrid parents and open-pollinated varieties supplied from ICRISAT Asia Center to seed-production agencies in India during 1994 (Jan-Dec).*

| Genotype | Quantity (kg) | No. of agencies |
|---|---|---|
| **Hybrid parents** | | |
| ICMA 1 (81A) | 228.5 | 34 |
| ICMB 1 (81B) | 96.5 | 34 |
| ICMA 2 (843A) | 130.0 | 32 |
| ICMB 2 (843B) | 63.5 | 32 |
| ICMA 3 (842A) | 72.5 | 19 |
| ICMB 3 (842B) | 34.5 | 19 |
| ICMA 4 (834A) | 3.0 | 1 |
| ICMB 4 (834B) | 1.5 | 1 |
| ICMA 841 (841A) | 123.5 | 28 |
| ICMB 841 (841B) | 61.5 | 28 |
| ~~ICMA 88004~~ | ~~42.0~~ | 17 |
| ICMB 88004 | 21.0 | 17 |
| ICMP 423 | 1.5 | 2 |
| ICMP 451 | 108.0 | 27 |
| ICMP 501 | 1.0 | 1 |
| ICMR 312[1] | 13.5 | 31 |
| ICMR 356 | 24.0 | 18 |
| **Open-pollinated varieties** | | |
| ICMV 1 (WC-C75) | 153.5 | 23 |
| ICMV 4 (ICMS 7703) | 7.0 | 2 |
| ICMV 155 (ICMV 84400) | 112.0 | 10 |
| ICMV 221 (ICMV 88904) | 214.5 | 29 |
| MP 124 (ICTP 8203) | 138.5 | 24 |
| Raj 171 (RCB-IC 9) | 70.0 | 4 |
| RCB-IC 911[1] | 45.0 | 1 |
| Total | 1766.5 | 68 |

1. Nucleus seed only.

# Chickpea

Chickpea Breeding was coordinated from two centers: ICRISAT Asia Center and the International Center for Agricultural Research in the Dry Areas (ICARDA). These Centers represent two different production domains: IAC is characterized by a dry and hot growing season, while ICARDA's winter-sowing season is only moderately dry and cold. Such differences in environment have an important bearing on chickpea genetic enhancement, as they are accompanied by differences in constraints to which the crops are exposed. In ICRISAT's new research organization, research project CP1 focuses on the former domain and research project CP3 on the latter. The domain of research project CP2 is characterized by a moderately dry and cool climate. The main constraints in the CPI domain are drought, pod borers, and soilborne diseases; for CP3, ascochyta blight (AB) and freezing cold are the most important, while CP2 faces major problems in botrytis gray mold (BGM), stunt, and chilling cold. The main developments and achievements during 1994 in these areas are presented below.

## ICRISAT Asia Center

### Varietal releases

- ICCV 2 and ICCC 42 were released in Myanmar. ICCV 2 won First and Second FAO Prizes in Yield Maximization Demonstration Trials on legume crops in Myanmar.
- ICCX 86047-BP-20H-BP-B was released in the USA under the name Myles for the States of Idaho, Washington, and Oregon.
- ICC 4998 was released in Bangladesh under the name of Bina Sola 2.

### Breeding for drought resistance

The root-based and yield-based selections derived from a cross involving drought-resistant (ICC 4958), disease-resistant (ICC 12237), and well-adapted (Annigeri) parents were evaluated in a joint Agronomy/Genetic Enhancement Division common trial, both in Alfisols and Vertisols, under irrigated and rainfed conditions. The two approaches seemed to be equally effective. The yield-based approach seemed to be superior to the root-based approach, in response to good moisture conditions; however, the latter was superior in terms of drought tolerance index. Interestingly, the former selections approximated more to Annigeri in growth habit, while the latter to ICC 4958. The yield-based selection, ICCV 94927, performed consistently well in all the treatments.

### Determinate growth habit

The study of the inheritance of the determinate growth habit, which was induced in ICCV 6 by means of gamma radiation, was concluded in 1994. It was postulated that this characteristic, which is important to curb excessive vegetative growth, is controlled by two genes, one recessive that is to be present to enable the plant to express the characteristic, or in other words, it conditions for determinancy (*cd*), and one that makes the plant to express the determinate characteristic (*Dt*).

### Combined resistance to *Helicoverpa* pod borer and soilborne diseases

A backcross breeding program, aiming at combining resistance to *Helicoverpa* pod borer and soilborne diseases, yielded its first final products. The top five lines, in comparison with their controls, performed as given in Table 10.

## Polygon Breeding

Polygon breeding involving Indian NARS and IAC continued actively and proved very fruitful. Based on superior yields and agronomic characteristics, Punjabrao Krishi Vidyapeeth (PKV), Akola, entered JAKI 9303, 9324, and 9309, and Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Sehore, entered SAKI 9313, 9320, and 9328 into the All India Coordinated Pulse Improvement Project trials (AICPIP). Out of nine varieties contributed by the program to the AICPIP trials in the previous year, seven were promoted to the next stage of testing.

### Molecular marker work: collaboration with John Innes Centre (JIC), UK

The work on molecular markers for fusarium-wilt resistance continued at the JIC. The $F_2$ population of ICCV 2 × JG 62 cross, which was developed at IAC, was scanned for Amplified Fragment Length Polymorphisms (AFLP) band

***Table 10. Performance of five best breeding lines with resistance to soilborne diseases and pod borer at ICRISAT Asia Center, postrainy season 1993/94.***

| | Diseased and nonsprayed condition | | Disease-free and sprayed condition |
|---|---|---|---|
| Test entry | Yield (t $ha^{-1}$) | Pest score[1] | Yield (t $ha^{-1}$) |
| ICCX-850123-BP-7P-3P-BP | 1.27 | 3.0 | 1.66 |
| ICCX-850123-BP-7P-9P-BP | 1.10 | 3.5 | 1.93 |
| ICCX-850123-BP-3P-4P-1P-3P-BP | 1.11 | 5.0 | 2.19 |
| ICCX-850123-5P-16P-1P-BP | 0.98 | 3.5 | 2.24 |
| ICCX-850123-BP-8P-2P-BP | 1.14 | 3.5 | 1.76 |
| **Control[2]** | | | |
| Annigeri | 0.35 | 7.0 | 1.05 |
| ICCL 86111 | 0.55 | 4.5 | 1.76 |
| Mean (25 entries) | 0.83 | 4.5 | 2.01 |
| SE | ±0.096 | ±0.45 | ±0.174 |
| CV(%) | 24.4 | 19.7 | 17.3 |

1. *Helicoverpa* pod borer damage score on a 1–9 scale, where 1 = no damage, and 9 = all pods damaged.
2. The control Annigeri is resistant to fusarium wilt but susceptible to pod borer, while control ICCL 86111 is resistant to both pests.

differences at JIC. Of about 8000 sites scanned for the presence of allelic differences in the genome between the two parents, 122 band differences were identified.

It appears that a sufficient number of markers have been identified for the generation of genomic map. Further work on segregation of the AFLP markers is in progress. We expect to receive $F_3$ seeds of the $F_2$ plants used for molecular maps. These will be scored for fusarium wilt resistance, flower color, and pod number. We will attempt to link the genes known for these characteristics with the molecular markers.

## Breeding for cold tolerance

Early-flowering cold (chilling)-tolerant genotypes hold promise in the 25–30° latitudes, where they can check excessive growth, escape damage due to leaf diseases (ascochyta and botrytis) and *Helicoverpa*, and mature early to avoid terminal heat stress. These lines have been demonstrated to perform equally well in the lower latitudes (15–20°) also, where they take advantage of their early-flowering characteristic. These lines were yield tested at IAC (18°N), Gwalior (26°N), and Hisar (29°N) against short- and long-duration controls, Annigeri, and Pant G 114. The best line, ICCV 92501, yielded 2.14, 1.75, and 3.46 t $ha^{-1}$ at the three locations, whereas Annigeri gave 1.77, 1.36, and 1.97 t $ha^{-1}$ and Pant G 114 gave 1.74, 1.93, and 1.99 t $ha^{-1}$. ICCV 92501 gave the highest yields at IAC and Hisar, and on an overall basis, whereas Annigeri and Pant G 114 had low ranks. There seemed a scope for breaking the latitudinal barriers of adaptation by breeding for high yield, early flowering, and cold tolerance. A breeding program to this effect has been initiated. Efforts are also continuing to increase the degree of cold tolerance by crossing chilling- and freezing-tolerant parents.

### Enhancement of resistance to ascochyta blight

We continued efforts to enhance resistance to ascochyta blight. Populations of two double crosses and one eight-way cross were screened in the chickpea growth room. We selected 60 resistant plants from (NARC 9004 × ICC 1069) × (NARC 9008 × E 100YM), and 206 plants from (C 235 × NEC 138-2) × (FLIP-87-4C × ILC-4421) double crosses. There were no resistant plants in the eight-way cross, where we need to screen a larger population. The resistant plants were transplanted and seed harvested for further work. We contributed 100 advanced progenies, earlier found resistant to AB in the growth room for field screening in northern India. Several of these lines have shown good resistance (a rating of 3 compared with 9 for control) in the AB nursery at Hisar and Ludhiana.

## Collaboration with NARS

### AICPIP variety testing and international nurseries

Collaborative NARS-ICRISAT breeding programs resulted in the submission of a number of entries in the AICPIP variety testing system. For example, one line yielding 41% higher than the local control cultivar was contributed by our cooperating center JNKVV, Gwalior, under the name GICG 860262. Three lines were contributed to the AICPIP's High Fertility Trial under the names of GICG 91124, 92212, and 92228, again by the same institution.

We distributed 276 sets of International Chickpea Screening Nurseries and Cooperative Trials to cooperators in 24 countries. Data were received for 116 sets only. We supplied 684 samples of released varieties, advanced breeding lines and parents, and 1025 samples of segregating populations to cooperators.

## ICARDA-ICRISAT Kabuli Chickpea Project

### Varietal releases

During 1994, seven chickpea cultivars were released by three countries. Morocco released FLIP 84-79C, FLIP 84-145C, and FLIP 84-182C; Turkey released 'Damla' (FLIP 85-7C) and 'Azizyie' (FLIP 84-15C); and the USA released 'Dwelley' (Surutato × FLIP 85-58C) and 'Sanford' (Surutato × FLIP 85-58C).

### Resistance screening

Sixteen years of research on screening for resistance to seven stresses have resulted in identification and release of 13 resistant sources to ascochyta blight, six to fusarium wilt, four to seed beetle, one to cyst nematode, two to cold, and one to drought.

### Breeding for increased biomass

Earlier research studies established that seed yield is highly correlated with biomass yield, and low biomass yield is one of the major limiting factors in several farming systems in West Asia and North Africa. Current research has shown that increased height and increased number of secondary branches contribute to increase in biomass yield. A line, S 92260, produced 30% higher biomass yield, 44% higher seed yield, 24% taller plant, and 120% more secondary branches than the tall parent ILC 3279.

### Enhancement of ascochyta blight resistance

To increase the level of resistance to ascochyta blight, crosses were made between resistant lines of diverse origin to pyramid genes for resistance. This project helped us in the identification of 200 plants in $F_3$ to $F_7$ generations, with a rating of 3 (on a scale of 1–9, where 1=no symptoms and 9=killed by disease). These plants had higher level of resistance than earlier identified material.

### Mutation breeding

Mutation studies have proved effective in generating early mutants in genotypes with resistance to ascochyta blight or to leaf miner. Three short-duration mutants with resistance to ascochyta blight, derived from FLIP 84-92C and FLIP 90-73C, will be useful genetic stock. The other two short-duration mutants with resistance to leaf miner, developed from ILC 5001, will also be useful as genetic stocks. Such genotypes are not available in the germplasm collection, and can be exploited in breeding programs.

# Pigeonpea

This report covers the first year of the medium-term plan (MTP) for 1994–98. The research work links to the pigeonpea research project (PP) portfolio initiating in 1995, with focus on the enhancement of short-duration pigeonpea, search for cytoplasmic male sterility, integrated disease and pest management, G × E interaction and on-farm adaptation studies.

This report does not give a complete coverage of pigeonpea research at IAC during 1994, but only highlights areas of work where conclusions have been drawn. Planning of a concise and focussed research program for pigeonpea under the 1994-98 MTP for ICRISAT was done during 1994.

## Short-duration Pigeonpeas

### Rapid early growth

The initial growth of pigeonpea is very slow compared with other tropical legumes such as cowpea. In order to improve initial growth rate of pigeonpea, rate of germination and subsequent seedling growth should be improved. We detected significant differences in the rate of germination among five short-duration genotypes: ICPL 4, ICPL 84023, ICPL 87, ICPL 93086, and ICPL 93075 whereas ICPL 4 was fastest in germination. It appears that physiological and biochemical efficiencies differ among cultivars in relation to growth stages. It remains to be seen if genotypes with higher seedling growth could be improved further by combining this characteristic with higher germination rate. We intend to screen all short- and extra-short-duration cultivars for characterization of germination and subsequent seedling growth. This information will be useful to identify suitable parents for enhancing initial growth of pigeonpea.

### Adaptability to low and high input

Traditionally, medium-duration pigeonpea is intercropped with cereals and oilseeds on Alfisols under rainfed conditions in Andhra Pradesh (AP) where IAC is located. The average pigeonpea dry grain yield in this cropping system is ± 300 kg $ha^{-1}$. Improved short- and medium-duration pigeonpea cultivars were tested for 2–5 years in

***Table 11. Performance of short- and medium-duration pigeonpea genotypes under high- and low-input conditions at ICRISAT Asia Center, rainy seasons 1990–94.***

| | Dry grain yield (t ha$^{-1}$) | |
|---|---|---|
| Genotype | High input | Low input |
| **Short duration** | | |
| ICPL 151 (5)[1] | 1.59 | 0.68 |
| ICPL 87 (5) | 1.57 | 0.27 |
| ICPL 85010 (2) | 1.72 | 0.59 |
| ICPL 84031 (3) | 1.77 | 0.48 |
| ICPL 88034 (2) | 1.58 | 0.43 |
| ICPL 85012 (2) | 1.85 | 0.79 |
| **Medium duration** | | |
| C-11 (3) | 1.44 | 0.27 |
| ICPL 87119 (3) | 1.62 | 0.31 |

1. Figures in parentheses are mean of number of years.

nonreplicated observation plots of 20–50 m$^2$ for their adaptability to low-input (rainfed, nonprotected) and high-input (irrigated, and protected) conditions. The data are summarized in Table 11.

On Alfisols under low-input conditions, short-duration pigeonpeas had a definite edge over medium-duration pigeonpeas, escaping terminal drought and peak *Helicoverpa* populations. Even under high-input conditions, per day productivity in short-duration pigeonpeas is high.

## Study of some agronomic characteristics in two environments

We studied 80 short-, and extra-short-duration genotypes at Dholi (26°N) and IAC (17°N), India, during the rainy season 1994. At Dholi, the flowering duration (days from flowering to maturity) increased by 10–20 days, and likewise the maturity, but the days to 50% flowering were similar at both the locations. The grain yield differences were large at Dholi (0.5–3 t ha$^{-1}$), whereas at IAC, they ranged between 1 and 2 t ha$^{-1}$. The interactions for flowering duration and grain yield were large at Dholi. The selection for these characteristics in the northern Indian environment is likely to be more effective than at IAC. The characteristics of high-yielding genotypes at Dholi and IAC are given in Table 12.

***Table 12. Characteristics of some short-duration pigeonpeas tested at ICRISAT Asia Center (IAC) and Dholi, India, rainy season 1994.***

| | Time to 50% flowering (days) | | Time to 75% maturity (days) | | Flowering duration (days) | | Plant height (cm) | | Grain yield (t ha$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Genotype | IAC | Dholi | IAC | Dholi | IAC | Dholi | IAC | Dholi | IAC | Dholi |
| ICPL 88023 | 70 | 71 | 113 | 130 | 43 | 59 | 99 | 108 | 1.7 | 3.3 |
| ICPL 87109 | 70 | 68 | 109 | 132 | 39 | 64 | 121 | 107 | 1.3 | 3.1 |
| ICPL 86005 | 70 | 72 | 112 | 126 | 42 | 54 | 118 | 127 | 2.6 | 2.3 |
| ICPL 91052 | 64 | 69 | 110 | 122 | 47 | 53 | 134 | 162 | 1.9 | 2.3 |
| ICPL 4 (C) | 63 | 65 | 104 | 111 | 41 | 46 | 96 | 103 | 1.6 | 1.0 |
| ICPL 87 (C) | 70 | 71 | 119 | 132 | 49 | 60 | 96 | 98 | 1.9 | 2.0 |
| Trial mean | 64 | 64 | 107 | 122 | 44 | 59 | 102 | 111 | 1.3 | 1.4 |
| SE | ±2.7 | ±2.2 | ±2.7 | ±2.6 | ±3.5 | ±2.9 | 12.5 | 9.2 | 0.6 | 0.3 |
| CV (%) | 2.6 | 5.9 | 1.6 | 3.7 | 4.9 | 8.5 | 7.5 | 14.2 | 26.2 | 40.5 |

## Extra-short-duration Pigeonpeas

We succeeded in reducing the pigeonpea crop duration (<120 days) at IAC (17°N latitude) when pigeonpeas are sown around the longest day (in June), with higher yields, or retaining similar yield levels with higher seed mass. The selected genotypes are given in Table 13.

The extra-short-duration genotypes having mean dry grain yield of >2.0 t ha$^{-1}$ in international adaptation trials at Kiboko (2°S, 980 m above sea level) in Kenya in two sowings (1 Nov 1993 and 26 Mar 1994) are ICPLs 87, 88009, 88027, 89018, 90002, 90028, 91039, 92028, and 92038. These flowered in 60–65 days and matured in 95–110 days.

**Advance over ICPL 87 (a short-duration cultivar).** We identified genotypes with large white seed, in the duration of ICPL 87 with yield potential of 2 t ha$^{-1}$. These seed characteristics are preferred in eastern and southern Africa and in some parts of India. The performance of these genotypes is given in Table 14.

## Hybrids

Evaluation of medium-duration wilt and sterility mosaic resistant hybrids under normal and disease-sick fields for the past 2 years showed that the hybrids under normal field conditions were marginally better than the best standard control ICPL 87119. However, in the wilt-sick fields, 100% mortality was recorded in the susceptible controls.

***Table 13. The selected extra-short-duration pigeonpea genotypes at ICRISAT Asia Center, rainy season 1994.***

| Genotype | Time to 50% flowering (days) | Time to 75% maturity (days) | Plant height (cm) | Grain yield (t ha$^{-1}$) | 100-seed mass (g) |
|---|---|---|---|---|---|
| ICPL 90008 | 61 | 113 | 82 | 2.0 | 9 |
| ICPL 92030 | 57 | 111 | 80 | 2.0 | 9 |
| ICPL 88009 | 68 | 114 | 98 | 2.0 | 8 |
| Trial mean | 70.1 | 116.6 | 88.5 | 1.69 | 9.18 |
| SEM | 0.9 | 1.9 | 3.1 | 0.21 | 0.18 |
| CV(%) | 2.3 | 2.9 | 6.2 | 21.56 | 3.43 |
| ICPL 94045 | 56 | 110 | 84 | 2.3 | 11 |
| ICPL 94044 | 67 | 116 | 116 | 1.5 | 11 |
| ICPL 93090 | 72 | 117 | 77 | 1.9 | 10 |
| Trial mean | 73.9 | 119.8 | 98.0 | 1.99 | 11.52 |
| SEM | 1.2 | 0.7 | 4.5 | 2.59 | 0.24 |
| CV(%) | 2.8 | 1.0 | 7.9 | 22.5 | 3.64 |
| ICPL 94005 | 63 | 114 | 89 | 2.4 | 11 |
| ICPL 93072 | 62 | 113 | 83 | 2.0 | 8 |
| ICPL 93078 | 71 | 119 | 97 | 2.4 | 10 |
| ICPL 94011 | 70 | 119 | 87 | 2.3 | 11 |
| Trial mean | 66.3 | 114.9 | 91.7 | 1.96 | 10.02 |
| SEM | 1.0 | 1.1 | 2.9 | 1.65 | 0.29 |
| CV(%) | 2.7 | 1.7 | 5.5 | 14.5 | 5.0 |
| ICPL 94025 | 57 | 109 | 92 | 2.0 | 11 |
| ICPL 4 (C) | 70 | 110 | 102 | 2.0 | 7 |

*Table 14. Large, white-seeded, short-duration pigeonpeas selected at ICRISAT Asia Center, rainy season 1994.*

| Genotype | Time to 50% flowering (days) | Time to 75% to maturity (days) | Plant height (cm) | Grain yield (t $ha^{-1}$) | 100-seed mass (g) |
|---|---|---|---|---|---|
| ICPL 93087 | 82 | 130 | 107 | 2.3 | 15 |
| ICPL 94046 | 76 | 127 | 102 | 2.0 | 12 |
| ICPL 94022 | 74 | 126 | 112 | 1.9 | 14 |
| ICPL 94039 | 81 | 130 | 113 | 1.8 | 15 |
| ICPL 94047 | 75 | 124 | 92 | 2.8 | 12 |
| ICPL 94043 | 78 | 123 | 116 | 2.3 | 12 |
| ICPL 93091 | 80 | 127 | 111 | 2.2 | 15 |
| ICPL 87 | 79 | 126 | 100 | 2.0 | 10 |
| Trial mean | 79 | 128 | 112 | 1.7 | 13 |
| SE | ±1.5 | ±0.9 | ±4.8 | ±0.17 | ±0.3 |
| CV (%) | 3.2 | 1.2 | 7.5 | 17 | 4.2 |

Compared with the control (2.3 t $ha^{-1}$), the best hybrid IPH 1326 yielded 2.5 t $ha^{-1}$, expressing 12.5% heterosis in normal fields. In the wilt-sick field, the susceptible hybrids and controls did not produce any grains and the resistant control ICPL 87119 (wilt 6%, sterility mosaic 12%) produced 0.9 t $ha^{-1}$, while hybrid IPH 1326 (wilt 3%, sterility mosaic 5.5%) yielded 1.6 t $ha^{-1}$, expressing 86.9% superiority over the control. These observations suggest that the pigeonpea hybrids can withstand high disease pressure much better than cultivars having similar levels of resistance, and can therefore play a greater role in stabilizing pigeonpea production in disease-prone areas.

In the ICAR-ICRISAT collaborative project on hybrid pigeonpea two short-duration hybrids, PPH 4 in Punjab and CoH1 in Tamil Nadu were released for cultivation.

## Cytoplasmic-genic Male Sterility in Pigeonpea

At present, pigeonpea hybrids are made using genetic male sterility where hybrid seed production remains expensive. Search for cytoplasmic-genic male sterility (cms) was intensified at IAC in 1990, using wide hybridization (*Cajanus sericeus* × *C. cajan*) and mutagenesis. We have identified progenies from wide hybridization showing more than 75% male sterility for further testing.

Six progenies derived from QMS-1 treated with sodium azide (0.025% for 48 h) in $M_6$ and $M_7$ generations showed the indication of the presence of cms. These were selected for further advancing and evaluation.

Cytological investigation of the microsporogenesis revealed that the development of pollen grains in suspected cms progenies is normal up to the tetrad stage. After the release from tetrads, the microspores were without nuclei and disintegrated. This is in contrast to the breakdown of microsporogenesis at PMC stage in $ms_2$ type genetic male steriles, and at tetrad stage in $ms_1$ type, indicative of a different mechanism of sterility.

Considering the lead in the work on cms in pigeonpea, the ICAR's All India Coordinated Pulses Improvement Project (AICPIP) requested IAC to convene a working group on cms, involving interested NARS and private seed companies to develop a collaborative workplan focussing on cms. The first working group meeting was held at IAC 26–27 Jul 1994.

## Vegetable Pigeonpea

During 1994, we evaluated 25 short-duration, long-podded vegetable types for their green pod yield and other agronomic characteristics. Green pod yield of these lines ranged between 2.3 and 4.4 t $ha^{-1}$. The most promising lines were ICPLs 93017 (4.4 t $ha^{-1}$), 93050 (4.2 t $ha^{-1}$), and 93020 (4.2 t $ha^{-1}$). Nine vegetable lines were also evaluated at Kiboko in Kenya, where the green pod yield ranged between 4.0 (ICPL 93047) and 7.3 (ICPL 87091) t $ha^{-1}$. These lines were also significantly superior to the control, ICPL 87, in important quality parameters such as pod color (green), seed size >12 g (100 dry seed $mass^{-1}$), and pod length (7–8 cm). We also collected information on some organoleptic parameters by distributing green pods to a number of womens groups in and outside IAC. In general, they liked the taste of green pigeonpea seeds in various recipes; however, they felt that it would be better if something could be done to ease the problem of pod shelling. We are in the process of developing a green pod sheller at IAC.

## Medium-duration Pigeonpeas

### Wilt and sterility mosaic resistance

In the central and southern zones of India, and tarai region of Nepal, wilt and sterility mosaic diseases are widespread, and considerable yield losses in the medium-duration pigeonpeas continue to occur either by fusarium wilt or sterility mosaic, or by both the diseases.

In the 1993/94 rainy season, 13 wilt- and sterility mosaic disease resistant lines with three control cultivars (ICPL 87119, C 11, and BDN 1) were tested for yield and other agronomic characteristics at seven locations in India.

On the basis of mean performance across locations, ICPL 92060 was the highest-yielding entry. This line produced grain yield of 2.14 t $ha^{-1}$ compared with 1.97 t $ha^{-1}$ for the best control, ICPL 87119.

### Cream-seeded mutant of ICP 8863

ICP 8863 is a brown-seeded, medium-duration, wilt-resistant genotype released as 'Maruthi' in Karnataka (India) in 1985. Although farmers in Karnataka prefer this variety for its wilt resistance, its brown seed color is not preferred. White/cream seed coat is preferred and receives premium price.

In the 1988 rainy season, the dry seeds of ICP 8863 were treated with gamma rays (ranging from 5 kR to 25 kR) at IAC. From $M_2$ generation onwards the material was advanced in the wilt-sick nursery. In the $M_2$ generation cream-seeded mutants were identified in 5 kR and 20 kR treatments only.

One mutant (ICP 8863-5kR-1-WB-WB-B) produced similar grain yield (2.14 t $ha^{-1}$) as the original parent, ICP 8863 (1.90 t $ha^{-1}$), but had higher seed mass [10.3 g (100 $seeds)^{-1}$] compared with 8.8 g (100 $seeds)^{-1}$ of ICP 8863. This mutant has resistance to fusarium wilt. It will be tested in Karnataka, Maharashtra, Gujarat, and parts of Madhya Pradesh (India), where cream colored pigeonpea varieties are preferred.

# Groundnut

Asia produces 69.9% of the world's groundnut in 64.2% of the world's groundnut area, with an average productivity of 1.33 t $ha^{-1}$. India ranks first in area (8.40 million ha) and production (8.20 million t), followed by China (3.41 million ha area; 7.57 million t production). Whereas China records the highest productivity of the crop in the region (2.219 t $ha^{-1}$), the productivity in India is only 0.976 t $ha^{-1}$. Other important groundnut-growing countries in Asia are Indonesia (0.670 million ha area; 1.08 million t production; 1.612 t $ha^{-1}$ productivity), Myanmar (0.466 million ha area; 0.431 million t production; 0.925 t $ha^{-1}$ productivity), and Vietnam (0.250 million ha area; 0.275 million t production; 1.100 t $ha^{-1}$ productivity).

Groundnut is grown with or without irrigation during the main growing season, generally as a sole crop. Cultivation of groundnut with irrigation in rice-fallows or under residual moisture occupies a significant place in Asia. Although there has been a significant increase in productivity in China, groundnut productivity is low in many other countries. The crop suffers from various biotic and abiotic stresses. Some of these stresses are amenable to genetic manipulations, while others await further scientific developments. In this report, we present some of the significant results that have been obtained in genetic enhancement of the crop.

## Abiotic Stresses

### Breeding for drought tolerance

At IAC, we evaluated 81 drought-tolerant varieties in three trials in an Alfisol field under two treatments (normal irrigation and induced midseason drought stress) during the 1993/94 postrainy season. Analysis of variance revealed highly significant effect of treatments, and treatment × variety interactions for both pod and haulm yields. Out of 81 test varieties, 31 gave significantly higher pod yield than the control cultivar TMV 2 under both the treatments.

During the 1994 rainy season, 112 drought-tolerant varieties were tested in four trials in Alfisol fields under high inputs (HI) (60 kg $P_2O_5$, 400 kg gypsum $ha^{-1}$, full irrigation, and full protection against foliar diseases and insect pests) and low inputs (LI) (20 kg $P_2O_5$, rainfed, and no protection against diseases and insect pests). The pod yield in the trials under HI ranged from 2.29±0.134 to 0.68±0.152 t $ha^{-1}$, and under LI from 1.6±0.070 to 0.40±0.119 t $ha^{-1}$. In an elite varietal trial under LI, ICGV 92109 (1.53±0.119 t $ha^{-1}$) significantly outyielded all the three control cultivars including ICGS 44 (1.01 t $ha^{-1}$). It had significantly outyielded all the control cultivars, including ICGS 44, in both 1992 and 1993 rainy season trials [ICRISAT Legumes Program Annual Reports 1992, (p.110) and 1993, (p.98)]. In an advanced trial, five varieties (ICGVs 93242, 93260, 93261, 93232, and 93240) significantly outyielded all the three controls under both HI and LI. ICGV 93242 ranked first both under HI and LI. It gave 75% higher pod yield (2.29±0.134 t $ha^{-1}$) than the best control, ICG(FDRS) 55, in HI and 80% higher pod yield (1.34±0.094 t $ha^{-1}$) than the best control, ICGS 44, in LI.

### Collaboration with NARS

**Bangladesh.** In the First International Drought Resistance Groundnut Varietal Trial, ICGV 86743 (3.81±0.28 t $ha^{-1}$) gave significantly superior pod yield than the local control, Acc 12 (2.41 t $ha^{-1}$) at Joydebpur, during 1992/93 postrainy season.

**India.** ICGV 86699 has been identified in the Andhra Pradesh Agricultural University-ICRISAT collaborative research in groundnut breeding project for on-farm trials in the drought-prone areas of the Rayalaseema region in Andhra Pradesh.

## Biotic Stresses

### Breeding for foliar diseases resistance

During the 1993/94 postrainy season, we evaluated 81 foliar diseases resistant varieties in four trials in an Alfisol field. These trials received high inputs except for fungicide sprays. Three varieties ( ICGVs 91230, 91247, and 91246; pod yield: 3.1–3.2±0.133 t $ha^{-1}$) in an elite varietal trial and three varieties (ICGVs 92080, 92102, and 91244; pod yield: 2.9–3.0±0.153 t $ha^{-1}$) in an advanced varietal trial, significantly outyielded the respective best controls (pod yields: 1.9–2.6 t $ha^{-1}$). ICGV 91230 had ranked first both in HI and LI trials during the 1992 rainy (ICRISAT Legumes Program, Annual Report 1992, p.117) and during the 1992/93 postrainy season (ICRISAT Legumes Program, Annual Report 1993, p.105) also.

During the 1994 rainy season, 77 foliar diseases resistant varieties, along with three controls were evaluated in three trials, both under HI (without fungicide spray) and LI.

Pod yield under HI ranged from 1.98±0.135 to 0.26±0.135 t $ha^{-1}$, and under LI from 1.66±0.196 to 0.24±0.172 t $ha^{-1}$. In an elite varietal trial under HI, ICGVs 92093 and 92097 with pod yield of 1.86 and 1.83±0.086 t $ha^{-1}$, significantly outyielded the highest-yielding control, ICGV 86699 (1.55 t $ha^{-1}$). In an advanced varietal trial, two varieties, ICGVs 93218 and 93222, with 1.98 and 1.79±0.135 t $ha^{-1}$ pod yields, occupied the top two positions both under HI and LI (with pod yields 1.53 and 1.60±0.172 t $ha^{-1}$); the former significantly outyielded the best controls in both LI (85% yield advantage) and HI (36% yield advantage) trials. The latter significantly outyielded the best control by 93% yield advantage under LI only.

## Collaboration with NARS

**South Africa.** In the Fifth International Foliar Diseases Resistance Groundnut Varietal Trial (IFDRGVT), three varieties produced significantly more pod yield than the local control cultivar Sellie (0.82±0.176 t $ha^{-1}$). ICGV 87882 (1.55 t $ha^{-1}$) ranked first.

**Thailand.** In the Fifth IFDRGVT (conducted under a wide spacing of 50 × 30cm) two varieties produced significantly more pod yield than the local control cultivar Khon Kaen 60–1 (0.65±0.099 t $ha^{-1}$). ICGV 87281 (0.92 t $ha^{-1}$) ranked first.

**Comores.** In the Fifth IFDRGVT, six varieties produced significantly more pod yield than the local control cultivar Malgache (2.06±0.269 t $ha^{-1}$). ICGV 87281 (3.98 t $ha^{-1}$) ranked first.

**India.** Six varieties gave significantly more pod yield than the control cultivar JL 24 (1.13±0.119 t $ha^{-1}$) in IFDRGVT at Jagtial in Andhra Pradesh. ICGV 89402 (3.14 t $ha^{-1}$) ranked first.

Two resistant varieties, ICGV 87281 and ICGV 88247, produced significantly more pod yield than the local control cultivars in South Africa, Thailand, and Comores, indicating their wide adaptation.

## Breeding for resistance to *Aspergillus flavus*

We evaluated 140 varieties in four trials in the 1993/94 postrainy season. In an elite varietal trial, 10 out of 19 varieties produced significantly greater pod yields than the highest-yielding resistant control UF 71513 (2.09±0.091 t $ha^{-1}$). ICGV 91276 gave the highest pod yield of 2.90 t $ha^{-1}$. The promising varieties which had higher pod yield and seed infection (SI) and seed colonization (SC) by *Aspergillus flavus*, similar to the best resistant control cultivar J 11 (1.99 t $ha^{-1}$, 1.3% SI, 15.5% SC), were ICGVs 86168, 91283, and 91284. In an advanced trial, 14 out of 31 varieties produced significantly greater pod yields than the resistant control cultivar J 11 (2.30±0.109 t $ha^{-1}$, 1.3% SI, 18.5% SC). ICGV 92292 (3.43 t $ha^{-1}$) gave the highest pod yield. The promising varieties were ICGVs 91315, 91323, 92299, and 91341.

We evaluated 143 varieties in four replicated trials in the 1994 rainy season. In an elite varietal trial, 6 out of 21 varieties produced significantly greater pod yields than the best resistant control cultivar J 11 (0.96±0.041 t $ha^{-1}$, 0.0% SI). ICGV 92302 (1.33 t $ha^{-1}$, 0.0% SI) ranked first. Other promising varieties were ICGVs 91334, 91278, 91323, 91322, and 92292. ICGVs 91278, 91322, 92292, and 92302 gave significantly more pod yield than J 11 (2.30±0.109 t $ha^{-1}$) in the 1993/94 postrainy season also.

In an advanced varietal trial, 10 out of 32 varieties gave significantly more pod yield than the resistant control cultivar J 11 (0.90±0.047 t $ha^{-1}$). ICGV 93353 (1.39 t $ha^{-1}$) ranked first. Other promising varieties were ICGVs 93294, 93328, and 93305.

## Collaboration with NARS

**Thailand.** ICGV 91278, an *A. flavus* seed infection resistant variety, produced a pod yield of 1.69±0.137 t $ha^{-1}$, compared with 1.31 t $ha^{-1}$ of the resistant control cultivar J 11, and 1.28 t $ha^{-1}$ of the susceptible local control cultivar Tainan 9 at the Field Crops Research Center, Khon Kaen.

**Vietnam.** ICGV 91328, an *A. flavus* seed infection resistant variety, gave the highest pod yield of 3.64±0.272 t $ha^{-1}$, followed by ICGV 91278 (3.59 t $ha^{-1}$), compared with 3.19 t $ha^{-1}$ of the resistant control cultivar J 11, and 3.12 t $ha^{-1}$ of the susceptible control cultivar Ly at Cu Chi, South Vietnam. At Trang Bang also, ICGV 91328 gave the highest pod yield of 3.12±0.137 t $ha^{-1}$, compared with 2.84 t $ha^{-1}$ of J 11 and 2.98 t $ha^{-1}$ of Ly.

## Breeding for resistance to peanut bud necrosis disease (PBND)

ICGVs 91288 and 91229 and an interspecific derivative 886 × 2741-28 in an elite varietal trial, conducted over two locations at IAC during the 1994 rainy season, produced an average pod yield of 1.45–1.74 t $ha^{-1}$, compared with 1.20 t of the highest-yielding control ICGV 87141. They ranked among the top five highest-yielding varieties at both the locations. These varieties showed only 23–32% disease incidence, while the susceptible control JL 24 recorded 68% PBND in a separate trial conducted at Narkoda, Andhra Pradesh,

We confirmed resistance to PBNV (at $10^{-2}$ dilution of infected plant extract) in ICGV 86388. In a greenhouse test conducted over three seasons, ICGV 86388 recorded, on average, 30% PBND incidence compared with 87% in JL 24. It also showed moderate resistance to the vector (*Thrips palmi*). In three seasons of yield trials conducted over 11 locations, ICGV 86388 produced an average pod yield of 2.04 t $ha^{-1}$ compared with 1.68 t $ha^{-1}$ of JL 24.

## Breeding for resistance to insect pests

Four sequentially branched varieties (ICGVs 91190, 91185, 91180, and 91187) in an elite varietal trial, conducted over three locations during the 1993/94 postrainy season, produced an average pod yield of 2.7–3.7 t $ha^{-1}$, compared with 2.2–2.4 t of controls (ICGVs 87123, 87141, and NC Ac 343). ICGV 91190 ranked among the five highest-yielding varieties across locations. While the controls scored 8 for leafminer damage, these varieties had a score of either 5 or 6 on a 1–9 scale, where 1=highly resistant, and 9=highly susceptible. ICGV 91190 also ranked second in an advanced varietal trial conducted at IAC in the 1992/93 postrainy season (ICRISAT Legumes Program, Annual Report 1993, p.130).

In an elite varietal trial, conducted over two locations at IAC during the 1994 rainy season, ICGVs 92186 and 92187 produced an average pod yield of 1.6 t $ha^{-1}$, compared with 1.3 t of controls (ICGV 87141 and NC Ac 343). They ranked among the five highest-yielding varieties at both the locations. In an advanced varietal trial conducted at two locations at IAC, ICGV 92187 ranked among the top five highest-yielding varieties during the 1993 rainy season (ICRISAT Legumes Program, Annual Report 1993, p.132). It also ranked second in a preliminary trial, conducted at two locations at IAC, during the 1992 rainy season (ICRISAT Legumes Program, Annual Report 1992, p.136). In an advanced varietal trial conducted over two locations at IAC, ICGV 93009 produced an average pod yield of 1.9 t $ha^{-1}$, compared with 1.2 t of ICGV 87141 and NC Ac 343. It ranked first at both the locations.

## Collaboration with NARS

**South Africa.** Two insect pests resistant varieties (ICGVs 89259 and 86436) significantly outyielded the local cultivar Sellie (1.8 t $ha^{-1}$). They produced a pod yield of over 2.6 t $ha^{-1}$.

**Comores.** Eight insect pests resistant varieties (ICGVs 86252, 86522, 86436, 86398, 89280, 87415, 86462, and 86031) significantly outyielded the local cultivar Malgache. They produced pod yields of 2.9–3.3 t $ha^{-1}$ compared with 1.9±0.31 t $ha^{-1}$ of Malgache. These varieties also recorded greater 100-seed mass (56–72 g) than Malgache 49 g.

### Varietal release

**India.** Our cooperator from the Agricultural Research Station, Aliyarnagar, Tamil Nadu, released a pure line selection from ICGV 86011, an insect-pests resistant variety, as ALR 2 for cultivation in the Pollachi tract of Tamil Nadu. Besides resistance to thrips and jassid, it is also reported tolerant to rust and late leaf spot. It possesses seed dormancy up to 15 days.

## High Yield and Adaptation

### Short-duration group

We evaluated 151 varieties in four trials in the 1993/94 postrainy season. In an elite varietal trial harvested at 1470 $^0$Cd [equivalent to 90 days after sowing (DAS) in rainy season at IAC] under HI, 11 varieties produced significantly greater pod yields than the highest-yielding control cultivar TMV 2 (1.32±0.065 t $ha^{-1}$). ICGVs 91146 and 91112 gave the highest pod yields of 1.95 t $ha^{-1}$. Under HI in a Vertisol field, none of the varieties produced significantly greater pod yields than the highest-yielding control cultivar, JL 24 (2.08±0.062 t $ha^{-1}$). At Bhavanisagar, two varieties gave significantly greater pod yields than the highest-yielding control cultivar, JL 24 (1.29±0.086 t $ha^{-1}$). ICGV 91117 (1.83 t $ha^{-1}$) ranked first. In the 1240 $^0$Cd (equivalent to 75 DAS in the rainy season at IAC) harvest, four varieties produced significantly greater pod yields than the highest-yielding control cultivar, J 11 (0.80±0.062 t $ha^{-1}$). ICGV 91117 gave the highest pod yield of 1.16 t $ha^{-1}$. On the basis of mean pod yield, shelling and sound mature seeds percentages, the promising varieties were ICGVs 91109, 91112, 91114, 91116, 91117, and 91146.

In an advanced varietal trial harvested at 1470 $^0$Cd, nine varieties produced significantly greater pod yields than the highest-yielding control cultivar TMV 2 (1.53±0.062 t $ha^{-1}$). ICGV 92267 (2.01 t $ha^{-1}$) ranked first. Other promising varieties were ICGVs 92224, 92234, 92229, and 92243.

In the 1994 rainy season, we evaluated 161 varieties in five trials. In an elite varietal trial, 18 varieties at 90 DAS harvest and 13 varieties at 75 DAS harvest under HI, and 13 varieties under LI produced significantly greater pod yields than the highest-yielding control cultivar JL 24. In all three evaluations, ICGV 92206 ranked first and yielded 2.07±0.052 t pods $ha^{-1}$ in 90 DAS harvest (JL 24, 1.39 t $ha^{-1}$), 1.86±0.052 t $ha^{-1}$ in 75 DAS harvest under HI (JL 24, 1.28 t $ha^{-1}$), and 0.90±0.021 t $ha^{-1}$ under LI (JL 24, 0.44 t $ha^{-1}$). Other promising varieties were ICGVs 92234, 92242, 92195, and 92267. In an advanced varietal trial harvested at 90 DAS under HI, 10 varieties produced significantly greater pod yields than the highest-yielding control cultivar TMV 2 (1.39±0.058 t $ha^{-1}$). ICGV 93388 produced the highest pod yield of 1.94 t $ha^{-1}$. Under LI, 11 varieties produced significantly greater pod yields than the highest-yielding control cultivar JL 24 (0.49±0.056 t $ha^{-1}$). ICGV 93382 (0.97 t $ha^{-1}$) ranked first. Other promising varieties were ICGVs 91118, 91155, 93420, 93383, and 93389. In a dormancy trial, 5 out of 18 fresh seed dormant varieties produced significantly greater pod yields than the highest-yielding dormant control cultivar M 13 (1.59±0.059 t $ha^{-1}$). ICGV 93463 (1.93 t $ha^{-1}$) ranked first. Other promising varieties were ICGVs 93470, 93469, 93471, and 93467.

### Collaboration with NARS

**Comores.** In the Fifth International Short-duration Groundnut Varietal Trial (V ISGVT), five varieties produced significantly greater pod yields than the local control cultivar Malgache (2.46±0.274 t $ha^{-1}$) . ICGV 90068 gave the highest pod yield of 3.52 t $ha^{-1}$.

**Vietnam.** In a short-duration trial, ICGV 91123 produced the highest pod yield of 5.21±0.306 t $ha^{-1}$, 24% more than the highest-yielding control cultivar 41–4–5 (4.22 t $ha^{-1}$), and 26% more than the popular cultivar Ly (4.14 t $ha^{-1}$) in 90 DAS at Cu Chi, South Vietnam. Other promising varieties were ICGVs 92206 (4.98 t $ha^{-1}$), and 92234 (4.67 t $ha^{-1}$). ICGV 91123 had the highest shelling percentage of 79 compared with 72 of 41–4–5 and 77 of Ly.

ICGVs 86055, 87054, and 87391 performed exceedingly well and will be evaluated in on-farm trials in North Vietnam.

**Nepal.** In the Fifth ISGVT, ICGV 87378 gave the highest pod yield of 1.35±0.111 t $ha^{-1}$, 22% more than the popular control cultivar B 4 (1.11 t $ha^{-1}$) at Nawalpur. Other promising varieties were ICGVs 87391, 87981, 90068, and 87884. In a coordinated trial conducted by the national program, ICGV 86015 (1.98 t $ha^{-1}$) at Nawalpur (B 4, 1.74 t $ha^{-1}$), ICGV 86124 (2.12±0.242 t $ha^{-1}$) at Doti (B 4, 0.97 t $ha^{-1}$), and ICGV 86010 (3.42±0.336 t $ha^{-1}$) at Kavre (B 4, 2.82 t $ha^{-1}$) ranked first, and produced 14, 118, and 21% more pod yield than B 4.

ICGV 86015 is likely to be proposed for release in Nepal.

**Malawi.** In a short-duration trial, ICGV 92194 ranked first and produced 2.20±0.123 t pods $ha^{-1}$ and 1.56±0.087 t seeds $ha^{-1}$, compared with 1.97 t pods $ha^{-1}$ and 1.33 t seeds $ha^{-1}$ of the highest-yielding control ICGV-SM 91002, and 0.99 t pods $ha^{-1}$ and 0.48 t seeds $ha^{-1}$ of the local control cultivar, Malimba, at Chitedze. Other promising varieties were ICGV 92245 and ICGV 92224.

ICGV 87069 produced 1.80±0.088 t pods $ha^{-1}$; 17% more than the highest-yielding control cultivar, JL 24, in the Southern African Development Community regional trial at Chitedze.

**India.** ICGV 89017 produced 2.14±0.248 t pods $ha^{-1}$ compared with 1.74 t $ha^{-1}$ of the control cultivar, JL 24, at Ankola, Karnataka. ICGV 89027 produced 1.27±0.137 t $ha^{-1}$ compared with 0.83 t $ha^{-1}$ of JL 24 at Raichur, Karnataka. Three varieties, ICGVs 89027, 91112, and 91116 have been included in a multilocational trial (short-duration) of the University of Agricultural Sciences, Dharwad.

In the APAU-ICRISAT collaborative research in groundnut breeding project trials, five varieties gave significantly greater pod yields than the control cultivar TPT 1 at Palem, Andhra Pradesh. ICGV 89013 gave the highest pod yield of 1.97±0.198 t $ha^{-1}$, compared with 1.39 t $ha^{-1}$ of TPT 1. Six out of seven short-duration fresh seed dormant varieties gave significantly greater pod yield than JL 24 (0.80±0.119 t $ha^{-1}$) at Yellamanchelli, Andhra Pradesh. ICGV 93463 (1.67 t $ha^{-1}$) ranked first.

Two fresh seed dormant varieties, ICGV 86155 and ICGV 93463, have been given for minikit trials in the farmers' fields in Andhra Pradesh.

ICGV 91123 and ICGV 92206 with a crop duration of 80–85 DAS have been identified for on-farm trials in the coastal sands of Andhra Pradesh under residual moisture conditions.

ICGVs 91117 and ICGV 92206 were identified as stable, high-yielding, short-duration varieties in trials conducted in the past 3 years at four to five locations in Andhra Pradesh.

## Varietal release

**India.** ICGV 86143 was released as BSR 1 under the ICRISAT-Tamil Nadu Agricultural University collaboration by Tamil Nadu State Variety Release Committee for cultivation in Tamil Nadu, India.

**Vietnam.** ICGV 86015 was released as Hung Loc 25 (HL 25) for intercropping with cassava and maize in the southeast coastal and southeastern regions of the country.

**Pakistan.** ICGV 86015 released as BARD 92 for double cropping with wheat in rainfed (*barani*) conditions in the country.

## Medium-duration group

We evaluated 186 varieties in eight trials in the 1993/94 postrainy season. In an elite trial of 22 sequential branching (SB) varieties, four varieties each under HI in an Alfisol field and LI in a Vertisol field at IAC produced significantly greater pod yields than the highest-yielding control cultivar ICGS 11, which produced 3.32 ± 0.160 (HI, Alfisol at IAC), 1.52 ± 0.201 (LI, Vertisol at IAC), and 2.39 ± 0.251 t $ha^{-1}$, (Bhavanisagar). ICGV 91015 produced the highest pod yield of 4.17 t $ha^{-1}$ under HI, and 2.99 t $ha^{-1}$ at Bhavanisagar. ICGV 91035 produced the highest pod yield of 2.41 t $ha^{-1}$ under LI. Other promising varieties were ICGVs 91030 and 91023. ICGV 91030 ranked first on the basis of average pod yield at two locations in an advanced trial in the 1992/93 postrainy season (ICRISAT Legumes Program, Annual Report 1993, p.141).

In an elite varietal trial of 14 alternate branching (AB) varieties, ICGV 91074 (4.28 t $ha^{-1}$) under HI and ICGVs 91001 (2.85 t $ha^{-1}$) and 91060 (2.69 t $ha^{-1}$) at Bhavanisagar produced significantly greater pod yields than the highest-yielding control cultivars ICGS 76 (3.52 ± 0.206 t $ha^{-1}$) and Kadiri 3 (1.85 ± 0.246 t $ha^{-1}$). ICGV 91060 ranked first on the basis of average pod yield at three locations in an elite varietal trial in the 1993 rainy season (ICRISAT Legumes Program, Annual Report 1993, p.145). Other promising varieties were ICGVs 91077 and 91003.

In an advanced SB trial, ICGVs 92027 (4.23 t $ha^{-1}$) and 92028 (4.16 t $ha^{-1}$), gave significantly more pod yield than the highest-yielding control cultivar ICGV 86590 (3.53 ± 0.198 t $ha^{-1}$). Other promising varieties were ICGVs 92040, 92034, and 92003. In an advanced AB trial, two varieties, ICGVs 92072 (4.73 t $ha^{-1}$) and 92071 (4.66 t $ha^{-1}$), gave significantly greater pod yields than the highest-yielding control cultivar ICGS 76 (4.15 ± 0.172 t $ha^{-1}$). Other promising varieties were ICGVs 92049, 92046, and 92064.

We evaluated 197 varieties in seven trials in Alfisol fields in the 1994 rainy season. In an elite SB trial, six varieties under HI and one variety under LI produced significantly greater pod yields than the highest-yielding control cultivar ICGS 11 (1.80 ± 0.145 t $ha^{-1}$) under HI, and ICG (FDRS) 10 (0.74 ± 0.098 t $ha^{-1}$) under LI. ICGV 92035 produced the highest pod yield both under HI (2.89 t $ha^{-1}$) and LI (1.09 t $ha^{-1}$) conditions. Other promising varieties were ICGVs 92034, 92040, 92007, and 92020. In an elite AB trial, one variety under HI and seven varieties under LI produced significantly greater pod yields than the highest-yielding control cultivar, ICGS 76, which gave 2.14±0.164 t $ha^{-1}$ under HI and 0.71±0.092 t $ha^{-1}$ under LI. ICGV 92069 gave the highest pod yield, 2.95 t $ha^{-1}$, under HI and, 1.56 t $ha^{-1}$, under LI. It ranked third on the basis of average pod yield at two locations in an advanced trial in the 1993 rainy season (ICRISAT Legumes Program, Annual Report 1993, p.147). The other promising varieties were ICGVs 92049, 92052, 92064, 92054, 92061, 92062, and 92050.

In an advanced SB trial, three varieties under HI and one variety under LI produced significantly greater pod yields than the highest-yielding control cultivar ICGS 11 (1.40±0.106 t $ha^{-1}$) under HI, and ICG (FDRS) 10 (0.65±0.137 t $ha^{-1}$) under LI. ICGV 93135 (2.11 t $ha^{-1}$) under HI and ICGV 93137 (1.34 t $ha^{-1}$) under LI produced the highest pod yields. Other promising varieties were ICGVs 93128, 93115, 93123, and 93133, and ICG 3220. In an advanced AB trial, none of the 22 varieties under HI and only 2 varieties under LI gave significantly greater pod yields than the highest-yielding control cultivar, ICGS 76, which yielded 1.85±0.146 t $ha^{-1}$ under HI and 0.68±0.111 t $ha^{-1}$ under LI. ICGV 93171 (2.22 t $ha^{-1}$) under HI and ICGV 93171 (1.24 t $ha^{-1}$) under LI produced the highest pod yields. The other promising varieties were ICGVs 93162, 93161, 93164, 93157, and 93155.

In an advanced multiple stresses resistance trial, seven varieties under HI and three varieties under LI gave significantly more pod yields than the highest-yielding control cultivar ICGS 76 (1.28±0.125 t $ha^{-1}$) under HI and ICGV 86031 (0.65±0.086 t $ha^{-1}$) under LI. ICGV 93184 (2.08 t $ha^{-1}$) under HI and ICGV 92307 (1.33 t $ha^{-1}$) under LI gave the highest pod yields. The other promising varieties were ICGVs 93183, 93181, 93180, 93174, and 93173.

## Collaboration with NARS

**Vietnam.** In the Fifth International Medium-duration Groundnut Varietal Trial-SB (IMGVT-SB), two varieties produced significantly greater pod yields than the local cultivar 1686 (2.05±0.199 t $ha^{-1}$). ICGV 88348 gave the highest pod yield of 3.14 t $ha^{-1}$.

**Comores.** In the Fifth IMGVT-SB, all the 14 varieties produced significantly greater pod yields than the local control cultivar Malgache (1.59±0.313 t $ha^{-1}$). ICGV 88348 gave the highest pod yield of 3.80 t $ha^{-1}$. In the Fifth IMGVT-VB, 10 varieties produced significantly greater pod yields than Malgache (1.95±0.254 t $ha^{-1}$). ICGV 88314 gave the highest pod yield of 2.73 t $ha^{-1}$.

**Nepal.** In the Fifth IMGVT-SB, ICGV 86928 produced the highest pod yield of 2.26 t $ha^{-1}$, compared with 2.05 t $ha^{-1}$ of the local control cultivar B 4. In the Fifth IMGVT-VB, ICGV 86300 gave the highest pod yield of 2.53 t $ha^{-1}$, compared with 2.29 t $ha^{-1}$ of the highest-yielding local control cultivar B 4.

**Ethiopia.** In the Fourth IMGVT-VB, ICGV 86230 (2.75 t $ha^{-1}$) produced significantly greater pod yield than the local control (1.93±0.199 t $ha^{-1}$).

In the Fifth IMGVT-SB, three varieties produced significantly greater pod yields than the local control cultivar Sarhu (0.75±0.126 t $ha^{-1}$). ICGV 86885 gave the highest pod yield of 1.16 t $ha^{-1}$.

**South Africa.** In the Fifth IMGVT-SB, two varieties gave significantly more pod yields than the local control cultivar Sellie (0.52 t $ha^{-1}$). ICGV 88336 gave the highest pod yield of 1.44 t $ha^{-1}$.

In the Fifth IMGVT-VB, two varieties gave significantly greater pod yields than Sellie (0.71 t $ha^{-1}$). ICGV 88308 gave the highest pod yield of 1.60 t $ha^{-1}$.

**India.** Under the APAU-ICRISAT collaborative research project in groundnut breeding, ICGS 65, a variety with compact plant type, was identified for on-farm trials in the northcoastal zone of Andhra Pradesh, where excessive vegetative growth is a problem. Further, ICGVs 86300 and 86347 were also identified for inclusion in the multilocational trials in the state.

ICGV 86350 has been included in the multilocational trial (normal duration) of the University of Agricultural Sciences, Dharwad, Karnataka.

## Varietal release

**India.** ICGV 86325 was released by the Central Subcommittee on Crop Standards, Notification, and Release of Varieties, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India for rainy season cultivation in southern Maharashtra, Andhra Pradesh (excluding northcoastal districts), Karnataka, and Tamil Nadu.

## Confectionery group

Four sequentially branched varieties (ICGVs 91099, 91104, 91101, and 91105) in an elite varietal trial, conducted under HI conditions at IAC during the 1993/94 postrainy season, significantly outyielded (3.8–4.5 t pods $ha^{-1}$) control cultivar ICGV 87123 (2.9±0.26 t pods $ha^{-1}$). They were also comparable to the alternately branched control cultivar, Chandra. They showed distinct superiority in 100-seed mass (87–105 g), extra-large seeds (46–82%), and O/L ratio (1.7–2.0), compared with ICGV 87123 (100-seed mass 58 g, extra-large seeds 30%, and O/L ratio 1.0). ICGV 91099 ranked among the five highest-yielding varieties across two locations in an advanced varietal trial conducted during the 1992/93 postrainy season. It produced an average pod yield of 4.6 t $ha^{-1}$, compared with 4.0 t of ICGV 87123 (ICRISAT Legumes Program, Annual Report 1993, p.151). It also ranked third in a preliminary varietal trial during the 1991/92 postrainy season (ICRISAT Legumes Program, Annual Report 1992, p.152).

In an elite varietal trial, conducted under HI conditions at IAC during the 1994 rainy season, ICGVs 92158, 92143, 92172, 92173, and 92138 produced similar pod yields (2.0–2.3 t $ha^{-1}$) as that of Chandra (2 t $ha^{-1}$). However, they showed distinct superiority in 100-seed mass (64–95 g), extra-large seeds (25–49%), and O/L ratio (1.7–1.9), compared with Chandra (100-seed mass 55 g, extra-large seeds 5%, and O/L ratio 0.9). ICGV 92143 and ICGV 92172 ranked among the five highest-yielding varieties in preliminary trials conducted at IAC during the 1992 rainy season (ICRISAT Legumes Program, Annual Report 1992, p.154).

## Collaboration with NARS

**Republic of Korea.** Five confectionery varieties (ICGVs 88391, 88399, 88402, 88389, and 88378) were selected for further evaluation because of their large seed size and good seed quality.

**Vietnam.** ICGV 93064 at Cu Chi and ICGV 93070 at Trang Bang significantly outyielded (19–24% greater pod yield) local cultivar Ly and showed greater 100-seed mass. The local cultivar Ly produced a pod yield of 3.91±0.245 t $ha^{-1}$ at Cu Chi and 3.53±0.191 t $ha^{-1}$ at Trang Bang.

## Varietal release

**Cyprus.** Our cooperators from Agricultural Research Institute, Nicosia, Cyprus, released three confectionery varieties (ICGV 89214 as Kouklia, ICGV 88438 as Nikoklia, and ICGV 91098 as Gigas) for cultivation in coastal areas of Paphos.

## Seed supply

**International trials.** A sixth series of groundnut international trials was formulated, and seed of entries included in these trials was multiplied.

We supplied 45 sets of 14 international trials to our cooperators in 13 countries. The trials included Fifth International Medium-duration Groundnut Varietal Trial-SB (V IMGVT-SB, 4 sets), V IMGVT-VB (3 sets), Fifth International Short-duration Groundnut Varietal Trial (V ISGVT, 8 sets), Fifth International Foliar Diseases Resistant Groundnut Varietal Trial (V IFDRGVT, 3 sets), Fifth International Confectionery Groundnut Varietal Trial (V ICGVT, 7 sets), Fifth International Insect Pests Resistance Groundnut Varietal Trial (V IIPRGVT, 3 sets), Second International Drought Resistance/Tolerance Groundnut Varietal Trial (II IDTGVT, 7 sets), VI IMGVT-SB (1 set), VI IMGVT-VB (1 set), VI ISGVT (2 sets), VI IFDRGVT (1 set), VI ICGVT (3 sets), VI IIPRGVT (1 set), and IDTGVT (1 set).

**Breeding material.** We supplied 1310 breeding lines and 153 segregating populations to our cooperators in 13 countries and 116 germplasm lines and released varieties to scientists in 14 countries. Twelve $F_1$ crosses were made, and their seed supplied to collaborators at Jagtial in India and at Joydebpur in Bangladesh.

**Breeder/Nucleus Seed.** We provided 5.04 t of breeder/nucleus seed (pod) of eight ICRISAT-bred varieties to the public and private seed-producing agencies in India.

GRD

# Genetic Resources Division

*The Genetic Resources Division (GRD) of ICRISAT acts as a world repository of sorghum, millets, chickpea, pigeonpea, and groundnut genetic resources, and is responsible to make this diverse and viable germplasm readily available for use to scientists in ICRISAT and National Agricultural Research Systems (NARS) in the semi-arid tropics (SAT) and elsewhere. This responsibility will become even more important in future, as landraces gradually become extinct and NARS become involved in their own crop improvement programs. Therefore, the maintenance and long-term conservation of world collections are of paramount and strategic importance for present and future use in crop improvement programs of NARS.*

*To date, over 113 590 germplasm accessions of these crops have been assembled from 128 countries. In accordance with the agreement that has been reached by the International Agricultural Research Centers (IARCs), ICRISAT formally placed these vast and diverse collections under the auspices of the Food and Agriculture Organization of the United Nations (FAO) in the framework of 'The FAO Undertaking on Plant Genetic Resources.' Although good progress has been made in germplasm assembly, the total number of accessions of our crops is relatively small compared with some other crops such as rice, wheat, barley, soybean, and common bean. ICRISAT's genetic resources project indicates that increased effort must be made to collect in remote and priority areas, particularly the wild relatives of our crops that are presently surviving in fragile environments.*

## Organization and Project Development

To promote multidisciplinary efforts, and in line with ICRISAT's recent reorganization of research into a project-based structure, the former 19 research projects of GRD were combined into a single research project, 'Genetic resources assembly, evaluation, and management for conservation and utilization', with the following four activity-oriented subprojects:

1. Germplasm characterization, preliminary evaluation for documentation, and development of databases and core collections.
2. Germplasm collection, biodiversity studies, and ecoregional surveys on mandate and some nonmandate crops, jointly with NARS.
3. Germplasm maintenance, ex situ, and in situ conservation of mandate crops at ICRISAT Asia Center (IAC) and other ICRISAT locations.
4. Germplasm distribution for crop improvement and its impact assessment (to be conducted in close collaboration with the Socioeconomics and Policy Division).

The advantage of this reorganization is that NARS and ICRISAT scientists will be actively involved together in the planning and implementation of genetic resources research activities. With ICRISAT's economists, concerted effort will be made to assess the impact of germplasm distribution and utilization on crop improvement.

Special efforts will be made to complete most of our germplasm collection work in the next 5 years. Future collection efforts will emphasize collections for germplasm with special traits, and for wild relatives rather than general collections. The main purpose will be to exploit untapped resources in wild relatives, especially for gene diversification, and resistance to stress factors. Germplasm maintenance, evaluation, documentation, conservation, and distribution activities will be continued. More emphasis will be laid on making the assembled material more dynamic, well classified, documented, and readily accessible. With the use of biotechnology and molecular markers, vast numbers of germplasm accessions will be reclassified to establish 'core collections' which will represent the diversity of the complete collections with smaller numbers of accessions that will be more manageable for users. This part of our work will be undertaken with the help and collaboration of ICRISAT's Cellular and Molecular Biology Division (CMBD).

One outcome of the Biodiversity Convention, was the formation of the Consultative Group on International Agricultural Research (CGIAR) System-wide Genetic Resources Program (SGRP). This has generated NARS' and donors' interests. It proposes to develop and strengthen ecoregional research activities in biodiversity and in situ conservation in close collaboration with NARS, nongovernmental organizations, other regional and international organizations, and IARCs. Initial consultations and exploratory surveys will be undertaken, possibly with funding from the SGRP of the CGIAR, and other sources.

# Germplasm

## Collection and Assembly

This year, we added 3143 accessions of mandate crops and minor millets (Table 1) to the existing 110 447 accessions, raising the total genebank holdings to 113 590. In collaboration with scientists in the NARS, germplasm collection missions were launched in India (Karnataka) for sorghum, Tanzania and India (eastern Maharashtra) for chickpea, and Brazil for *Arachis* species, and 420 samples were collected (Table 2). A collaborative collection effort with the Department of Primary Industries, Central Region, Queensland, Australia, added many distantly related wild sorghums to our collection. All the germplasm samples collected or assembled from outside India are with the Plant Quarantine Regional Station of the National Bureau of Plant Genetic Resources (NBPGR), Rajendranagar, for quarantine examination and subsequent sowing in the Post-Entry Quarantine Isolation Area (PEQIA) for inspection and seed increase.

*Table 1. Number of germplasm samples from different countries assembled at the ICRISAT Asia Center genebank during 1994.*

| Origin | Sorghum | Pearl millet | Chickpea | Pigeonpea | Groundnut | Minor millets | Total |
|---|---|---|---|---|---|---|---|
| **Africa** | | | | | | | |
| Algeria | 2 | - | - | - | - | - | 2 |
| Burundi | 1 | - | - | - | - | - | 22 |
| Cameroon | 2 | - | - | - | 86 | - | 88 |
| Egypt | 3 | - | - | - | - | - | 3 |
| Ethiopia | 21 | 1 | - | - | - | - | 22 |
| Kenya | 35 | - | - | - | - | - | 35 |
| Mali | 35 | 1 | - | - | - | - | 36 |
| Niger | 1 | 43 | - | - | 3 | - | 47 |
| Nigeria | 199 | 654 | - | 129 | - | 19 | 1001 |
| South Africa | 6 | 3 | - | - | - | - | 9 |
| Sudan | 1 | 1 | - | - | - | - | 2 |
| Swaziland | 1 | - | - | - | - | - | 1 |
| Togo | 1 | - | - | - | - | - | 1 |
| Uganda | 200 | - | 1 | 25 | 2 | 88 | 316 |
| Zaire | 1 | - | - | - | - | - | 1 |
| Zambia | 1 | - | - | - | - | - | 1 |
| Zimbabwe | 4 | 4 | - | - | - | 29 | 37 |
| **Asia** | | | | | | | |
| CIS | 50 | 2 | 9 | - | - | - | 61 |
| India | 164 | 102 | 128 | 130 | - | - | 524 |
| Indonesia | - | - | - | 1 | - | - | 1 |
| Myanmar | 12 | 10 | - | 2 | - | 8 | 32 |
| Malaysia | - | - | - | - | 2 | - | 2 |
| Pakistan | - | 4 | 4 | - | 2 | - | 10 |
| Philippines | 51 | - | - | - | - | 209 | 260 |
| Syria | - | - | 3 | - | - | - | 3 |
| Turkey | 1 | - | - | - | - | - | 1 |
| Vietnam | - | - | - | - | 50 | - | 50 |
| Yemen | - | 229 | - | - | - | - | 229 |
| **Europe** | | | | | | | |
| Italy | 2 | - | 2 | - | - | - | 4 |
| Portugal | 1 | - | 80 | - | - | - | 81 |
| Spain | - | - | 2 | - | - | - | 2 |
| **Americas** | | | | | | | |
| Argentina | 16 | - | - | - | - | - | 16 |
| Brazil | - | - | - | - | 215 | - | 215 |
| Chile | 1 | - | - | - | - | - | 1 |
| Dominican Republic | 1 | - | - | - | - | - | 1 |
| USA | 1 | 34 | - | - | 5 | - | 40 |
| **Oceania** | | | | | | | |
| Austrália | 5 | 1 | - | - | - | - | 6 |
| New Zealand | 1 | - | - | - | - | - | 1 |
| Total in 1994 | 820 | 1089 | 229 | 287 | 365 | 353 | 3143 |
| Cumulative total to date | 35 186 | 25 288 | 17 107 | 12 680 | 14 314 | 90 15 | 113 590 |
| Countries represented | 88 | 49 | 44 | 56 | 89 | 43 | |

## Evaluation

Before germplasm can be used, it must be evaluated. As new germplasm is assembled, its morphological and agronomical characteristics need to be assessed. This year, we characterized 3968 new accessions (816 sorghum, 991 pearl millet, 585 chickpea, 713 pigeonpea, 293 groundnut, and 570 minor millets), using the crop descriptors co-published by the International Board for Plant Genetic Resources (IBPGR) and ICRISAT.

In a collaborative effort involving NBPGR, Indian Council of Agricultural Research (ICAR), and ICRISAT, 1600 accessions of grain sorghum, forage sorghum, pearl millet for grain and forage, late- and early-maturing chickpea, and a range of pigeonpea and groundnut germplasm accessions were evaluated at nine locations in India (Table 3). Five hundred diverse chickpea germplasm lines were evaluated at Rampur and Nepalgunj in Nepal, in collaboration with the NARS of Nepal, and 12 promising lines were jointly selected.

***Table 2. Collection missions executed, and germplasm samples collected during 1994.***

| Country | Sorghum | Chickpea | Groundnut | Total |
|---|---|---|---|---|
| Brazil | - | - | 67 | 67 |
| India | 160 | 106 | - | 266 |
| Tanzania | - | 87 | - | 87 |
| Total | 160 | 193 | 67 | 420 |

***Table 3. Collaborators, locations, number of accessions, and type of material jointly characterized/evaluated during 1994.***

| Crop | Collaborator[1] (in India) | Location | Number of accessions | Type of material |
|---|---|---|---|---|
| Sorghum | NBPGR | Issapur | 200 | Forage |
| | IAC | Patancheru | 200 | Forage |
| | NBPGR | Akola | 200 | Grain |
| | AICSIP | Surat | 200 | Grain |
| | AICSIP | Indore | 200 | Grain |
| | NRCS | Rajendranagar | 200 | Grain |
| | TNAU | Coimbatore | 200 | Grain |
| | IAC | Patancheru | 200 | Grain |
| Pearl millet | NBPGR | Issapur | 200 | Grain |
| | NBPGR | Jodhpur | 200 | Grain |
| | IAC | Patancheru | 200 | Grain |
| | NBPGR | Issapur | 200 | Fodder |
| | IAC | Patancheru | 200 | Fodder |
| Chickpea | IIPR | Kanpur | 200 | Long duration |
| | IAC | Patancheru | 200 | Short duration |
| | NBPGR | Akola | 200 | Short duration |
| Pigeonpea | NBPGR | Akola | 200 | Diverse |
| Groundnut | NBPGR | Akola | 200 | Diverse |
| | NBPGR | Jodhpur | 200 | Diverse |

1. NBPGR = National Bureau of Plant Genetic Resources, IAC = ICRISAT Asia Center, AICSIP = All India Coordinated Sorghum Improvement Project, NRCS = National Research Center for Sorghum, TNAU = Tamil Nadu Agricultural University, and IIPR = Indian Institute of Pulses Research.

## Catalogs

Earlier, ICRISAT and NBPGR, New Delhi, India, had collaborated in the publication and distribution of catalogs of forage sorghum, grain sorghum, and pearl millet germplasm to scientists in India and in other countries. This year, a catalog of chickpea germplasm was published and distributed for the benefit of chickpea scientists worldwide.

Computer printouts/diskettes containing the characterization data of germplasm of ICRISAT mandate crops, either in full or in part, were supplied to NARS scientists who needed them.

## Long-term Conservation

For conservation as base collections, 2604 accessions of ICRISAT mandate crops were processed and transferred to the long-term storage chambers of the ICRISAT genebank, raising the total number conserved at IAC to 18 761. These accessions were, on average, 96% viable with the viability ranging from 93% to 98%. Germplasm conserved for more than 5 years under medium-term cold storage conditions (+4°C and 20% relative humidity) was regularly monitored for seed viability. To date, 50 743 accessions conserved under medium-term storage have been tested for viability, which was found to be 94% on average.

## Safety Duplicate Conservation

In continuation of our efforts to ensure safe, duplicate conservation of ICRISAT mandate crops in India and southern, eastern, and West Africa, 1702 accessions of pigeonpea germplasm were transferred to NBPGR and another 2000 accessions of groundnut to the ICRISAT Sahelian Center (ISC) at Niamey, Niger. We entered into a formal agreement with the Southern African Development Community (SADC) Plant Genetic Resources Centre (SPGRC), Lusaka, Zambia, for duplicate conservation of germplasm from southern Africa, previously maintained only in the ICRISAT genebank. A similar understanding for duplicate conservation was reached with the Kenya Agricultural Research Institute (KARI), Nairobi. Following the signing of a Memorandum of Agreement with SPGRC, 1000 diverse sorghum accessions and 500 finger millet accessions originating from southern Africa were grown at SPGRC. The crops established and grew well, and adequate seed was produced (with appropriate pollination control) and stored. Sorghum, pearl millet, and finger millet accessions from eastern Africa will be rejuvenated and adequate seed multiplied for duplicate conservation at KARI, Nairobi.

## Distribution

We distributed 36 479 germplasm samples of mandate crops (Table 4) to scientists at IAC (12 865), within India (11 607), and in other countries (12 007) for evaluation and use in crop improvement programs. Up to December 1994, 1 141 270 seed samples have already been supplied on request from the ICRISAT genebank for use by crop improvement programs worldwide, mainly by NARS in the SAT.

## Training

The GRD conducted various types of specialized training, designed to strengthen national research capabilities in plant genetic resources. This varied from field training in the principles and practices of germplasm collection, maintenance, and evaluation, to laboratory-oriented activities in germplasm conservation, and genebank operations.

We provided practical training to eight in-service trainees from China, Kenya, Malawi, Myanmar, Sudan, and Uganda in the genetic resources activities of sorghum, pearl millet, and groundnut, and also in genebank activities. We also gave special training and orientation on germplasm management and GRD activities to eight more in-service trainees/visiting scientists during the year.

*Table 4. Number of germplasm samples distributed from ICRISAT genebank during 1994.*

| Crop | Within ICRISAT | Within India | Other countries | Total samples |
|---|---|---|---|---|
| Sorghum | 552 | 2574 | 4889 | 8015 (18)[1] |
| Pearl millet | 684 | 1336 | 323 | 2343 (9) |
| Chickpea | 8175 | 1033 | 133 | 9341 (12) |
| Pigeonpea | 3017 | 2123 | 1512 | 6652 (11) |
| Groundnut | 437 | 1311 | 4468 | 6216 (12) |
| Minor millets | 0 | 3230 | 682 | 3912 (6) |
| Total in 1994 | 12 865 | 11 607 | 12 007 | 36 479 |
| Cumulative total to date | 524 457 | 324 047 | 292 766 | 1 141 270 |

1. Figures in parentheses are the number of countries covered.

## Future Trends and Development

Earlier, ICRISAT gave high priority to the collection and assembly of germplasm of ICRISAT's mandate crops. Now, systematic characterization, evaluation, classification, documentation, and screening, and continued maintenance and conservation are emphasized. To facilitate germplasm utilization, we hope to develop core collections of different crops based on information on molecular markers. Although we must continue to collect and evaluate germplasm from remote priority areas, emphasis, in the future, will be on germplasm maintenance, long-term conservation, duplicate (base) conservation, diversification, enhancement, the search for new and desirable traits, and utilization of the conserved landraces and their wild relatives.

As a consequence of the Biodiversity Convention, increased emphasis will be given to ecoregional studies and in situ conservation in collaboration with NARS. Recent developments in Plant Genetic Resources (PGR) warrant us to be more cautious about germplasm collection and distribution. The Biodiversity Convention gives sovereign rights over germplasm to the states of origin. Intellectual property rights to germplasm may soon become a regulation. According to the CGIAR policy on PGR, ICRISAT will continue to provide germplasm to all users without cost for use in crop improvement for the benefit of humankind.

## Sorghum Germplasm

During February 1994, a collection mission, jointly launched by ICRISAT and NBPGR to collect postrainy (rabi)-season sorghums from Karnataka, India, yielded 160 samples (Fig. 1). Postrainy-season sorghums in Karnataka known locally as Maldandi, Bili Jola, Gundu Tenai, Kempu Jola, Bijapur Jola, and Dundu Tenai belong to race Durra while Allina Jola belongs to race Durra-bicolor. These sorghums are a source of good grain quality and adaptation to areas where sorghum is grown under residual soil moisture conditions. ICRISAT partially funded a special collection mission launched by the Department of Primary Industries, Central Region, Queensland, Australia, to collect wild sorghum species belonging to the sections Parasorghum, Chaetosorghum, Stiposorghum, and Heterosorghum of the genus *Sorghum*. The seed samples are currently being prepared for dispatch from Australia to IAC.

Eight-hundred-and-twenty new accessions were added to the genebank, raising the total sorghum germplasm accessions assembled at IAC to 35 186. These were from: Algeria (2), Argentina (16), Australia (5), Burundi (1), Cameroon (2), Chile (1), CIS (50), Dominican Republic (1), Egypt (3), Ethiopia (21), India (164), Italy (2), Kenya (35), Mali (35), Myanmar (12), New Zealand (1), Niger (1), Nigeria (199), the Philippines (51), Portugal (1), South Africa (6), Sudan (1), Swaziland (1), Togo (1), Turkey (1), Uganda (200), USA (1), Zaire (1), Zambia (1), and Zimbabwe (4). We characterized and evaluated these accessions at IAC. In collaboration with NBPGR, New Delhi, India, 200 accessions were evaluated for grain yield at six locations, and 200 accessions for forage traits at two locations in India (Table 3) in addition to IAC.

Some white Guinea-race sorghums with hard grain were tested by IAC's sorghum pathologists for resistance to grain mold fungi, using a newly developed in vitro screening technique. Interestingly, some of these accessions were found to be resistant. They all belong to the subraces roxburghii, margaritiferum, guineense, and conspicuum of race Guinea. They are highly photoperiod-sensitive and difficult to screen in the field for grain mold resistance at IAC, or any location that is away from the Equator.

***Figure 1. National Bureau of Plant Genetic Resources and ICRISAT scientists jointly collecting postrainy-season (rabi) sorghums in Dharwad district, Karnataka, India.***

In collaboration with NBPGR, we identified Vellayani (8°–18'N, 77°–22'E) near Trivandrum, Kerala, India, as a location that receives very high rainfall and is suited to screen for grain molds. Two-thousand-and-thirty-nine accessions of highly photoperiod-sensitive sorghum germplasm (belonging mostly to race Guinea) were grown and tested there. The following IS numbers were found to be free from grain molds, whereas other germplasm lines, including the control, were severely affected.

| | | | | | | |
|---|---|---|---|---|---|---|
| IS 2430 | IS 3861 | IS 6790 | IS 6821 | IS 25060 | IS 3811 | IS 6714 |
| IS 6796 | IS 6830 | IS 25069 | IS 3822 | IS 6772 | IS 6799 | IS 6832 |
| IS 25070 | IS 3825 | IS 6783 | IS 6800 | IS 24911 | IS 25084 | IS 3852 |
| IS 6789 | IS 6809 | IS 25025 | IS 25098 | | | |

These lines are to be further tested by sorghum pathologists using the new in vitro screening technique.

We rejuvenated 2500 accessions that had reached critically low seed quantity in medium-term storage, or whose seed viability was below 85%. To maintain the accessions in their original genetic form, representative panicles from each accession were selfed and bulked.

We supplied 8015 samples of seed during the year; 2574 to scientists within India, 4889 to scientists in 18 other countries, for evaluation and utilization in sorghum enhancement programs, and 552 samples to scientists within ICRISAT (Table 4).

## Pearl Millet Germplasm

During 1994, for reasons beyond our control, field collection trips for pearl millet germplasm were not made. However, we were able to assemble 34 accessions from USA. Germplasm collected by others was released, including accessions from: Australia (1), CIS (2), Ethiopia (1), India (102), Mali (1), Myanmar (10), Niger (43), Nigeria (654), Pakistan (4), South Africa (3), Sudan (1), USA (34), Yemen (229), and Zimbabwe (4). These raised the total number of pearl millet accessions conserved in the ICRISAT genebank to 25 288 from 50 countries. This includes 688 accessions of wild relatives of *Pennisetum.*

A set of 741 accessions sown in the 1993/94 postrainy season was evaluated for time to 50% flowering, plant height, spike length, spike thickness, and grain characteristics. During the rainy season, we evaluated 997 accessions from: Mali (1), Myanmar (10), Nigeria (669), USA (88), and Yemen (229) for flowering, plant height, tiller number, and spike characteristics. Data obtained from this material reveal that most of the accessions from Yemen are medium-duration, and those from Nigeria are medium- to late-duration. Germplasm samples from Nigeria produced longer spikes than those from Yemen. The germplasm from Yemen was found to have more tillers than that from Nigeria. During the postrainy season, 397 smut-resistant accessions, 47 downy mildew resistant accessions, and 86 accessions introduced from USA were sown for evaluation.

In collaboration with NBPGR, 200 accessions selected for forage yield were evaluated at IAC and Issapur. Another set of 200 accessions selected for grain yield was evaluated at IAC, Issapur, and Jodhpur (Table 3).

Passport information on 997 new accessions was computerized. The database of passport information was updated by adding the data on accessions received in the early days of the Institute from the Rockefeller Foundation. A list of all pearl millet germplasm accessions including wild species, was prepared for use by FAO. Selected passport information was also listed.

Five-hundred-and-thirty-nine accessions were successfully rejuvenated in the 1993/94 postrainy season. We identified 1017 accessions for which the seed quantity had reached critically low levels in the medium-term storage facility, and/or where the seed viability was <85% for rejuvenation in the 1994/95 postrainy season. To maintain population structure close to its original form, we carried out cluster bagging for landraces, sibbing for male-sterile lines, and selfing for inbreds and genetic stocks.

To facilitate germplasm utilization, we developed early, high-tillering, large spike, and large grain genepools. These were evaluated by sowing the seed obtained after four to six random matings in four replications. There was considerable reduction in the range of variation for important characteristics in the final random mating. However, the mean values of the target traits increased considerably. These four genepools form an excellent genetic base for pearl millet improvement. One of the genepools, the high-tillering genepool (HTGP-K), has been selected for testing in the All India Coordinated Forage Improvement Program.

During 1994, we distributed seed of 2343 pearl millet germplasm accessions. These included 684 samples provided to other disciplines within ICRISAT, 1336 samples to NARS scientists in India, and 323 samples to NARS scientists in 9 other countries (Table 4). Germplasm distributed in India included material for multilocational evaluation in collaboration with NBPGR, New Delhi.

## Minor Millets Germplasm

We assembled 353 new accessions comprising 135 finger millet [*Eleusine coracana* (L.) Gaertn.], 7 foxtail millet (*Setaria italica* Beauv.), 2 little millet (*Panicum sumatrense* Roth. ex Roem. & Schult), 98 barnyard millet [*Echinochloa colona* (L.) Link.], and 111 kodo millet (*Paspalum scrobiculatum* L.) samples. These were accessions carried from Myanmar (8), Nigeria (19), the Philippines (209), Uganda (88), and Zimbabwe (29). They raised the total genebank holdings to 9015.

We evaluated 1744 minor millets germplasm accessions including finger millet (586), foxtail millet (115), little millet (2), barnyard millet (98), proso millet (832), and kodo millet (111) for important morpho-agronomic characteristics.

In collaboration with the All India Coordinated Small Millets Improvement Project, Bangalore, a set of 500 diverse finger millet germplasm accessions from Uganda was evaluated at the Gandhi Krishi Vignan Kendra Campus, University of Agricultural Sciences, Hebbal, near Bangalore; Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu; Millet Research Station, Vijayanagaram, Andhra Pradesh; Birsa Agricultural University, Kanke, Ranchi, Bihar; and Gandhi Krishi Vignana Kendra, Almora, Uttar Pradesh. The same 500 finger millet accessions from Uganda were characterized at IAC during the rainy season.

We supplied 3230 samples to scientists in India and 682 samples to six other countries for use in their programs (Table 4).

## Chickpea Germplasm

This year was particularly rewarding for the assembly of new chickpea germplasm. One-hundred-and-six samples were collected jointly with NBPGR during a germplasm collection mission to northern Maharashtra, India. These samples included typical desi chickpeas (purplish stem, purple flower, yellow-brown angular seed), gulabi types (green stem, white flower with light orange, and round seed), tuberculated types (seedcoat with tiny projections), twin-podded, and thakkar (desi, large-seeded) types of chickpea. The major constraints to chickpea cultivation in Maharashtra, which we noticed during the mission, were fusarium wilt, dry root rot and collar rot diseases, and low yield potential of local varieties.

***Figure 2. Chickpea grows very well in Tanzania, where the crop has bright prospects.***

A second germplasm mission was organized in Tanzania, jointly with the National Plant Genetic Resources Centre, Arusha. Eighty-seven samples were collected. In Tanzania, chickpea is grown in the postrainy season and takes about 120 days (April-August) to mature. Generally, desi chickpeas, which were relatively short (about 35 cm), had a semi-spreading growth habit, and producing yellow or yellow-brown seeds, weighing 16–18 g (100 seeds)$^{-1}$ were grown. The seed yield of the landraces was very good in most of the fields (Fig. 2). Because of the rainfed agriculture and dry environment, the crops were almost free from insects and diseases and, therefore, prospects for chickpea cultivation in Tanzania are bright.

During the year, we also added 229 samples from India (128), Italy (2), Pakistan (4), Portugal (80), Russia (9), Spain (2), Syria (3), and Uganda (1). Additions also included 22 elite chickpea lines obtained from other institutions and six lines developed by us through hybridization for specific traits. With these additions, the genebank's chickpea germplasm strength has grown to 17 107 accessions from 44 countries, and it includes 135 accessions of wild *Cicer* species.

During the 1993/94 crop season, we sowed 585 accessions for preliminary evaluation and seed increase, during which the following 10 accessions with special characteristics were identified.

| | |
|---|---|
| ICC 55 | Long basal branches, long duration. |
| ICC 2060 | Heavy branching, short duration. |
| ICC 1695 | Semi-erect, high seed yield. |
| ICC 4581 | Small leaf, short duration |
| ICC 5335 | Short duration, desi, high yield. |
| ICC 7504 | Short duration, high yield. |
| ICC 11147 | Short duration, desi, high yield. |
| ICC 11529 | Short duration, desi, high yield. |
| ICC 13021 | Short duration, desi, erect growth, high yield. |
| ICC 13026 | Short duration, kabuli, long basal branches. |

These accessions can be further evaluated and used for chickpea improvement. We sowed 1450 accessions for seed increase and subsequent medium- and long-term conservation. As part of collaborative germplasm evaluation with NBPGR, a set of 200 short-duration accessions was sown at Akola and IAC, and a set of 200 long-duration accessions at the Indian Institute of Pulses Research (IIPR), Kanpur. These accessions were evaluated for 15 botanical and agronomic characteristics. At Akola, the performance of four accessions (ICC 10443, ICC 10444, ICC 16024, and ICC 16048) was the best among the 200 when scored visually for total biomass and seed yield. Another set of 500 long-duration accessions was evaluated at Rampur and Nepalganj in Nepal, jointly with the NARS. Based on visual scoring for agronomic characteristics, ICC 129, ICC 154, ICC 187, ICC 192, ICC 258, ICC 470, ICC 9972, ICC 14515, ICC 16168, and ICC 16176, in addition to the cultivars K 850 and Dhanush, were identified as promising for cultivation in Nepal.

The passport data of the entire chickpea germplasm collections have been computerized. The evaluation data recorded in 1994 were added to the chickpea germplasm database.

During the year, 9341 seed samples were supplied on request. A large portion (87%) of the samples was used by IAC pathologists to screen for resistance to gray mold disease (Table 4).

## Pigeonpea Germplasm

During 1994, we added 287 accessions to the ICRISAT genebank raising the total collection of pigeonpea and its wild relatives to 12 680 accessions from 56 countries. The new additions are from India (130), Indonesia (1), Myanmar (2), Nigeria (129), and Uganda (25).

After growing the accessions in the PEQIA, the NBPGR released to ICRISAT, 177 exotic accessions originating from Myanmar, Nigeria, and Uganda. Another set of 53 samples of pigeonpea and 250 samples of related wild species was cleared by NBPGR, to be grown in the PEQIA and subsequently released to ICRISAT.

We sowed 234 accessions for characterization, including 202 new entries and 32 accessions, for which data from the previous seasons were incomplete. A set of 10 germplasm selections was sown for preliminary yield evaluation and seed increase (Fig 3). Under the on-going ICRISAT/NBPGR collaborative program for multilocational germplasm evaluation, we evaluated 200 medium-duration and 200 long-duration accessions at IAC. During this exercise, we identified the following 54 medium-duration and 35 long-duration accessions with seed yield over 2 t $ha^{-1}$.

**Medium-duration accessions**

| | | | | | |
|---|---|---|---|---|---|
| ICP 60 | ICP 62 | ICP 65 | ICP 72 | ICP 75 | ICP 77 |
| ICP 79 | ICP 83 | ICP 87 | ICP 130 | ICP 150 | ICP 180 |
| ICP 182 | ICP 206 | ICP 219 | ICP 252 | ICP 275 | ICP 288 |
| ICP 297 | ICP 334 | ICP 335 | ICP 388 | ICP 410 | ICP 487 |
| ICP 538 | ICP 607 | ICP 617 | ICP 633 | ICP 664 | ICP 676 |
| ICP 730 | ICP 731 | ICP 755 | ICP 785 | ICP 788 | ICP 791 |
| ICP 800 | ICP 802 | ICP 816 | ICP 821 | ICP 828 | ICP 829 |
| ICP 836 | ICP 844 | ICP 848 | ICP 867 | ICP 872 | ICP 874 |
| ICP 902 | ICP 908 | ICP 916 | ICP 941 | ICP 1026 | ICP 1083 |

**Long-duration accessions**

| | | | | | |
|---|---|---|---|---|---|
| ICP 48 | ICP 58 | ICP 202 | ICP 408 | ICP 432 | ICC 433 |
| ICP 447 | ICP 570 | ICP 624 | ICP 707 | ICP 772 | ICP 826 |
| ICP 876 | ICP 919 | ICP 932 | ICP 1226 | ICP 1283 | ICP 1327 |
| ICP 1590 | ICP 1661 | ICP 1673 | ICP 1758 | ICP 1923 | ICP 2016 |
| ICP 2019 | ICP 2085 | ICP 2155 | ICP 2205 | ICP 2420 | ICP 2726 |
| ICP 3068 | ICP 3102 | ICP 3125 | ICP 3150 | ICP 3397 | |

Annual plant growth habit is a desirable characteristic in pigeonpea, but is not available in the cultivated species. In an attempt to search for this characteristic, we evaluated 14 accessions of *Cajanus platycarpus*. The experiment is still in progress.

We sowed 200 lines for long-term conservation, and 1154 lines for seed increase. Seed from 415 selfed accessions was dried to 7% seed moisture level, and transferred to long-term cold storage in the ICRISAT genebank for conservation as a base collection. A set of 400 accessions was deposited at NBPGR, New Delhi, for duplicate conservation. This set included 54 accessions of closely related species and 31 bulk samples to be used to monitor seed viability. Results of the viability monitoring of 8259 samples in medium-term storage indicated that the average viability of pigeonpea germplasm conserved as active collections was 94%.

We distributed 3017 samples of germplasm to ICRISAT scientists, to be screened for disease resistance, agronomic, and quality characteristics. In India, we distributed 2123 samples, which included 786 samples supplied to IIPR, Kanpur, Uttar Pradesh, for screening for podfly resistance, and 400 samples provided to NBPGR, New Delhi, for duplicate conservation. We distributed 1512 samples to users in 10 other countries. These included 500 samples sent to South Africa, and 931 samples supplied to Kenya for maintenance and duplicate conservation.


***Figure 3. A pigeonpea germplasm selection with a large number of racemes.***

## Groundnut Germplasm

***Figure 4. A good groundnut crop in Mato Grosso, Brazil.***

During 1994, a joint collection expedition was launched in collaboration with Centro Nacional de Pesquisa deRecursos Geneticos e Biotechnologia (CENARGEN), Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), and Céntro Internacional de Agricultura Tropical (CIAT) to Goias, Mato Grosso do Sul, and Mato Grosso provinces of southern Brazil. Sixty-seven seed/live plant samples of 26 *Arachis* species representing six of the nine sections of the genus *Arachis* were collected (Fig. 4). Another 315 accessions of both wild *Arachis* species and cultivated groundnut were assembled from Brazil during the visit. In addition, 305 accessions, of which 300 belonged to wild *Arachis* species and 5 to *A. hypogaea* subspecies *hypogaea* var *hirsuta* were obtained from Texas A and M Research and Extension Center, Stephenville, and the Southern Regional Plant Introduction Station, Griffin, Georgia, USA. The five accessions of var. *hirsuta* were the first entries of this variety to be included in the ICRISAT world collection. About 600 accessions are ready for addition to the existing collection in the genebank.

Three-hundred-and-sixty-five samples from Brazil (113 cultivated and 102 wild species), Cameroon (86), Malaysia (2), Niger (3), Pakistan (2), Uganda (2), USA (5), and Vietnam (50) were released by NBPGR, Rajendranagar, Hyderabad. All the samples were sown in the PEQIA except for the wild species from Brazil, which were sown in pots in isolation in a greenhouse. With this release, the total ICRISAT groundnut collection increased to 14 314 accessions.

We characterized and evaluated 1418 accessions sown in the 1993/94 postrainy season and 927 accessions sown in the 1994 rainy season. Of the 1418 accessions sown in the rainy season, 996 were sown in four replicated trials for agronomic evaluation and production of sufficient seeds for long-term conservation as a base collection. Of the four trials, two had 399 accessions each of spanish and valencia types, and the other two had 99 accessions each of virginia bunch and runner types. The remaining accessions were characterized and evaluated in an observation nursery. Of the 927 accessions sown in the rainy season, 380 new accessions were characterized and evaluated in an observation nursery, and the remaining 547 were multiplied for seed increase and to record missing data on various groundnut descriptors.

This year, we evaluated another set of 200 germplasm accessions at Akola and Jodhpur under the NBPGR/ICRISAT joint evaluation program.

Four-hundred-and-fifty-five accessions (399 germplasm accessions belonging to the *vulgaris* group, and 56 accessions belonging to the *fastigiata* group) were processed for long-term conservation.

We distributed 6216 accessions to researchers within India (1311), in other countries (4468), and at IAC (437). The germplasm distributed included 2000 accessions for duplicate conservation at ISC and another 2011 accessions sent to Malawi where they will be screened for resistance to groundnut rosette virus and early leaf spot diseases.

## Genebank and Seed Laboratory

The genebank functioned normally throughout the year. The environment control systems were monitored regularly, and fluctuations due to power failures and mechanical breakdowns were attended to on a priority basis. A few modifications were made to the power supply system of the dehumidifiers in the medium-term storage facilities to improve their safety and efficiency. Additional storage facilities were created to accommodate more accessions of chickpea and pigeonpea in the medium-term storage rooms.

During this year, we processed 2604 accessions of freshly harvested seeds of ICRISAT mandate crops for long-term conservation (–20°C) as base collections, after drying to safe, low seed moisture levels (4–7%) and testing initial viability. This total included, 702 sorghum, 515 pearl millet, 364 chickpea, 415 pigeonpea, and 608 groundnut accessions. With these additions, the total number of accessions conserved as base collections in the genebank have gone up to 18 761; comprising 5014 sorghum, 4583 pearl millet, 4470 chickpea, 1694 pigeonpea, and 3000 groundnut accessions (Table 5). The average viability of all lines stored till now was 96%.

For duplicate conservation, as security against loss of the base collection conserved in the ICRISAT genebank, 400 accessions of pigeonpea germplasm were safely deposited in the NBPGR long-term (–20°C) conservation facilities in New Delhi. By the end of 1994, we had deposited 1702 accessions of pigeonpea at NBPGR.

***Table 5. Initial viability of germplasm accessions of different crops conserved in long-term storage facilities (–20°C), at the ICRISAT genebank.***

| Crop | Accessions conserved | Average viability (%) |
|---|---|---|
| Sorghum | 5014 | 95 |
| Pearl millet | 4583 | 97 |
| Chickpea | 4470 | 98 |
| Pigeonpea | 1694 | 96 |
| Groundnut | 3000 | 93 |
| Total | 18 761 | |

The germinability of 4844 accessions of mandate crops, consisting of 76 sorghum, 1427 pearl millet, 2890 chickpea, and 451 groundnut samples stored for 5 or more years in the medium-term storage facilities (4°C and 20% RH) was tested, and one sorghum, 95 pearl millet, 360 chickpea, and 25 groundnut accessions with less than 85% viability were identified for immediate rejuvenation. By the end of 1994, we had monitored a total of 50 743 accessions of the mandate crops conserved in medium-term storage. Their average viability was 94%.

SEPD

# Socioeconomics and Policy Division

*Socioeconomics and Policy Division (SEPD) was established after the new organization and management changes in ICRISAT during 1994. It is one of the seven disciplinary groups guiding the administration of research. The divisional activities are spread across the Institute's global projects and regional locations. The main priority areas of the Division are defined in four general areas of disciplinary interest, encompassing multiple subtopics. These are : (i) Impact Assessment, which includes documentation of successful technologies, assessment of research programs, documenting research spillovers, and research policy setting. (ii) Product and input market which covers commodity situation and outlooks, changing crop patterns and comparative advantage, public and private sector seed multiplication, indigenous seed markets, and fertilizer and agrochemicals. (iii) Resource Management and Sustainability focuses on soil and fertility management, moisture conservation options, crop-livestock-agroforestry interactions, changing land use systems, and integrated pest and disease management. (iv) Germplasm Development initiates research in areas of targeting breeding strategies, and adoption studies.*

*The research programs of the Division are in multidisciplinary framework. There is extensive collaboration with ICRISAT cooperators from the national agricultural research systems in executing research activities.*

# Research Evaluation and Impact Assessment

## Success of Pigeonpea Cultivar ICP 8863 (Maruti) in Peninsular India

Large-scale adoption of ICP 8863 among farmers in the wilt-endemic areas of Karnataka, Maharashtra, and Andhra Pradesh was confirmed in the recent reconnaissance surveys by the Research Evaluation and Impact Assessment (REIA) team of ICRISAT.

Two approaches were undertaken to assess the extent of adoption and adoption speed of ICP 8863: (1) analysis of seed sale statistics from the Karnataka State Seeds Corporation; and (2) targeted farm-level survey in the wilt-endemic districts of Maharashtra where ICP 8863 has been taken up on a large scale.

### Analysis of seed sales in Karnataka

ICP 8863, popularly known to farmers as Maruti, is a wilt- resistant, medium-duration pigeonpea cultivar, released in Karnataka in 1986. Pigeonpea variety-wise seed sale data from the Karnataka State Seeds Corporation (KSSC) showed that the sale of ICP 8863 increased from 49 t in 1990 to 140 t in 1994 (Figure 1). Its share in the total sale of all pigeonpea varieties increased from 32% in 1990 to 47% in 1994. Using KSSC's average seed replacement rate of 14.7% for pigeonpea, the area grown to ICP 8863 in Karnataka has reached approximately 95 000 ha or 18% of total pigeonpea area in Karnataka. Higher estimates were given by subject-matter specialists of the various Principal Agriculture Offices of the Ministry of Agriculture in this state. They reported that adoption of ICP 8863 has steadily risen from 1987 and has reached about 116 120 ha area in eight major pigeonpea-growing districts of Karnataka, including Gulbarga, Bidar, Dharwad, Belgaum, Bijapur, Raichur, Bellary, and Mysore. A conservative estimate of the area grown to this variety in the above-mentioned districts (using farmers' average seed rate of 10 kg per ha) is approximately 95 238 ha.

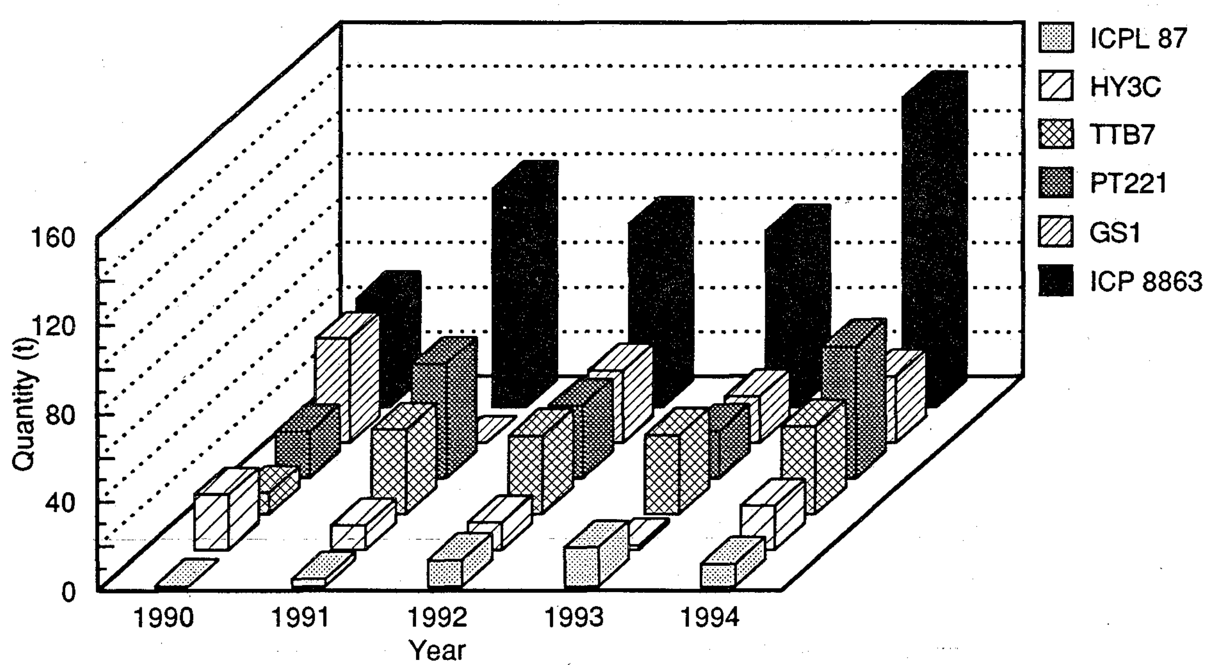


***Figure 1. Pigeonpea seed sales in Karnataka state by the Karnataka State Seeds Corporation (KSSC), 1990–94. (Source: KSSC).***

To confirm these estimates, a systematic sampling scheme was developed. At the first stage, Gulbarga and Bidar districts were selected as these are top ranking districts with respect to pigeonpea area. In these two districts, pigeonpea is grown over 298 876 ha, which represents 55% of the total pigeonpea area in Karnataka and about 8% in India. At the next stage, talukas were selected on the basis of relative importance of pigeonpea area to gross cropped area. Sedam and Chitapur talukas in Gulbarga district, and Bhalki and Humnabad talukas in Bidar district were selected. Two highest pigeonpea-growing villages from each taluka were selected. At the final stage, 10 pigeonpea-growing farmers from each village were randomly selected, forming a sample of 80 farmers, to estimate area under different pigeonpea varieties grown by them. On the basis of a sample of 80 farmers, it was observed that about 52.5% farmers grew ICP 8863, covering about 58% of the pigeonpea area (Table 1).

### Adoption in other states

ICP 8863 has also become popular in the adjoining districts of Maharashtra and Andhra Pradesh, particularly in the Vidharbha region of Maharashtra, although the variety has not been released in these states. A survey of 119 farmers in Maharashtra was conducted in well-targeted ICP 8863 growing districts of Akola, Amravati, Buldhana, Nanded, Wardha, and Yavatmal, to ascertain its adoption. Preliminary results show that ICP 8863 was adopted in about 61% of the total pigeonpea area in the sample districts in 1993, increasing from 46% in 1991. It was noted that farmer-to-farmer seed distribution is a major means of widespread adoption of ICP 8863 in Maharashtra. The Maharashtra State Seeds Corporation is unable to sell ICP 8863 in Maharashtra as it has not been released in this state. As ICP 8863 became more popular in recent years, one private seed company started multiplying and distributing this variety in the Vidharbha area. This year, the company produced about 25 t of ICP 8863 seeds; of this, 16.9 t are certified and the rest truthfully labeled.

## Pigeonpea Variety ICPL 87 in Two Semi-Arid Tropical States of India

ICPL 87, a short-duration variety, released as Pragati in central India in 1986, has found niches in western and Marathwada regions of Maharashtra, covering the districts of Ahmednagar, Dhule, Nasik, Pune, Solapur, Jalgaon, Osmanabad, Latur, Beed, Aurangabad, and Jalna. Sales of ICPL 87 seeds by the Maharashtra State Seeds Corporation (MSSC) have risen significantly from 13.2 t in 1987 to 1003.5 t in 1994 (Figure 2). Its share out of MSSC's total pigeonpea seed sale has risen from 31% to 78% during the 5-year period from 1989 to 1993. Considering MSSC's estimate that it meets 45% of the total seed demand (other sources are private seed companies and seed-producing farmers) and that the farmers' average seed rate for short-duration pigeonpeas is 15 kg $ha^{-1}$, the area grown to ICPL 87 has reached about 148 700 ha in 1994. This is considered as a lower limit estimate, as the seed replacement rate for ICPL 87 may actually be lower than assumed.

***Table 1. Estimated adoption of pigeonpea cultivar ICP 8863 in two sample districts of Karnataka, India.***

| | | | Area (%) under | |
|---|---|---|---|---|
| District | Taluka | Village | ICP 8863 | Other varieties |
| Gulbarga | Sedam | Malkhed | 83 | 17 |
| | | Adiki | 52 | 48 |
| | Chitapur | Hosur | 34 | 66 |
| | | Malag(n) | 58 | 42 |
| Bidar | Bhalki | Ambesangir | 47 | 53 |
| | | Dongpur | 78 | 22 |
| | Humnabad | Sultanabad | 26 | 74 |
| | | Nandgaon | 62 | 38 |
| Total | 4 | 8 | 58 | 42 |

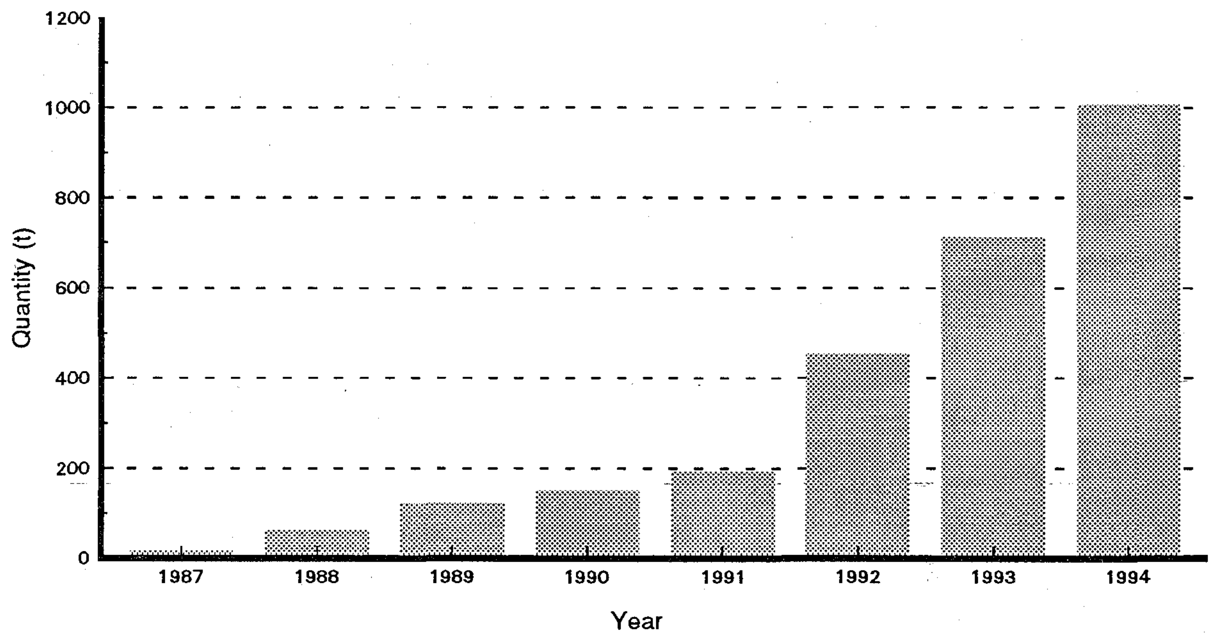


*Figure 2. ICPL 87 seed sales in Maharashtra state by the Maharashtra State Seeds Corporation, 1987–94. (Source: MSSC).*

ICPL 87 is mostly grown as a sole crop, and has found its way mostly to drought-prone areas, where rainfall averages around 600 mm in medium-deep black and well-drained soils. Farmers in these areas prefer this variety because:

- it allows them to grow a second crop during the postrainy season;
- its ability for multiple flushes allows escape from total crop failure due to *Helicoverpa armigera*, or erratic and low rainfall;
- it has been observed to maintain soil fertility;
- it provides good fodder; and
- its green pods can be harvested early and sold as a vegetable.

It is also grown in areas where protective irrigation is available, so that farmers can also harvest a ratoon crop. ICPL 87 has found a niche in the fallow lands and in crop rotation with sugarcane; it has mostly replaced pearl millet and minor millets in sugarcane-growing areas of western Maharashtra. ICPL 87 has also replaced medium- to long-duration pigeonpeas in some districts such as Dhule and Jalgaon, and is finding increasing acceptance by farmers in northern Karnataka, covering the districts of Gulbarga and Bidar, where seed sales of this variety were 17.3 t in 1993.

## Potential Benefits and Constraints to Adoption of Groundnut Production Technology

A study was conducted to develop an approach to quantify the adoption of the Groundnut Production Technology (GPT), which involves research outputs of resource management and genetic enhancement research. Important among these are better soil, water, and nutrient management, and adoption of improved varieties and plant protection measures. Parbhani district in Maharashtra was targeted for this study, because the initial program of the GPT transfer started from that district during 1987–90. Two villages, Gunjegaon and Kokhalewadi of the Gangakhed block of Parbhani, were identified for sample selection. A sample of 20 groundnut-producing farmers were taken from each village. Gunjegaon was characterized as the adopter of GPT, while Kokhalewadi was classified as the nonadopter.

Adoption data of various components of the technology included initial year of adoption, modifications made, and the status of technology adoption in 1993–94. Data were generated on the cost and benefits of different components of the technology. Information was also collected from the Training-and-Visit Program of Agriculture, Office of the Agricultural Development Officer, and several traders dealing with the components of the Groundnut Production Technology.

### Benefits of the GPT

Farmers realized the benefits of the raised bed and furrow method in improving soil and water conservation and management. Some of the benefits reported are as follows:

- The adopter farmers obtained higher yields of groundnut (2.3 t $ha^{-1}$) than the nonadopter farmers (1.6 t $ha^{-1}$). About 80% of the farmers who adopted the technology obtained groundnut yields of 2–2.5 t $ha^{-1}$, while only 20% of the nonadopter farmers achieved this level. As high as 90% of farmers who adopted various components of the technology obtained groundnut yields greater than 2 t $ha^{-1}$, while only 20% of the nonadopter farmers reached that level.
- All the farmers who adopted the technology reported that the raised bed and furrow improves root and pod development, and helps in plant growth. It also improves irrigation efficiency. It was also reported that the technology facilitates easy agricultural operations.
- The applicability of the raised bed and furrow concept extended to other crops. Among other sample farmers, 15% were practising raised bed and furrow for chickpea cultivation, and they reported 15–45% gains in chickpea yields.

### Constraints to technology adoption

Two major constraints were brought up in the study:

- Lack of knowledge regarding various components of the technology such as raised bed and furrow, improved varieties, micronutrients, and plant protection measures.
- Farmers reported that the cost of bed-former was beyond the affordable limit of small and marginal farmers. These group of farmers were not aware of the subsidy extended by the government on the purchase of bed-formers.

## ICRISAT-LASIP Program Impact Study

The ICRISAT Latin American Sorghum Improvement Program (LASIP) Annual Report 1993 provided useful information for a preliminary assessment of the impact of the program in the Latin American region during the last 16 years. Analysis of the data contained in the report, along with complementary FAO sorghum area and production statistics, highlights the achievement of the program, particularly in Guatemala, El Salvador, Honduras, and Nicaragua.

The releases of sorghum cultivars, based on materials identified or bred by ICRISAT-LASIP Program in the above-mentioned countries from 1976 to 1993 are shown in Table 2. Significant area under commercial production of many of the new cultivars introduced through the program have been reported by the National Agricultural Research Systems (NARS) cooperating agencies (LASIP Annual Report, 1993, Table 16). Table 3 consolidates the above data on area for 1993, with available national-level statistics on area grown to sorghum. Almost half of the sorghum area in Guatemala is covered by improved cultivars released via the LASIP Program. Similarly, significant coverage is shown for Honduras (30%), Nicaragua (21%), and El Salvador (20%). Overall, 27% of the total sorghum-growing area in these four countries is sown to improved cultivars released via the LASIP Program.

***Table 2. Sorghum releases based on materials identified or bred by the ICRISAT Latin American Sorghum Improvement Program (LASIP) in EL Salvador, Guatemala, Honduras, and Nicaragua.***

| Country | Year of release | Genotype | Pedigree | Origin of genotype |
|---|---|---|---|---|
| EL Salvador | 1976 | CENTA S-2 | Selected from crosses of materials from Chapingo | CIMMYT |
| EL Salvador | 1980 | CENTA SS-41 | ATx623 x Sweet Sudan | INTSORMIL/LASIP/CENTA |
| EL Salvador | 1983 | ISIAP Dorado[2] | [(GPR 148 x E-35-1)4-1 x (CS 3541 deriv.)]1-1 | ICRISAT/CENTA |
| Honduras | 1984 | Tortillero 1 | Selection from CS 3541 | India via ICRISAT |
| Honduras | 1984 | Catracho | ATx623 x Tortillero 1 | INTSORMIL/LASIP |
| Guatemala | 1985 | Mitlan 85[2] | Selection from M-90975 | ICRISAT/LASIP |
| Honduras | 1985 | Sureno | [SC 423 x CS 3541) x E-35-1]-2-5 | ICRISAT/LASIP |
| Nicaragua | 1985 | Nicag-Sor (T-43)[2] | Selection from ICRISAT SEPON 1977 Sorghum Elite Progeny Observation nursery | LASIP/CLAIS |
| Honduras | 1986 | ISIAP Dorado[3] | [(GPR 148 x E-35-1)4-1 x (CS 3541 deriv.)]1-1 | ICRISAT/LASIP |
| EL Salvador | 1987 | Agroconsa 1 | ATx625 x M-90362 | INTSORMIL/ICRISAT/LASIP |
| Guatemala CB | 1989 | H-887 V1 | TAMU A-line x ICRISAT pollinator | TAMU x LASIP |
| Guatemala CB | 1989 | H-887 V2 | TAMU A-line x ICRISAT pollinator | TAMU x LASIP |
| Guatemala CB | 1989 | H-887 V | TAMU A-line x ICRISAT pollinator | TAMU x LASIP |
| Nicaragua | 1990 | Pinolero 1[2] | ICSV 112 (SPV-475) | ICRISAT/LASIP |
| Guatemala | 1990 | ICTA Jutiapa[2] | Selected from Criollo Peloton | Honduras/CLAIS/LASIP |
| EL Salvador | 1992 | ES 727 | CENTA S-1 x Criollo Sapo | LASIP/CLAIS |
| EL Salvador | 1993 | ES 726 | Selection from M-90894-1-1 | LASIP/CLAIS |
| Nicaragua | 1993[4] | ICSV-LM 86513 | (M-90322 x M-90812)bk-3-1-1-bk | LASIP/CLAIS |

1. CIMMYT = Centro Internacional de Mejoramiento de Maíz y Trigo; CLAIS = Comision Latinoamericano de Investigadores en Sorgo; INTSORMIL = USAID Title XII International Sorghum/Millet Collaborative Research Support Program.
2. Released in collaboration with the LASIP Agronomy Project S-122 (89)IC .
3. ISIAP Dorado is grown on about 20 000 ha in Egypt (J.W. Stenhouse, IAC, personal communication 1992).
4. Release pending.

***Table 3. Area under improved cultivars and estimated value of yield gains under commercial production, Latin American countries, 1993.***

| Country | Total area under sorghum ('000 ha) | Area under improved cultivars[1] | | Value of yield gain[2] (US million $) |
|---|---|---|---|---|
| | | Area ('000 ha) | (%) | |
| EL Salvador | 149 | 29.7 | 20 | 3.86 |
| Honduras | 62 | 18.3 | 30 | 5.00 |
| Guatemala | 55 | 26.7 | 49 | 8.00 |
| Nicaragua | 42 | 8.7 | 21 | 1.40 |
| Total | 308 | 83.4 | 27 | 18.26 |

1. Latin American Sorghum Improvement Program Annual Report, 1993.
2. The value of yield gain obtained by farmers in the above four countries is estimated to be about US $ 18 million in 1993. This is based on a preliminary analysis using very limited data, and should not be considered conservative.

The value of yield gains obtained by farmers from these four countries in 1993 alone is estimated to be about US$ 18.26 million. This compares very favorably with LASIP's average annual research budget of about US$ 0.35 million (C.T. Hash, IAC, personal communication, 1994).

The very limited data so far available allowed some analysis indicative of substantial welfare gains by farmers in these four countries. Approximate direct benefit flow to farmers amounting to US$ 89 million are derived from utilization of new cultivars introduced via the LASIP Program over the past years.

## CLAN Impact Study

The Cereals and Legumes Asia Network (CLAN) was established to enhance exchange of information, materials, and technology in its member countries in Asia. Two surveys have been conducted to assess the contribution of CLAN in enhancing the research capabilities of member countries, in alleviating production constraints and increasing crop production of CLAN mandate crops in Asia. The first survey was a benchmark survey conducted in 1989 to collect basic and descriptive feedback information from participating NARS; the second was a detailed survey undertaken in 1993 to elicit responses from CLAN country coordinators regarding the benefits from specific CLAN activities, as well as changes in yield levels due to technologies introduced via the network. The above surveys collected data for three legume crops—groundnut, pigeonpea, and chickpea.

The achievements of CLAN with respect to its general network activities are:

- Exchange of germplasm and breeding material in the network has been significant. This has resulted in release of 50 varieties, and identification of another 78 promising lines for further tests.
- The training of NARS scientists has helped to enhance the research capabilities of scientists by improved skills and new techniques needed for research.
- Participating countries acknowledged the considerable support of the network in improving interaction and information exchange among scientists.
- The support provided by the network to organize regional meetings and for in-country research activities has been substantial.

Summary responses for the groundnut research and technology transfer activities are as follows:

- The major constraints to increasing yield levels of groundnut are nonavailability of high-yielding varieties (HYV) seeds, incidence of disease, drought, and long duration of crop.
- CLAN's initiatives facilitated the development and adoption of improved high-yielding and disease-resistant varieties, along with efficient agronomic/crop management practices in the Asian NARS.
- Application of new technologies introduced via the network increased yield levels from 5% in Thailand to 25–30% in Nepal.
- A wide range of adoption ceiling levels were reported, e.g., 15–85% in Myanmar and 50–80% in Vietnam.
- Technologies related to the control of insects and pests, and improved agronomic practices yielded high dividends in southern Vietnam, where yield levels increased by 10–20%.
- Various forms of technologies were adopted by the farmers, depending upon the technology transfer program and other supporting activities initiated in the country.

The participating countries under CLAN reported several biotic and abiotic constraints faced by the farmers in the production of chickpea and pigeonpea. Several improved varieties of chickpea and pigeonpea were released to overcome some of these constraints. For chickpea, in addition to improvement in yield, the achievement of yield stability which minimizes risks from diseases, pests, drought, and cold was reported to be significant.

Notable improvement in the productivity in pigeonpea are reported to be due to introduction of improved varieties: yield levels increased from 15 to 37% in Myanmar; 25% in Indonesia; and 10 to 20% in India. Introduction of extra-short and short-duration varieties that reduce the crop period up to 70–85 days has enabled the crop to be grown in nontraditional production systems, and also avoid terminal drought in some countries. In Sri Lanka, pigeonpea is a new crop, and has been introduced quite aggressively by the government as a substitute for imported lentil. The ultimate objective is to save the annual import bills due to imports of lentil, amounting to US$ 28 million.

An indepth impact assessment in CLAN member countries has been identified as a high priority research activity under the Research Evaluation and Impact Assessment (ECON1) Project for 1995–96, to demonstrate the contribution of CLAN activities.

### Seed Sector Study

Two public sector agencies in India, namely: National Seeds Corporation Ltd. and Rajasthan State Seeds Corporation Ltd., were visited, to follow up on seed production performance of ICRISAT mandate crops. Information provided by the National Seeds Corporation for 11 Indian states showed that production and demand of certified seeds is substantially higher for cereals than for legume crops (Tables 4 and 5). It is notable that the share of ICRISAT cultivars in the production of certified seeds is significant in pearl millet and pigeonpea. Pearl millet ICTP 8203 and WC-C75 remain in the top list of certified seed production. The expected demand for both cultivars remains high in the states of Rajasthan, Punjab, Karnataka, Gujarat, and Delhi. Pigeonpea ICPL 87 has performed very well during 1990–94, taking the lead in production in 1994. While the demand for pigeonpea hybrid (ICPH 8) remained relatively low, the demand for and distribution of certified seeds of ICPL 87 was high in the states of Punjab, Gujarat, West Bengal, Karnataka, and Assam. The performance of chickpea ICCV 1, ICCV 2, and groundnut ICGS 44 has been noted to be picking up during the 1993–94 season.

## Market and Policy

### Chickpea Competitiveness in India

While India remains the leading producer of chickpea, its share of world production is declining. Twenty years ago, more than 80% of the world's total chickpea was produced by India; today it produces only about 65%. Chickpea production in India has remained virtually stagnant during the last two decades, compared with other competing crops.

This stagnancy in chickpea production has resulted from a slow growth in productivity and declining area. This is most evident in northern India (Rajasthan, Punjab, Haryana, Uttar Pradesh, and Bihar), which is the traditional chickpea-growing region in India, where competing crops had higher rates of growth in yield and lower yield variability compared with chickpea. With the expansion of irrigation in northern India—favoring high input crop technologies—and the impressive research-led productivity advances in wheat, chickpea's position weakened considerably. Indeed, the decline in chickpea area in India can be attributed entirely to the decline in area in northern India: 1.7 million ha went out of production in this region. The secular decline in chickpea area in the north is likely to continue, as the driving force behind these changes is substitution of crops by more profitable postrainy-season crops such as wheat and rape/mustard under irrigation, which corresponds to a general decline in dryland crop area as irrigation expands (Table 6). Barring any major breakthrough in chickpea productivity to enhance its competitiveness, the overall declining trend in chickpea area is likely continue.

At the same time, chickpea's competitiveness in the central and southern regions appears to have improved. In the central region (Madhya Pradesh and Gujarat), higher prices of chickpea more than offset smaller yield differentials between chickpea and its competing crops. In southern India (Maharashtra, Karnataka, Andhra Pradesh), yield increases and higher prices contributed to better performance of chickpea. Chickpea area in the central and southern regions grew by 860 000 ha during the last two decades. Chickpea cultivation in India appears to be moving southward.

With the population growing by nearly 2% per annum, per capita availability of chickpea has declined sharply–from 23 to 16 g per day since 1971–73. This has led to an overall decline in the availability of total pulses in India, because chickpea is the most important of the pulses. As a consequence, real chickpea prices have risen sharply during the 1970s and 1980s inducing consumers to shift to cheaper substitutes. With chickpea production projected to grow only marginally during the nineties, imports will have to increase significantly (by 1.3 million t) from present levels to meet the demand in 2000. Imports are not likely to close this gap entirely, as the world market for chickpea is relatively small. Rather, prices of chickpea are expected to rise, thereby reducing demand from projected levels. Expanding chickpea production in the short run—sufficient to satisfy future demand in India—without resorting to substantial imports, depends primarily on the rigidity of supply constraints. The question is whether there is a possibility of significantly reducing per unit costs of production in chickpea—primarily by raising yields—which

**Table 5. Certified seed demand from various states, National Seeds Corporation, India 1993–95.**

| Variety | Total expected requirement (t) | Location[1] and quantity (t)[2] AHD | BNG | CAL | CHD | DLI | HYD | GHT | JPR | LKO | PN | PTA | Total expected allocation (t) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1993/94** | | | | | | | | | | | | | |
| Pearl millet | | | | | | | | | | | | | |
| MH 179 | 150 | 20 | 5 | | | 30 | | | | 50 | | | 105 |
| BK 560 | 100 | 20 | 10 | | | 20 | | | 150 | | 120 | | 320 |
| MH 169 | 100 | 10 | | | | 20 | | | 50 | | | | 80 |
| HHB 50 | 50 | | | | | 10 | | | 50 | | | | 60 |
| HHB 60 | 100 | | | | 50 | 10 | | | 50 | 50 | | | 160 |
| HHB 67 | 250 | | | | 150 | 20 | | | 100 | | | | 270 |
| ICTP 8203 | 200 | 20 | | | | 20 | | | 100 | | 100 | | 240 |
| WC C-75 | 100 | 20 | 40 | | | 20 | | | 50 | | | | 130 |
| ICMV 155 | | | | | | 10 | | | | | | | 10 |
| ICMV 221 | | | | | | 10 | | | | | | | 10 |
| RESEARCH HYB | 170 | 10 | | | | 10 | | | 20 | | 20 | | 60 |
| Total | 1220 | 100 | 55 | | 200 | 180 | | | 570 | 100 | 240 | | 1445 |
| CSH 1 | 100 | | 10 | | 2.5 | | | | 5 | | 22.5 | | 40 |
| CSH 5 | 230 | 100 | 40 | | | | | | 10 | | 200 | | 350 |
| CSH 6 | 300 | 50 | 5 | | | | | | 67 | | 120 | | 242 |
| CSH 9 | 400 | 50 | | | 2.5 | | | | 10 | | 220 | | 282.5 |
| SPM 468 | 50 | | | | | | | | | | | | |
| MALDANDI | 100 | 10 | 60 | | | | | | | | 50 | | 120 |
| SPV 86 | 20 | | 20 | | | | | | | | 20 | | 40 |
| Total | 1200 | 210 | 135 | | 5 | | | | 92 | | 632.5 | | 1074.5 |
| Pigeonpea | | | | | | | | | | | | | |
| UPAS 120 | 100 | | 10 | 100 | 5 | 10 | | | | 15 | | 40 | 180 |
| T 21 | 50 | | | | | | | 20 | | | | | 20 |
| ICPL 87 | 200 | 10 | 10 | 20 | | | 5 | 10 | | | 60 | | 115 |
| ICPH 8 | 50 | | 5 | | | 1 | | | | | | 5 | 11 |
| ICPL 151 | | | | | | | | | | 6 | | | 6 |
| Total | 400 | 10 | 25 | 120 | 5 | 11 | 5 | 30 | | 21 | 60 | 45 | 332 |
| Chickpea | | | | | | | | | | | | | |
| Annigeri | | | | | | | 20 | | | | | | 20 |
| G 5 | 100 | 10 | | | | | | | | | 50 | | 60 |
| Chaffa | 50 | 20 | | | | | 30 | | | | | | 50 |
| C 235 | 100 | 20 | 10 | 12 | 50 | 10 | | 10 | 20 | | | | 132 |
| Total | 250 | 50 | 10 | 12 | 50 | 10 | 50 | 10 | 20 | | 50 | | 262 |
| Groundnut | | | | | | | | | | | | | |
| JL 24 | 700 | | 50 | | | | | 150 | 10 | | 20 | 100 | 330 |
| MR 13 | 100 | | | | 10 | | | | | | | | 10 |
| TMV 2 | | | 100 | | | | | | 50 | | | | 150 |
| Total | 800 | | 150 | | 10 | | | 150 | 60 | | 20 | 100 | 490 |
| **1994/95** | | | | | | | | | | | | | |
| Pearl millet | | | | | | | | | | | | | |
| MH 179 | 200 | 25 | 10 | | | 30 | | | 150 | | | | 210 |
| BK 560 | 150 | 25 | 20 | | | 20 | | | 100 | | 120 | | 285 |
| MH 169 | 100 | 15 | | | | 20 | | | 50 | | | | 85 |
| HHB 50 | 50 | | | | | 10 | | | 50 | | | | 60 |
| HHB 60 | 50 | | | | 50 | 10 | | | 100 | | | | 160 |
| HHB 67 | 200 | | | | 200 | 20 | | | 100 | 50 | | | 370 |
| ICTP 8203 | 200 | 20 | | | | 20 | | | 50 | 20 | 120 | | 235 |
| WC-C75 | 100 | 10 | 40 | | | 20 | | | 50 | | | | 120 |

*Continued*

*Table 6. Change in yield between 1971 and 1973, and 1986 and 1988, and variability in yields in 1984 in the irrigated and dryland cropped area of northern and central India.*

| Region in India/ crop | Irrigated area: Change in irrigated yield (kg ha$^{-1}$) | Irrigated area: CV (%) | Irrigated area: Change in gross returns (Rs ha$^{-1}$) | Dryland: Change in dryland yield (kg ha$^{-1}$) | Dryland: CV (%) | Dryland: Change in gross returns (Rs ha$^{-1}$) |
|---|---|---|---|---|---|---|
| **Northern** | | | | | | |
| Chickpea | 154 (20%)[1] | 19.1 | 2997 | 131 (23%) | 22.9 | 2333 |
| Wheat | 1170 (74%) | 7.7 | 3724 | 696 (87%) | 13.9 | 2074 |
| Rape/mustard[2] | 466 (73%) | 11.2 | 3818 | 343 (69%) | 25.7 | 2869 |
| **Central** | | | | | | |
| Chickpea | 28 (4%) | 12.1 | 2331 | –9 (–1%) | 15.8 | 1838 |
| Wheat | 797 (62%) | 12.0 | 3142 | 70 (10%) | 10.3 | 984 |
| Rape/mustard | 521 (90%) | 18.7 | 4517 | 68 (16%) | 24.7 | 1218 |

1. Figures in parentheses are percentage of change in yield.
2. For rape/mustard, irrigated and nonirrigated yields are based on 1974–76 average, since yield data for 1971–73 are not available.

Sources: Government of India (various years). Area and Production of Principal Crops; Fertilizer Association of India 1992. Fertilizer Statistics; Government of India (various years). Farm Harvest Prices in India. All published by Directorate of Economics and Statistics, Ministry of Agriculture, New Delhi, India.

production contracted and became more highly concentrated in Maharashtra. Area losses were primarily in the states of Madhya Pradesh, Andhra Pradesh, Karnataka, and Gujarat, across a wide range of soil and rainfall environments. Expansion in irrigation (favoring irrigated crops), low producer prices, and lagging productivity appear to have contributed in some measure to the weakening competitiveness of rainy-season sorghum over time. Competing crop-based clusters were used to compare growth rates in crop prices and yields for rainy-season sorghum and competing crops. A preliminary analysis suggests that price movements working in favor of crops competing with sorghum had the strongest effect on decreasing the relative area under rainy-season sorghum.

Rainy-season sorghum has maintained its competitiveness (i.e., sorghum area has remained unchanged) in about 30% of the districts; and in another 10%, sorghum area has actually increased. Irrigation growth rates have been lower and sorghum crop yields higher in the latter two groups of districts. The results are consistent with the theory that changes in relative area are positively related to growth in productivity and prices, and negatively correlated with growth in irrigated area. These are certainly not the only factors affecting the relative area under rainy-season sorghum. Sorghum is still a noncommercial crop in many areas and thus, in such places, changes in home consumption requirements may have more to do with reducing or increasing rainy-season sorghum acreage than relative prices. Further, sorghum stover is still a major source of dry roughage for draft and milk animals in the Indian semi-arid tropics. Fodder considerations are as important as grain yield considerations in some areas where rainy-season sorghum is maintaining its competitiveness i.e. sorghum area has either remained unchanged or has increased.

The decline in rabi or postrainy-season sorghum area—more than 1.0 million ha—was less than that observed for rainy-season sorghum, but was still considerable. Clear regional patterns emerged. The vast majority of the districts where relative area under postrainy-season sorghum declined, were located in relatively higher rainfall regions (above 750 mm) of Andhra Pradesh, Tamil Nadu, and eastern Maharashtra. Postrainy-season sorghum is being replaced there by higher-value cereal, pulse, and oilseed crops. Postrainy-season sorghum has maintained or even increased its shares of gross cropped area in a large arid region of the western Deccan Plateau, primarily Maharashtra and Karnataka. This is an area where, due to low and erratic rainfall, few viable crop alternatives exist. Livestock are important here too, and postrainy-season sorghum provides the bulk of the dry roughage to these

***Table 5. Continued.***

| Variety | Total expected requirement (t) | Location[1] and quantity (t)[2] | | | | | | | | | | | Total expected allocation (t) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AHD | BNG | CAL | CHD | DLI | HYD | GHT | JPR | LKO | PN | PTA | |
| ICMV 155 | 50 | | | | | 10 | | | | | | | 10 |
| ICMV 221 | 50 | | | | | 10 | | | | | 20 | | 30 |
| RESEARCH HYB | 350 | 20 | | | | 10 | | | 30 | | 10 | | 70 |
| Total | 1500 | 120 | 70 | | 250 | 180 | | | 680 | 70 | 270 | | 1640 |
| Sorghum | | | | | | | | | | | | | |
| CSH 1 | 100 | | 20 | | 4 | | | | 10 | | 22.5 | | 56.5 |
| CSH 5 | 300 | 120 | 40 | | | | | | 5 | | 200 | | 365 |
| CSH 6 | 400 | 60 | 10 | | | | | | 50 | | 120 | | 240 |
| CSH 9 | 450 | 80 | | | | | | | 10 | | 40 | | 130 |
| SPM 468 | 50 | 100 | | | 4 | | | | | | | | 104 |
| MALDANDI | 150 | | 60 | | | | | | | | 60 | | 120 |
| SPV 86 | 50 | | 20 | | | | | | | | 50 | | 70 |
| CSV 13 | | | | | | | | | | 100 | | | 100 |
| Total | 1500 | 360 | 150 | | 8 | | | | 75 | 100 | 492.5 | | 1185.5 |
| Pigeonpea | | | | | | | | | | | | | |
| UPAS 120 | 100 | | 15 | 50 | 7.5 | 10 | | | | 50 | | 40 | 172.5 |
| T 21 | 50 | | | | | | | 20 | | | | | 20 |
| ICPL 87 | 300 | 20 | 20 | 100 | | | 10 | 10 | | 50 | 60 | | 270 |
| Total | 450 | 20 | 35 | 150 | 7.5 | 10 | 10 | 30 | | 100 | 60 | 40 | 462.5 |
| Chickpea | | | | | | | | | | | | | |
| G 5 | 25 | 20 | | | | | | | | | 25 | | 45 |
| Chaffa | 25 | 20 | | | | | | | | | | | 20 |
| C 235 | 100 | 10 | 20 | | 60 | 10 | | | 50 | | 25 | 30 | 205 |
| Total | 150 | 50 | 20 | | 60 | 10 | | | 50 | | 50 | 30 | 270 |
| Groundnut | | | | | | | | | | | | | |
| JL 24 | 700 | 20 | 40 | | 10 | | | 200 | 10 | | 20 | 100 | 400 |
| MR 13 | 100 | | 70 | | | | | | 100 | | | | 170 |
| Total | 800 | 20 | 110 | | 10 | | | 200 | 110 | | 20 | 100 | 570 |

1. AHD = Ahmedabad, BNG = Bangalore, CAL = Calcutta, CHD = Chandigarh, DLI = Delhi, HYD = Hyderabad, GHT = Gauhati, JPR = Jaipur, LKO = Lucknow, PN = Punjab, PTA = Patna.
2. No data = no demand.

would make it more competitive with wheat and rape/mustard in northern and central regions, and more competitive with sunflower, cotton, pigeonpea, and sorghum in the central and southern regions. Improved technologies are already available to at least double the chickpea yields in many areas.

Much, however, still needs to be done to ascertain which on-farm constraints limit the adoption of new productivity-enhancing technologies in these specific regions.

New production technology in chickpea, if adopted, has the potential to realize significant gains in productivity, lower per unit production costs, and ultimately, ensure relatively lower prices on the market. This would improve chickpea's competitiveness, expand the consumption of traditional chickpea foods, and encourage chickpea substitution for other commodities in new uses. Without such gains in productivity, India will have to rely on imports to satisfy domestic consumption.

## Performance of Sorghum in India

Of approximately 4 million ha of sorghum replaced by other crops during the last two-and-half decades, 3 million ha can be attributed to kharif or rainy-season sorghum. A significant decline in its share of gross cropped area (the 'relative area') occurred in about 60% of the major rainy-season sorghum-growing districts, as the center of

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|---|---|---|---|---|---|---|
| **Northern** | | | | | | |
| Chickpea | 154 (20%)[1] | 19.1 | 2997 | 131 (23%) | 22.9 | 2333 |
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1. Figures in parentheses are percentage of change in yield.
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production contracted and became more highly concentrated in Maharashtra. Area losses were primarily in the states of Madhya Pradesh, Andhra Pradesh, Karnataka, and Gujarat, across a wide range of soil and rainfall environments. Expansion in irrigation (favoring irrigated crops), low producer prices, and lagging productivity appear to have contributed in some measure to the weakening competitiveness of rainy-season sorghum over time. Competing crop-based clusters were used to compare growth rates in crop prices and yields for rainy-season sorghum and competing crops. A preliminary analysis suggests that price movements working in favor of crops competing with sorghum had the strongest effect on decreasing the relative area under rainy-season sorghum.

Rainy-season sorghum has maintained its competitiveness (i.e., sorghum area has remained unchanged) in about 30% of the districts; and in another 10%, sorghum area has actually increased. Irrigation growth rates have been lower and sorghum crop yields higher in the latter two groups of districts. The results are consistent with the theory that changes in relative area are positively related to growth in productivity and prices, and negatively correlated with growth in irrigated area. These are certainly not the only factors affecting the relative area under rainy-season sorghum. Sorghum is still a noncommercial crop in many areas and thus, in such places, changes in home consumption requirements may have more to do with reducing or increasing rainy-season sorghum acreage than relative prices. Further, sorghum stover is still a major source of dry roughage for draft and milk animals in the Indian semi-arid tropics. Fodder considerations are as important as grain yield considerations in some areas where rainy-season sorghum is maintaining its competitiveness i.e. sorghum area has either remained unchanged or has increased.

The decline in rabi or postrainy-season sorghum area—more than 1.0 million ha—was less than that observed for rainy-season sorghum, but was still considerable. Clear regional patterns emerged. The vast majority of the districts where relative area under postrainy-season sorghum declined, were located in relatively higher rainfall regions (above 750 mm) of Andhra Pradesh, Tamil Nadu, and eastern Maharashtra. Postrainy-season sorghum is being replaced there by higher-value cereal, pulse, and oilseed crops. Postrainy-season sorghum has maintained or even increased its shares of gross cropped area in a large arid region of the western Deccan Plateau, primarily Maharashtra and Karnataka. This is an area where, due to low and erratic rainfall, few viable crop alternatives exist. Livestock are important here too, and postrainy-season sorghum provides the bulk of the dry roughage to these animals throughout the year. The major advantage of postrainy-season sorghum is its adaptability to drier and less fertile conditions. Its low-input, low-risk characteristics give it a comparative advantage over maize and other competing crops. Nevertheless, because it is grown in marginal environments under drought stress conditions, average yields have remained low—though higher yields could have been obtained in better-endowed areas.

Demand for sorghum for food consumption is geographically localized in the regions where it is grown. However, even in these regions, sorghum consumption continues to decline, as this crop plays out its role as a staple cereal in the diet of fewer and fewer people. The shift away from this coarse cereal is not the result of supply constraints, but rather a consequence of rising incomes and changing food preferences. Lack of consumer demand has led to a declining trend in prices, which discourages production. The scope for arresting or even reversing this trend depends on the development of alternative uses for sorghum. Here the potential of sorghum for domestic use in feed, starch, and other industries appears good. Prospects for expansion through trade appear promising too. Of course, this depends critically on the competitive position of sorghum relative to maize, which in turn depends on the rates of technical change for these crops. A condition for realizing these potentials, therefore, is significant and sustainable increases in sorghum yields, which can ultimately translate into lower grain production costs.

## Sustainable Sources of Growth

As part of a wider initiative led by the International Food Policy Research Institute (IFPRI), ICRISAT was asked to prepare two background papers for the '2020 Vision Workshop' held in Washington D.C., November 1994. One of these studies focused on Asia (the other on Africa) and included an assessment of: historical trends in key agricultural, sociodemographic and environmental variables; projections for food and feed requirements in the year 2020; and interventions required to realize alternative scenarios of growth and developments. Two agroecological zones in Asia were considered, the arid and semi-arid tropics (AEZ1) and the arid and semi-arid subtropics (AEZ5). AEZ1 in Asia encompasses most of southern, central, and western India (52% of the country) and a very small part of Thailand (6%). AEZ5 covers about 25% of India—mostly in the north, all of Pakistan, and about 15% of China. For purposes of this analysis—largely depending on data availability—only the AEZ1 and AEZ5 in India and Pakistan were considered.

AEZ1 covers an area of about 135 million ha in the eight Indian states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, and parts of Bihar and Rajasthan. The mean annual rainfall ranges between 400 and 1200 mm, and temperatures are above 18°C throughout the year. During the growing season, temperatures remain above 20°C. This region is often characterized as the warm tropics. In contrast, AEZ5, constituting all of Pakistan (116.5 million ha), and the five northern Indian states of Haryana, Punjab, Uttar Pradesh, and parts of Bihar and Rajasthan (totaling 32 million ha), is considered the warm/moderately cool subtropics. Temperatures fall below 18°C for several months of the year; during the growing season however, temperatures are generally above 20°C. Rainfall in this region has a similar range as AEZ1, between 400 and 1200 mm.

Supply and demand projections were made for cereals, pulses, oils, and milk for each region (Table 7). Future demand for these commodities was estimated using the projected growth rates from Radhakrishnan and Ravi (1990) (From Food demand projections for India, Center for Economic and Social Studies, Hyderabad, India). Supply projections were initially made based on 30-year historical trends, and later adjusted by factors likely to affect future growth rates. The future scenario was compared with the current situation.

In conclusion, major gains in production during the last three decades have come about mainly through increased use of inputs such as land (through intensification), water, fertilizers, and other agrochemicals. As resources are limited, and increasingly at risk through degradation, new sources of growth, based on more efficient use of existing inputs, must be found. Information-based technological growth, emphasizing development of human capital and improved management at the field level, offers the best scope to meet the demands of the future. Whereas in the past, a simple strategy of 'more inputs' brought about high agricultural growth, in the future, more judicious use of inputs—particularly water—will be required. No longer will raising land productivity be sufficient. Increasingly, the emphasis must shift to other factors of production to ensure sustainable agricultural growth.

*Table 7. Present production and consumption of cereals, pulses, and oils in AEZ1 and AEZ5, and projections to 2020.*

| Region[1]/ crop | 1986–88 Production Total | Net[2] | Consumption[3] | Surplus (+) Deficit (-) | 2020 Production[4] Total | Net | Consumption[5] | Surplus (+) Deficit (-) |
|---|---|---|---|---|---|---|---|---|
| | ......'000 t...... | | | | ......'000 t...... | | | |
| AEZ1 | | | | | | | | |
| Cereals | 40 716 | 36 644 | 47 690 | –11 046 | 77 988 | 70 189 | 90 608 | –20 419 |
| Pulses | 5 871 | 4 403 | 3 430 | +973 | 13 512 | 10 134 | 8 565 | +1 569 |
| Oils | | 1 656 | 1 606 | +50 | | 3 419 | 4 632 | –1 213 |
| Milk | 21 864 | 18 624 | 18 248 | +376 | 109 390 | 96 263 | 64 033 | +32 230 |
| AEZ5 | | | | | | | | |
| Cereals | 53 941 | 48 547 | 31 810 | +16 737 | 278 491 | 250 642 | 60 437 | +190 205 |
| Pulses | 4 804 | 3 603 | 2 591 | +1 012 | 3 121 | 2 340 | 6 470 | –4 130 |
| Oils | | 486 | 989 | –503 | | 1 622 | 2 854 | –1 232 |
| Milk | 18 479 | 16 261 | 9 796 | +6 465 | 66 568 | 58 589 | 34 375 | +24 214 |

1. AEZ1 = In India, this region covers an area of about 135 million ha in eight states: Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, and parts of Bihar and Rajasthan; AEZ5 = All of Pakistan, and five northern Indian states: Haryana, Punjab, Uttar, Pradesh, and parts of Bihar and Rajasthan.
2. Net production or availability, which accounts for losses from seed, waste, and processing is taken at 90% of total production of cereals and 75% of pulses.
3. Current consumption based on per capita consumption estimates from 43 round of National Sample Survey (1987/88) for states AEZ1 and AEZ5.
4. Based on 1960–88 growth rates in production.
5. Based on Radhakrishna and Ravi (1990) growth rates for the whole of India.

# Fodder, Agricultural Research, and Drought Management

Fodder surveys were carried out during 1990 and 1991 in four villages of Jodhpur district, Rajasthan, two villages in central and southern Maharashtra, and one village in central Andhra Pradesh, all in India. The surveys were conducted to assess the importance of pearl millet and sorghum straw production in meeting farmers' overall production objectives, and to compare 'improved' and traditional cultivars for straw yield and quality. A brief summary of the major findings are given below. All differences stated below are statistically significant.

## Pearl Millet Fodder Survey in Jodhpur during 1990 and 1991

Jodhpur district is located along the Thar desert margin in western Rajasthan, India. Livestock is the backbone of the rural economy in this region, where average annual rainfall is very low, ranging from 300 to 500 mm. Pearl millet is the major cereal crop grown here, and is important not only for its food grain value but for its straw value. Pearl millet based cropping systems predominate, but green gram (*Vigna radiata*), moth bean (*V. aconitifolia*), and guar (*Cyamopsis tetragonoloba*) are the other important crops commonly grown. Green gram, moth bean, and guar are particularly important in the drier, northwestern region of Jodhpur, where two of the four villages sampled are located. The other two villages selected from this district are closer to Jodhpur or to the east of Jodhpur, where rainfall is higher, and other crops such as sorghum, sesamum (*Sesamum indicum*), rape seed/mustard (*Brassica* spp), and wheat (*Triticum* spp) become important. The villages were selected on the basis of rainfall, distance to Jodhpur and accessibility.

**Results of the pearl millet fodder survey**

The results of the Jodhpur survey were as follows:

- The relative importance of straw yield varies, depending on the rainfall during that year. In a good-to-normal rainfall year, on average, only 5% of farmers considered straw yield to be more important than grain yield. But in a low-rainfall year, 55% thought so. There is no significant difference in farmer perception across the four villages (Table 8).
- Farmers' perceptions about straw yields of traditional vs improved pearl millet cultivars vary depending on the rainfall during that year. Most farmers (85%) believe that traditional varieties produce less straw than improved cultivars in a good-to-normal rainfall year. In a low-rainfall (or drought) year, however, the reverse is true. Once again, there is no significant difference in farmers perceptions across the four villages.
- With respect to probability of rainfall, farmers in all four villages expect that in 50% of the years (or more), low rainfall or drought is likely to occur (Table 9). In the two villages where traditional varieties are still popular (the drier, northwest part of the district), farmers indicate that improved cultivars are not adopted primarily because of poor grain and straw yield performance in low rainfall (dry) years. Another reason cited is inferior grain and straw quality associated with the improved cultivars. However, $F_2$ and $F_3$ generation hybrids, as opposed to $F_1$ hybrids, are being grown in these villages as they seem to reduce the risks associated with low grain and straw yields in dry years. The $F_2$ and $F_3$ generation hybrids also seem to be more acceptable in terms of grain and straw quality. In some cases, third and fourth generation hybrid seed has been labeled 'desi', i.e., local. In Pichayak and Doli villages where more irrigation facilities exist and where production conditions are better, use of new hybrids is common.
- Approximately 90% of the farmers surveyed across the four- village sample are of the opinion that traditional cultivars have superior straw quality over improved cultivars. Improved cultivars have thicker stems and are usually fed to animals only after chopping. There is also considerable wastage of straw associated with them.

***Table 8. Farmers' perceptions on the relative importance of pearl millet straw yields in a normal rainfall and low-rainfall year in four villages of Jodhpur district, Rajasthan, India.***

| Village | Normal rainfall | | | Low rainfall | | | Sample size |
|---|---|---|---|---|---|---|---|
| | Grain > straw[1] | Grain = straw | Grain < straw | Grain > straw | Grain = straw | Grain < straw | |
| | (%) | | | | | | |
| Baleswar | 10 | 90 | 0 | 20 | 40 | 40 | 20 |
| Ramalwara | 10 | 86 | 4 | 24 | 38 | 38 | 21 |
| Doli | 6 | 84 | 10 | 11 | 26 | 63 | 19 |
| Pichayak | 25 | 70 | 5 | 5 | 10 | 85 | 20 |
| Average | 13 | 83 | 5 | 15 | 29 | 56 | 80 |

1. > more important; = of equal importance; < less important.
Source: ICRISAT/CAZRI Fodder Survey, 1990.

Table 9. Farmers' perceptions on rainfall probability in four villages of Jodhpur district, Rajasthan, India.

| Village | No. of years out of 10[1] | | | |
|---|---|---|---|---|
| | Good rainfall year[2] | Normal rainfall year | Low rainfall year | Drought year |
| Baleswar | 2.0 | 2.2 | 3.5 | 2.6 |
| Ramalwara | 1.7 | 2.9 | 2.6 | 2.8 |
| Doli | 1.9 | 2.8 | 3.3 | 2.1 |
| Pichayak | 2.0 | 2.8 | 2.8 | 2.9 |
| Average | 1.9 | 2.7 | 3.1 | 2.6 |

1. Mean value averaged across village sample.
2. Farmers were asked to classify rainfall with reference to crop yield, as follows: Good rainfall year: good or high yields; Normal rainfall year: average yields; Low rainfall year: low yields; Drought year: zero or negligible yields.
Source: ICRISAT/CAZRI Fodder Survey, 1990/91.

Of five straw quality characteristics presented to farmers (leafiness, thin stem, color, height, and sweetness), thin stem is considered the most preferred in all four villages. In two of the four villages, however, leafiness and (light) color, along with thin stem, are considered the most important characteristics. Sweetness, the only nonvisible quality characteristic, is the least preferred.

### Fodder management

In all four villages, farmers are of the opinion that feed availability and quality have declined over time. The major reasons cited are: decline in fallow land (an important source of forage) due to increased cropping; increased use of hybrids (particularly in two of the villages); decline in common grazing lands and permanent pastures due to encroachment; low rainfall in recent years; overgrazing; and a decline in the number and productivity of tree crops–which provide fodder to sheep and goats. Generally, farmers reduce the number of their animals in order to cope with changing situations. Most farmers now use tractors rather than bullocks and the number of cows and buffaloes have declined, mainly due to frequent droughts. During the 1987 drought, almost all farmers in the four villages sampled purchased some straw or fodder. These were supplied from neighboring states. Supplies, however, were insufficient, resulting in a reported 30–60% mortality rate among livestock in the four villages.

## Sorghum Fodder Survey in Maharashtra and Andhra Pradesh, India, during 1991

Three ICRISAT benchmark villages were selected for the sorghum survey: Aurepalle village in Mahabubnagar district, located in the relatively dry and shallow red soil region of southern Telangana, Andhra Pradesh; Kanzara village in Akola district, located in the medium-to-deep black soil and assured rainfall region of Vidharba, Maharashtra; and Shirapur village in Sholapur district, located in the heart of postrainy season sorghum-growing tract on the Deccan Plateau, characterized by deep-to-medium deep Vertisols with low and unstable rainfall. In Aurepalle and Kanzara villages, sorghum is cultivated during the rainy season. Postrainy season sorghum is predominantly cultivated in Shirapur village.

## Results of the sorghum fodder survey

- In Aurepalle, only 5% of the farmers interviewed indicated that grain yield was a more important consideration than straw yield. The majority felt that grain and straw yield are equally important. This was true in both good-to-normal and low-rainfall years. Traditional sorghum varieties are predominantly grown in Aurepalle. In Kanzara, where hybrids have replaced traditional varieties, about 40% of the farmers indicate grain yield to be the overriding criterion. Again, this is true irrespective of the rainfall during the year. Straw yield, however, is also important. Another 40% indicate that straw yield is more important than grain yield. Further studies are necessary to identify and attribute preferences to specific farmer characteristics. In Shirapur village, only 15% of those interviewed consider grain yield to be more important than straw yield, and this was only in good-to-normal rainfall years. None feel grain yield is more important than straw yield in a low-rainfall year. While in good-to-normal rainfall years, 85% indicate grain and straw yield to be equally important, in low-rainfall years, almost half indicate that straw yield is most important. Shirapur receives the lowest rainfall of the three villages sampled, and, as with the case of pearl millet in Rajasthan, farmers tend to give greater relative importance to straw in drier environments.
- In Aurepalle village, farmers perceive traditional cultivars to be superior to improved cultivars with respect to straw yield, both in good-to-normal and low-rainfall years. In Kanzara village, traditional cultivars are rarely grown. Farmers are, however, aware of differences in straw yield performance of hybrids vs improved varieties. Straw yield of improved varieties is considered superior to that of hybrids both in normal and low-rainfall years. Only in Shirapur village do farmers indicate a significant difference in straw yields of traditional vs improved cultivars. Straw yields of traditional cultivars are considered superior only in a low-rainfall year; the reverse is true in good-to-normal rainfall years.
- In Aurepalle village, no single reason stands out as most important for the nonadoption of improved cultivars. Low grain and straw yield in a low-rainfall year and poor grain and straw quality in general seem to be equally important in the failure of the spread of sorghum hybrids. In Shirapur village, poor straw quality of hybrids is the most important reason given for nonadoption. Low grain and straw yield in low-rainfall years, and poor grain quality are the next most important reasons for not growing hybrids.
- In Aurepalle and Shirapur villages, 85–100% of the farmers are of the opinion that straw quality of traditional varieties is superior to hybrids. In Kanzara village, 90% of the farmers perceived straw quality of improved sorghum varieties to be superior to that of hybrids.
- Of the six straw quality characteristics presented to farmers (thin stem, leafiness, color, height, sweetness, and hardness of stem), farmers in both Aurepalle and Kanzara perceive leafiness to be the most important quality characteristic in sorghum (Table 10). Farmers are generally of the opinion that leafiness increases palatability. Thin stem is the next most important quality preferred by farmers. Color (lighter) and height (medium tall), are next in importance. Sweetness and hardness of stem were the least important. For postrainy season sorghum in Shirapur village, leafiness is also the most preferred quality. Color (lighter, with a tinge of green) and medium height are next in importance. Thin stem and hardness of stem were ranked lowest.

***Table 10. Farmers' preferences for sorghum straw quality characteristics[1] for three ICRISAT benchmark villages in Maharashtra and Andhra Pradesh in India.***

| Village | Thin stem | Leafiness | Color | Height | Sweetness | Hardness |
|---|---|---|---|---|---|---|
| Aurepalle | 2 | 1 | 3 | 4,3 | 4 | 4 |
| Shirapur | 3 | 1 | 2 | 2 | - | 3 |
| Kanzara | 2 | 1 | 4,3 | 3,2 | 4 | 5 |

1. Based on Friedman's two-way analysis of variance by ranks. Same rank indicates no significant difference in preference for particular straw quality characteristics (1 = most preferred; 5 = least preferred).

Source: ICRISAT Fodder Survey, 1990.

## Fodder management

About 80% of the farmers interviewed in Aurepalle village indicated that their animal numbers had declined in the last 10 years. Labor problems and shortage of fodder, particularly during dry years, are the main reasons given for this phenomenon. Crops such as cotton and castor have partially substituted for sorghum and pearl millet—important sources of livestock feed. To some extent, this has been offset by an increase in paddy straw due to an expansion in area under irrigation. Paddy straw now competes with sorghum as the most important source of animal feed in the village. Grazing land too has declined due to land redistribution, further accentuating the problem of fodder scarcity. A few large farmers have responded by increasing the area under irrigated green fodder crops such as paragrass, lucerne, and forage sorghum.

In contrast, in Shirapur village about 60% of the sampled farmers increased their animal numbers, particularly milch animals, during the last 10 years. This occurred, according to farmers, despite changes in the availability of sorghum straw—the main source of feed. Many farmers felt that sorghum straw yields had actually declined due to poor rains during the last 5 years. Grazing land too, appears to have declined due to government-introduced social forestry schemes. The question, therefore, remains where the extra feed came from. Area under cultivated fodder crops has increased due to expansion of irrigation facilities. Also, the sale of cultivated fodder crops within the village has increased.

In Kanzara village, only 5 of the 20 farmers interviewed had reduced their animal numbers in the last 10 years. For the remaining 15, no significant change in animal numbers had occurred. Sorghum straw continues to be the most important source of animal feed, though its area is declining. With the introduction of canal irrigation in the village, double cropping increased. The net effect of this has been to reduce the area under fallow land, an important source of feed for livestock. This has been offset somewhat by an increase in the area sown to pigeonpea and wheat. Of all the fodder sources available, leaves of pigeonpea are considered the most nutritious and thus, most preferred. Wheat straw is considered inferior to sorghum straw and is generally sold outside the village. This indicates that the fodder shortage problem may not be very severe. As in Shirapur, government social forestry programs are partly responsible for the decline in area under common grazing land.

# Farmers' Participatory Research

## Pearl Millet Study in Rajasthan

In contrast to 1993 which was a drought-stress season in most of Rajasthan, 1994 had normal levels of rainfall, and good-to-excellent distribution of rains for most farmers, particularly in western Rajasthan. The on-farm trial locations in Jodhpur, Bikaner, and Barmer districts were continued this season. In order to evaluate farmers' preferences for varietal characteristics in a wider range of west Rajasthan environments, additional sites were included in Churu, northwest Jodhpur, and in eastern Barmer districts.

Twenty farmers participated at each location (five farmers/genotype). The genotypes used during 1994 represent the following range of characteristics: HHB 67: very early maturity, tillering, small panicles; E Raj Pop 91: early maturity, high tillering, improved local variety; CZ-IC 912: medium maturity, low tillering, large panicles; ICMH 90852: medium maturity, high tillering, medium-sized panicles.

Seed was distributed to participating farmers in June. Village investigators visited each plot on a biweekly basis, taking measurements on crop growth. Midseason and preharvest evaluations were conducted collaboratively by ICRISAT staff, local contact people from the collaborating NGO/GO, and village investigators. These evaluations included discussions on differences in crop growth and characteristics between the experimental variety and the farmer's own variety. Unfortunately, the final evaluation was cut short due to the incidence of plague in northern India. Farmers harvest operations were also severely affected. Postharvest evaluations of grain and fodder quality preferences were conducted in winter.

In addition to the on-farm preference studies, demonstrations of a wide range of varieties and fertility trials were conducted at the Krishi Vigyan Kendra (farmer training center) farm at Bharka, Barmer. The fertility trials included the same varieties as the on-farm trials, fertility levels, and timing of applications. The purpose was to expose the farmer to different genetic materials and to other options for fertility management in the Barmer environment.

In Ajmer district, the previous on-farm trials were followed by the sale of 5 t of seed of the most preferred variety RCB-IC 911. The purpose was to make available a significant quantity of seed this season, to be able to track its spread through informal channels. Farmers purchased the seed at Rs 10 $kg^{-1}$, slightly more than the market price for local millet variety.

### Farmers' Participation in Watershed Management Program

(GTZ-funded collaborative project with the Hohenheim University, Germany)

Watershed management programs which involve soil and water conservation (SWC) measures such as field and contour bunding, gully plugging, percolation tanks, check dams, and tree plantations are receiving increasing attention and funds in India, both from the governmental and nongovernmental sector. Several such programs have been implemented over the last decade, but few of them have achieved sustainable results. One of the reasons for this is the lack of farmers' participation in constructing and maintaining SWC structures.

This study was intended to analyze farmers' perspective of SWC measures in order to understand their motivation for participating or reason for not participating in the programs. It was hypothesized that farmers will only invest cash or labor for SWC measures, if their perceived private benefits exceed the expected private costs. Costs include not only monetary costs, but also the social costs of collaboration, which can be considerable, depending on various social factors such as conflicts over ownership and control of resources.

Information about the project history and the institutional approach, as well as secondary data from the project villages were collected from 13 watershed management (WSM) projects in the states of Andhra Pradesh, Maharashtra, Karnataka, and Tamil Nadu in 1994. This was followed by discussions with different groups of farmers in each village, and by semi-structured individual interviews, using visualization aids.

While the analysis of the collected information is still going on, some preliminary conclusions can be drawn about factors associated with 'success' (here it means sustainability of SWC measures) or 'nonsuccess' of WSM projects. Important factors are summarized in Table 11. Other associated factors include: (i) emphasizing awareness creation and training, (ii) including income-generating components in the project design (e.g., raising poultry, aquaculture, processing of local raw materials, credit groups), and (iii) involving the landless labor by assuring that they have a stake in the improved or newly created resources.

The major constraints that were observed are:

- location and design of SWC structures that are not in line with farmers' objectives (leading to neglect or destruction of these structures);
- full subsidies for the implementation of SWC structures (resulting in farmers agreeing to or choosing technologies that assure the maximum days of wage labor without meeting farmers' objectives), and
- farmers perceive the benefits of SWC to be marginal, and prefer to invest in other activities.

Regarding the distribution of benefits from SWC measures, the pattern observed was (order of beneficiaries from most to least):

- those who have wells near recharge/percolation structures and land that has been improved through soil conservation,
- those who have wells and land that has been improved through soil conservation,
- those who have no wells, but land that has been improved through soil conservation,
- others (landless and marginal farmers: more employment, all: more firewood and fodder)

Watershed management projects can thus contribute to an increase of existing inequalities, as those who already have more also benefit more. Resources that are improved, increased, or newly created through SWC measures financed by government or other agencies are generally not considered community assets, but are viewed to belong to whoever owns the land where they accrue.

## Gender Issues

### Gender Perspective to the Pest and Disease Management of Groundnut Crop

After studying the gender roles and responsibilities in a crop substitution situation in Kolar district of Karnataka, India, a diagnostic study was conducted in Mittemari village, to find out the constraints faced by the farmers in groundnut production, as it was planned to introduce a suitable technology with a gender perspective to overcome the key constraints identified by men and women farmers.

*Table 11. Factors associated with success or nonsuccess of watershed management projects.*

| Factor | Underlying principle | Result |
|---|---|---|
| High contributions (in cash or kind/labor) from farmers for soil and water conservation measures. | Farmers invest only if they are convinced that the investment contributes to achieving their objectives (e.g., income increase or stabilization). | Farmers are interested in maintaining structures in which they invested. |
| Strong local institutions. | Local institutions are essential to enforce commonly agreed rules and regulations relating to soil and water conservation (such as social fencing of grazing land and forests), as well as to resolve conflicts within the community. | Functioning local institutions can take over management responsibilities, once the external project support is withdrawn. |
| Incorporation of indigenous knowledge and ideas into project design. | Local technologies are generally more suitable to meet farmers' multiple objectives and are more cost-effective. | Farmers will maintain structures that fit into their environment and that can be maintained locally at low cost. |

The general thrust of these trials was to give them a 'gender perspective'—in order to assess the likely impacts of such interventions on the women's labor allocation, their access to knowledge, resources, and decision-making.

The diagnostic study highlighted pest and disease problem as one of the key constraints faced by farmers in groundnut production. Both men and women farmers stated this as an important constraint, resulting in considerable groundnut yield losses. A quick survey was conducted to identify the most serious pest and disease problems. Handbooks prepared by ICRISAT scientists were used for identification and ranking in the order of importance of the problem by both men and women.

Leaf spots and leaf miner emerged as the major problems in the ranking. After discussing this problem with the ICRISAT entomologists and collaborators from the Central Research Institute for Dryland Agriculture (CRIDA), it was decided to conduct on-farm farmer-managed research trials to introduce leaf miner and leaf spot management practices, as it was found that farmers were not using any methods to control this problem.

The group discussions held with men and women farmers revealed the reasons for not adopting any control measures. The reasons given by the men's group were: lack of awareness regarding control measures and their benefits; with the major constraints being water, sprayer, and finance. The reasons given by the women's group were: lack of awareness regarding control measures, type of chemicals, etc., other farmers not adopting any control measures, and ignorance and illiteracy of the farmers.

## On-farm Trials: Approach and Selection of Cooperators

On-farm trials were conducted on groundnut farms of 14 farm households of Mittemari village in Kolar district, Karnataka, during the 1993 rainy season. These farm households were selected from a larger sample of 57 groundnut-growing households who earlier constituted the sample for socioeconomic surveys, pest and disease surveys, and gender analysis. The criteria for selection of these 14 households were their willingness to participate and cooperate with the trials, willingness of women members to participate along with the male members, women-headed households, farm size, location of the farm, and area under groundnut crop.

We carried out the trials only during the 1994 rainy season, purely under rainfed conditions. Formal surveys, group meetings with men and women farmers, and participatory rural appraisal (PRA) exercises were conducted to record the participation of men and women, and 'knowledge tests' were conducted to ascertain the extent of their understanding, regarding the trials process and the recommended management practices.

The aim of the trials was to introduce appropriate control measures to reduce the perceived yield losses in such a way that the costs incurred on control measures can be more than compensated by the returns from prevention, reduced yield losses caused by leaf miner and leaf spot. The management strategy evolved by the crop protection scientists was thus based on the philosophy of integrated pest and disease management. The strategy therefore, was to educate the farmers about the pest and disease cycles, timing to minimize spraying, and to make spraying more effective. It was decided to introduce minimum spraying, as the farmers do not practice any control at all, and this could be the most effective strategy to control the pest and disease. In addition to this, the farmers were instructed about the precautions to be taken and harmful effects of the chemicals if proper care was not taken. Women farmers were given special instructions about preserving the chemicals for the next spray and other precautions, as they are generally responsible for carrying water, mixing the spray, and cleaning the containers used for spraying.

## Gender perceptions of the trials

At the end of the trials, a knowledge test, with the use of flash cards was conducted on the participating men and women farmers separately to assess their understanding of the trials. Individual and group opinions were gathered regarding the trials and their usefulness as a whole. These results are presented in Tables 12, 13, and 14.

***Table 12. Identification of pests and diseases (from ICRISAT handbook) by men and women farmers during on-farm trials conducted on groundnut farms of 14 farm households during 1993, in Mittemari village, Karnataka, India.***

| | No. of farmers who were able to identify the pest and disease prevalent in their fields | | | |
|---|---|---|---|---|
| Category of farmers | Able to identify all | Able to identify at least two | Able to identify at least one | Could not identify any |
| Male | 11 | 1 | - | 1 |
| Female | 4 | 2 | 4 | 4 |

***Table 13. Identification of pesticide and fungicide used in the on-farm trials conducted on groundnut farms of 14 farm households during 1993, in Mittemari village, Karnataka, India.***

| | No. of farmers who could identify which chemical to be sprayed on which subplot | | | |
|---|---|---|---|---|
| Category of farmers | Could identify all three correctly | Could identify at least two correctly | Could identify at least one correctly | Could not identify any |
| Male | 7 | 1 | 5 | - |
| Female | 6 | 1 | 3 | 4 |

***Table 14. Matching color of the tags, pest and disease, pesticide and fungicide (used for experimental plots), by men and women farmers during on-farm trials conducted on groundnut farms of 14 farm households during 1993, in Mittemari village, Karnataka, India***

| | No. of farmers who could match the colour of the tags with pest and disease, and in turn with pesticide and fungicide | | | |
|---|---|---|---|---|
| Category of farmers | Could match all correctly | Could match at least two correctly | Could match at least one correctly | Could not match any correctly |
| Male | 7 | - | 3 | 3 |
| Female | 4 | - | - | 10 |

The knowledge test showed that men were able to understand the trials better than women. However the difference in their performance varied from question to question. Questions related to pest and disease identification, and pesticide and fungicide identification were answered comparatively better by women. However, they found it difficult to answer the questions related to pesticide and fungicide identification, and matching these to their corresponding pest or disease problem or to the right experimental plot. This indicates their low level exposure to technical information in general, and despite their direct involvement in this experiment, they were still conditioned by their initial drawbacks. It also suggests that women had very little interaction with men in their households on this aspect. There was also a feeling among men that they should be the prime recipients of technology as they believed they are the managers of their farms.

At the end of the experiment, men and women farmers were asked to give their opinions about the usefulness of the trials. While a majority of women could not make out the difference between the control plots and experimental plots in their performance, a majority of the men had a positive opinion about the usefulness of such a management strategy (Table 15).

It was found that these trials managed to create an awareness and a sense of involvement among women. They felt committed as they were approached to participate in the trials along with men which was not the case in any of the technology interventions cases earlier. It was encouraging to note that it created a lot of enthusiasm among women to participate more and more in such activities, and they were ready to organize themselves to overcome any constraints such as finding a sprayer, to participate in the trials.

Women were found to be performing all the complementary activities (carrying water, mixing the chemical, etc.) related to crop protection, except the actual spraying. Involving them in the management of pest and disease on a sustainable basis might prove to be beneficial both in terms of productivity and resource allocation.

***Table 15. Perceptions of men and women farmers regarding effects of spraying on groundnut crop, at the end of on-farm trials conducted on groundnut farms of 14 farm households during 1993, in Mittemari village, Karnataka, India.***

| Perceptions of farmers regarding effects of spraying | No. of households reported | |
|---|---|---|
| | Men farmers | Women farmers |
| Pests and diseases under control (60–70%) in experimental plots. | 7 | 1 |
| More yield in experimental plots. | 4 | 2 |
| No differences between control and experimental plot. Appearance of crop is good in experimental plots. | 5 | 3 |
| Unable to identify any differences. | 1 | 9 |

# Food Security Indicators

## Developing Alternative Indicators of Chronic Household Food Insecurity

This research note presents results from a study designed to identify alternative indicators of chronic household food insecurity in the Indian semi-arid tropics (SAT). A need for alternative indicators exists since many conventional indicators (such as household income or dietary intake) are often too cumbersome to be of practical use in targeting basic needs. Alternative indicators should be statistically reliable, yet straightforward to collect and analyze. This note reports on some potential indicators and tests the indicators in a targeting simulation.

## Indicator Concepts

An indicator should be accurate at identifying food insecure households. Two important concepts related to the identification of indicators are errors of inclusion and errors of exclusion. For this paper, an error of inclusion is one associated with identifying a household as food insecure when in fact it is not. Conversely, an error of exclusion is one associated with identifying a household as not being food insecure when it really is. Table 16 illustrates these concepts.

A successful indicator will have low errors of inclusion and exclusion. A common practice in the epidemiological literature is to minimize the sum of the errors of inclusion and exclusion. This method, however, gives equal weight to each type of error. An alternative method uses a measure of undernutrition that allows us to vary the severity of this tradeoff through the choice of an appropriate 'sensitivity' parameter. One such measure is the Foster, Greer, and Thorbecke (1984) (FGT) poverty measure, $P_\alpha$. $P_\alpha$ is defined as:

***Table 16. Errors associated with classifying households as food insecure, using an alternative indicator.***

| | Assessment by an accepted indicator of food security[1] | |
|---|---|---|
| Type of household | Food insecure households | Food secure households |
| Households identified as food insecure using the alternative indicator | A | B |
| Households identified as food secure using the alternative indicator | C | D |

1. Error of exclusion: C/(A+C); Error of inclusion: B/(B+D).
A = Overlap between the results given by the alternative and accepted indicators.

$$P_\alpha = 1/n \sum_{i=1}^{q} (1-y_i/z)^\alpha$$

where $y_i$ is the caloric adequacy of household i, z is the caloric adequacy cutoff which determines food insecurity (e.g., 80% of caloric adequacy), q is the number of households below this cutoff, and n is the total number of households in the sample. Alpha indicates the degree to which policy makers care about severe undernutrition; a high alpha indicates a heavier weight placed on severe shortfalls in caloric adequacy. A high value of $P_\alpha$ therefore means a high degree of food insecurity in the sample.

The FGT measure can be used to obtain a measure of the effectiveness of an alternative indicator. In this report, we use the FGT measure in simulation to measure the effectiveness of an alternative indicator for poverty targeting. Two scenarios are compared. Under the first scenario, the simulation distributes a fixed food transfer to the households that the alternative indicator identifies as food insecure. Then, the algorithm assesses the level of food insecurity in the sample using the FGT formula.

The second scenario provides a benchmark against which the performance of the alternative indicator may be evaluated. The second simulation is run without any targeting in place; the fixed-sized food aid transfer is divided among all households on a per capita basis. We then calculate the number of calories needed to achieve the targeted $P_\alpha$ with the untargeted transfer. The performance of each indicator is then expressed in terms of the calories saved by using the alternative indicator to target the food distribution. This gives an indication of the improvement expected by making use of an alternative indicator.

## The Alternative Indicator Study

To identify alternative indicators and to field-test their validity and reliability, qualitative and quantitative data were collected over three rounds in 1992–93 from 324 households in south-central India. We collected dietary recall data twice in each round to establish a food security benchmark against which to test the alternative indicators. The dietary data were used to identify households as chronically food insecure.

We tested conventional and alternative indicators of food insecurity against these benchmarks. Conventional indicators included total household expenditures and the share of the household budget spent on food. Alternative indicators tested include household size, number of unique foods consumed, and frequency of food purchase. Many of the alternative indicators were drawn from sets of biological and socioeconomic information that are typically collected by international or national research stations. Additional alternative indicators were based on a review of the food security literature as well as extensive qualitative work in the study sites.

The performance of the conventional and alternative indicators was evaluated using overlap analysis in conjunction with a targeting simulation. Overlap analysis essentially asks: what percent of households or individuals possessing a certain indicator characteristic are also food insecure households or individuals (Table 16). As described above, the targeting simulation tests the ability of these indicators to correctly target benefits to the food insecure, and to exclude those that are food secure.

Overlap analysis revealed that the following indicators were successful in identifying *chronically* food insecure households:

## Alternatives

- High household dependency ratio;
- ~~village the household is located in;~~
- household contains at least one child with diarrhea;
- household purchases many foods on a daily or weekly basis;
- household purchases grain daily or weekly;
- poor quality of drinking water in summer ($r^3$) and monsoon ($r^1$)
- households frequently substituting oilseeds for oil;
- households containing working women who have young children;
- households with a high dependency ratio and a low number of owned plots;
- households with a high dependency ratio and a low number of good quality plots;
- households with a high dependency ratio and a low number of agricultural wage workers in household;
- households with a high dependency ratio and a low number of income sources in household; and
- households with a high dependency ratio and have taken a food loan within the last 4 months.

## Conventional

- High share of household expenditure on food;
- low per capita household expenditure; and
- low per capita household food expenditure.

The overlap analysis only tells us whether an indicator is successful at identifying the food insecure. It does not tell us how many *false positives* are included in the group identified by the alternative indicator or the number of *false negatives* that have been excluded from the identified group. A complete assessment of an indicator therefore requires some analysis which penalizes an indicator which (1) incorrectly identifies a household as food insecure which it is truly food secure, and (2) excludes households which are truly food insecure.

The targeting simulation using the FGT measure achieves this. Specifically, $P_\alpha$ will decrease when food insecure households are identified by the alternative indicator and are given a transfer of calories (correct identification; see A in Table 16). This has the effect of 'rewarding' an indicator for correct identification. $P_\alpha$, however, does not decrease when food insecure households have been incorrectly excluded from the targeted sample (Table 16—C; false negatives). Further, $P_\alpha$ will not decrease when food secure households have been incorrectly identified for targeting (Table 16—B; false positives). In fact, $P_\alpha$ may rise due to the misallocation of food aid calories to *false positives*. The latter two situations have the desired effect of 'penalizing' an indicator for poor identification.

The food aid simulation was used to test 16 indicators that were successful in the overlap analysis. Two scenarios were tested, one with a food aid transfer of 100 000 calories, and another with a transfer of 50 000 calories (Table 17). Of the 16, 13 provided positive savings over the nontargeted transfer of 100 000 calories. Of these 13, only seven provided savings of 15% or more. The targeting is significantly improved if a smaller food aid transfer

***Table 17. Calories saved by using various alternative indicators of chronic household food insecurity as targeting tools.***

| Indicator | Transfer of 100 000 calories | | Transfer of 50 000 calories | |
|---|---|---|---|---|
| | Savings from indicator targeting | | | |
| | Calories | Transfer (%) | Calories | Transfer (%) |
| High dependency ratio 4: (number of children + number of preschoolers)/number of nonpreschoolers in household | 13 087 | 13 | 11 524 | 23 |
| High dependency ratio 8: (number of preschoolers)/(number of nondisabled individuals in household) | 14 844 | 15 | 12 598 | 25 |
| High dependency ratio 3: (number of disabled individuals in household)/ household size | 22 462 | 22 | 15 430 | 31 |
| Household located in Kanzara (round 1) | –18 652 | –19 | –4 687 | –9 |
| Household located in Shirapur (round 1) | 33 009 | 33 | 20 216 | 40 |
| High share of budget on food | 15 528 | 16 | 13 771 | 28 |
| Low per capita total expenditure | –3 472 | –3 | –1 268 | –3 |
| Low per capita food expenditure | 2 344 | 2 | 4 786 | 10 |
| High number of weekly food purchases | 8 692 | 9 | 7 326 | 15 |
| Purchases grain daily or weekly | 22 853 | 23 | 15 235 | 30 |
| High number of foods consumed from in-kind sources/own production | 7 228 | 7 | 7 618 | 15 |
| High dependency ratio 3 and low number of plots owned by household | 12 208 | 12 | 12 500 | 25 |
| High dependency ratio 10 (household size/household size-number of disabled household members) and number of plots owned or leased by household | 15 430 | 15 | 12 989 | 26 |
| Household had at least one child with diarrhea in last 7 or 14 days | 196 | 0.2 | 4 396 | 9 |
| Household had at least one woman reporting three illness symptoms in last 7 or 14 days | –20 604 | –21 | 4 201 | 8 |
| Poor quality water source: community well or community tap | 11 719 | 12 | 8 399 | 17 |

is used. The second column in Table 17 illustrates this result. Of the 16, 11 indicators show savings of 15% or more. The improvement in savings occurs because the number of calories to be distributed are much fewer. In a nontargeted situation, a smaller pool of food aid resources results in a smaller per household transfer.

Note that in both targeting scenarios, not all indicators that performed well in the overlap analysis do well in the simulation. Low per capita expenditure, for example, or the location indicator for the village of Kanzara, actually show negative savings over the nontargeting situation. This is because the indicator in question correctly identifies a large percentage of the food insecure, but in doing so it includes a large number of households that are truly food secure. The latter households are undeserving beneficiaries of the food aid transfer and the resources are wasted. Accordingly, the simulation reports that targeting with an alternative indicator is actually worse than, or costs more calories, than not targeting at all, and distributing food aid on a per capita or per household basis.

The study concludes that

- alternative indicators are viable and show promise in targeting food aid to the food insecure;
- targeting with a bad alternative indicator can be worse than no targeting at all;
- targeting with a good alternative indicator can provide savings for programs over and above a situation of no targeting; and
- savings will depend on the costs of collecting and acting on the alternative indicator as well as the ability of the indicator to correctly identify the food insecure.

SACD

# Soils and Agroclimatology Division

*The Organization and Management Review changes resulted, among others, in the creation of the Soils and Agroclimatology Division (SACD), with a global mandate of research on natural resources. The research areas of the Division include Agroclimatology, Soil Chemistry, Soil Physics and Soil Biology. Among the research themes identified under the Medium-term Plan (MTP), 28 themes call for the participation of SACD scientists. These themes were consolidated into three superthemes, i.e., characterization of production environments, integrated nutrient management, and soil and water conservation/management, with focus on both sustainability and productivity.*

***Characterization of production environments:*** *The production system (PS) was conceptualized as a geographic area defined by a set of environmental characteristics and their characteristic farming system(s). The PS working party identified a formal set of descriptors for PSs that contain four elements: geographical description, detailed description of physical environmental resources, description of key elements in the major farming systems and the list of the constraints to improving the productivity of the PS. Using tools such as Geographic Information System, it is possible to link different data bases on area and production of different commodities, soils, climate, socioeconomic factors, and biotic/abiotic constraints to provide a comprehensive characterization of PSs.*

***Integrated nutrient management:*** *Nutrient resources in the soils of SAT are continuously being depleted due to increased intensity of cropping without effective fertility restoration. Integrated nutrient management strategies that emphasize efficient cycling of nutrients among crops, animals, and soil help us optimize the nutrient inputs and maintain/enhance the resource base.*

***Soil and water conservation/management:*** *Soil conservation measures and improved crop management are strongly linked and they aim at both sustainability and productivity. Development of suitable soil and water management techniques to enhance both water and nutrient use efficiency is an important aspect of this theme.*

# Characterization and Modeling

## Agroclimatology of Groundnut-Growing Areas in Vietnam

Agriculture in Vietnam accounts for 45% of her Gross National Product (GNP). The country's economy is now opening up. Its agriculture is being diversified and to meet economic needs, emphasis is now being placed on including, in the cropping systems, crops having an export potential. Groundnut has been selected by the Ministry of Agriculture, Vietnam, to receive special attention. The area under the crop is proposed to be expanded from 217 000 ha in 1992 to 1 million ha by the turn of 2001. The Ministry of Agriculture in Vietnam has adopted a two-pronged approach: one, to increase production by intensification of the groundnut production system and two, to expand area under the crop.

D.T. Dzung, a Vietnamese scientist, is currently carrying out research under the supervision of C. Johansen and N.T. Dan, at ICRISAT Asia Center (IAC) on the extent and intensity of abiotic stresses that reduce groundnut yields for selected groundnut-growing areas in Vietnam. Two agroecological zones (AEZs), namely AEZs II and VI, were selected for a detailed agroclimatic analysis to address water-related abiotic stresses (Fig. 1).

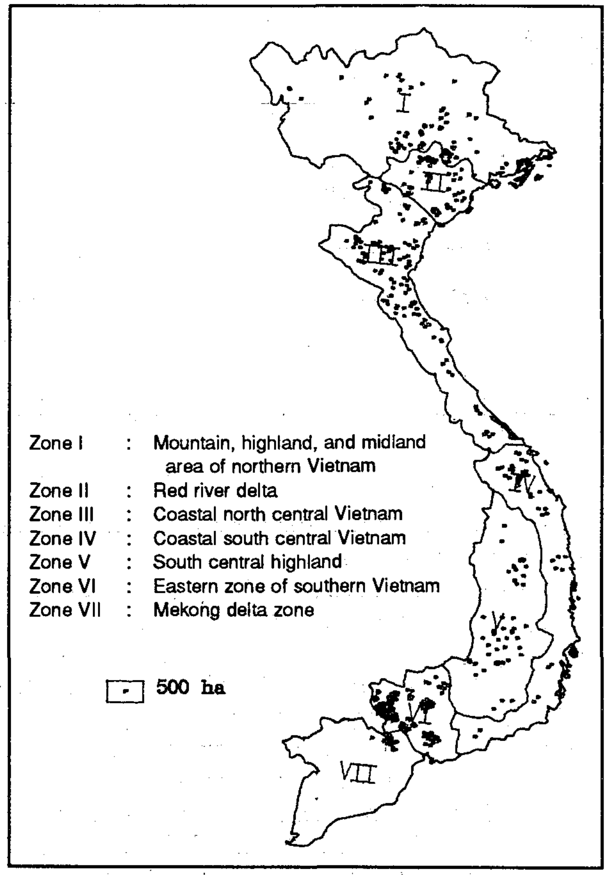


***Figure 1. Groundnut distribution in various agro-ecological zones in Vietnam.*** **(Source: Agricultural Statistics Department, Hanoi, Vietnam, 1983–92).**

### Agroclimatic features of selected AEZs

Vietnam is a monsoonal country, where the bulk of the annual rainfall is received due to southwest monsoons, between April/May to October/November. In the AEZs II and VI, a total of 1600–2000 mm rainfall is received annually. However, the distribution of rainfall in the two zones is quite different. AEZ II records 90% of the annual rainfall during April to October, with a core rainy season occurring from June to September. In AEZ VI, a significant amount of rainfall occurs in September and October (Fig. 2). During the rainy season, rice is grown in both the AEZs. Groundnut crop is raised in the postrainy cropping season.

### Moisture availability

Monthwise moisture availability index (MAI) for the two AEZs is shown in Figure 2. During the groundnut-growing season (January to May), the MAI for AEZ II progressively shows an increase from 0.15 to 0.94. Since an MAI ≥0.33 is considered as the lower threshold of moisture adequacy for groundnut crop, the crop is exposed to moisture deficit in January and February. An MAI value exceeding 0.66 represents water excess. In April and May, therefore, in AEZ II, some drainage requirements are indicated.

The eastern zone of southern Vietnam, represented by AEZ VI, has a particularly dry postrainy season. The MAI values are around zero from December to March. It is only in April that the MAI equals 0.31, and in May it is 1.02. The moisture deficit from January to March is particularly severe.

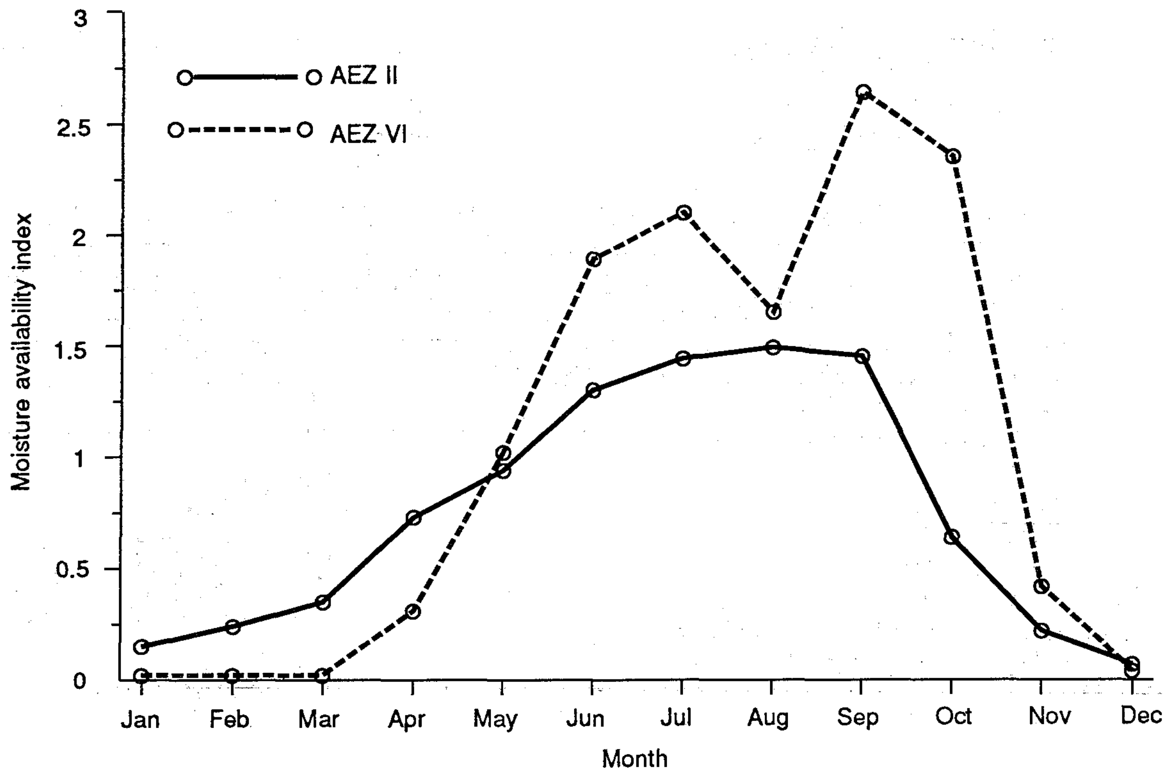


***Figure 2. Monthwise moisture availability index for AEZ II and AEZ VI.***

**Sustainable groundnut production in AEZs II and VI:** The implications of the water-related abiotic stresses featured for the two AEZs for groundnut production are: (1) In the AEZ II (Red River delta region), the management of soil moisture in January and February would be most critical for the establishment of the crop stand, and during the early growth stage of the crop. Scheduling of one or two irrigations may be necessary to stabilize and increase groundnut production in the rainfed areas. Drainage requirements are indicated at pegging and maturity stages of the crop, and (2) In the eastern zone of southern Vietnam (AEZ VI), the production of groundnut will be limited to areas having access to adequate irrigation resources. Four to six irrigations may be needed between January to March. This area is suitable for intensification of groundnut production. Some drainage needs are indicated at maturity stage of the crop.

In sum, it may be stated that agroclimatic analyses of the two widely separated groundnut-growing areas of Vietnam show that water-related abiotic stresses occur on a different scale. This information could provide a scientific basis for initiating research and development programs. For example, the crop cultivars suited to the two environments may be different. Soil and water management technologies will have to be tailored to available resources for sustainable production.

## Chickpea Modeling

Chickpea growth and development model, referred to as CHIKPGRO, has been developed by modifying the source-code of the groundnut model PNUTGRO, which was earlier developed by Boote et al. (Boote, K.J., Jones, J.W., Hoogenboom, G., and Wilkerson, G.G. 1987. PNUTGRO v1.0, Peanut crop growth and yield model. Technical documentation. Gainesville, FL, USA: Department of Agronomy and Agricultural Engineering, University of Florida. 121 pp.). The reason for using the source-code of the PNUTGRO model was that both the crops are legumes, and are similar in most of the crop developmental and growth processes. Another good feature of the PNUTGRO model is that it has a generic soil water balance submodel, which simulates soil water changes under the crop, provided crop-specific parameters have been substituted. This model also has a hedgerow subroutine which simulates light interception and photosynthesis, as influenced by plant population and row spacing. We also believed that any advancements made in modeling of legumes by the scientists at the University of Florida, would also benefit the chickpea model because of the similarities in computer code of the legume models.

We validated the chickpea model against the phenology, crop growth and yield, and soil moisture data obtained from the 1985, 1987, 1992, and 1993 postrainy season experiments conducted at IAC. Cultivars grown during these seasons were Annigeri and JG 74. The model had previously been calibrated against the 1984 and 1986 season data sets for crop, cultivar, and soil parameters, and these were fixed for model validation. However, the soil type during the 1992 and 1993 seasons was a high water holding capacity Vertisol and required recalibration for the growth reduction factor PHFAC3. The genetic coefficients of the cultivars were, however, not changed.

## Vegetative development

The model was tested against the 1992 and 1993 data for this plant characteristic of cv Annigeri. The rate of V-stage progression was accurately predicted by the model for both the irrigated and drought-stressed situations; however, the total number of V-stages finally achieved in the irrigated treatment were underestimated. This discrepancy is attributed to the error in predicting pod-initiation stage and growth rate of pods. These results indicate that the functions used to predict V-stage development are satisfactory, i.e., 0.60 nodes are produced per physiological day, using the base temperature of 0°C and optimum range of 22–34°C.

## Reproductive stages

Days to 50% flowering and pod initiation were predicted within ±3 days of observed values for the cultivars Annigeri and JG 74 (Table 1). However, the error was more in predicting initiation of seed growth and physiological maturity stages, especially in the irrigated situation. This is one characteristic of the chickpea crop where, under wetter conditions, pod filling and maturity are delayed. This may be attributed to the microclimatic factors that are influenced by irrigation and are not being considered in the model. The data sets obtained at IAC were not suitable

***Table 1. Observed (O) and simulated minus observed (S–O) time to 50% flowering (days), pod initiation, beginning of seed growth, and physiological maturity of chickpea cultivars in the irrigated (IR) and rainfed (RF) treatments during various seasons, 1985–93.***

| | | | Time to 50% flowering (days) | | Pod initiation (days) | | Beginning of seed growth (days) | | Physiological maturity (days) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Season | Treatment | Cultivar | O | S–O | O | S–O | O | S–O | O | S–O |
| 1985 | IR | Annigeri | 42 | 0 | 46 | 2 | 67 | –9 | 114 | –10 |
| | RF | | 42 | –1 | 45 | 3 | 60 | –5 | 99 | –6 |
| 1987 | IR | JG 74 | 50 | 1 | 57 | 1 | 72 | –4 | 110 | –3 |
| | RF | | 50 | 0 | 52 | 3 | 63 | 2 | 92 | –5 |
| 1992 | IR | Annigeri | 39 | –1 | 44 | 0 | 71 | –18 | 111 | –6 |
| | RF | | 38 | 0 | 44 | 0 | 48 | 3 | 89 | 1 |
| 1993 | RF | Annigeri | 46 | –3 | 52 | –2 | 55 | 1 | 89 | 3 |
| Root mean square error | | | | ±1.3 | | ±2.0 | | ±8.1 | | ±5.5 |

to test the model for the photoperiod-influence on reproductive development. Low temperatures, high humidity, overcast sky, and wet seed beds delay the initiation of pods in the northern Indian conditions. Because of the lack of response functions to these environmental factors, it was not possible to model and test the chickpea response to such weather conditions. Accurate prediction of reproductive stages by the model indicates that temperature and drought-stress functions used to predict reproductive phenology are satisfactory. The model needs recalibration for photoperiodic sensitivity coefficients of cultivars at higher latitudes, where photoperiod during the season is less than optimum during the initial phase of crop growth.

## Canopy development

Prediction of canopy development [leaf area index (LAI)] and its decay due to crop maturity and drought stress was fairly accurate during the 1985 and 1987 rainy seasons under irrigated and drought stress situations. Discrepancy between observed and simulated LAI for these two seasons can be attributed to the variation in soil fertility between the seasons. These results show that the model is accurate in predicting LAI under irrigated and drought-stressed situations, indicating that various processes involved in canopy development (V-stage development, allocation of dry matter to leaves, specific leaf area) and senescence (loss of leaves caused by nitrogen mobilization and drought stress) were accurately predicted by the model.

## Dry matter production and its allocation

During 1985, the model accurately predicted total dry matter (TDM) production of cv Annigeri, and its allocation to pods and seeds at various times during the season in the irrigated treatment. However, the prediction of TDM for the drought-stressed treatment was slightly overestimated. Allocation to pods and seeds was within the variability observed in the measured values. During 1987, TDM production by cv JG 74 was overestimated in both the irrigated and drought-stressed treatments. This overestimation may be because of differences in soil fertility between seasons. Dry matter allocation to pods and seeds in the irrigated treatment was close to the observed data, but it was underestimated and slightly delayed in the stressed treatment. Overestimation of TDM under drought stress situations may be attributed to the decline in nutrient availability with drought stress under field situations, which is not being considered in the model. Predicted TDM and seed yields of cvs Annigeri and JG 74 at final harvest were significantly correlated ($r^2 = 0.89$ for TDM and $r^2 = 0.82$ for seed) with the observed data (Fig. 3). The slopes of the regression lines did not differ from 1.0 and the intercepts did not differ from zero, indicating satisfactory predictability by the model for yields at harvest.

## Soil moisture dynamics

Soil moisture data collected from the irrigated and rainfed treatments of the 1992 rainy season experiment were used to illustrate the performance of the model to simulate soil moisture dynamics in the root zone. The model was able to accurately simulate the soil moisture changes in the root zone of the chickpea crop during the season, indicating accurate predictions of root growth and extension and water extraction processes by the model. These results on soil moisture dynamics indicate that Ritchie's model (1985) can accurately predict water balance of the chickpea crop, provided soil and crop parameters have been calibrated for a site.

It is concluded from this study that PNUTGRO model provided a good framework to predict chickpea growth and development. However, some changes in the source-code were required to incorporate chickpea crop-specific processes. The resultant model (CHIKPGRO) predicted chickpea phenology, canopy growth, dry matter production and its allocation, and yields at harvest accurately under water-limiting and nonlimiting situations. Soil moisture dynamics in the rooting zone was also predicted satisfactorily. The model needs further testing and validation in a wide range of environments, before it can be considered as fully validated. The present version of the model does not incorporate soil fertility aspects, and assumes soil fertility to be nonlimiting for crop growth. Use of the model under suboptimal fertility conditions would require adjustment of the factor PHFAC3. However, the model can be used to predict crop growth and yields of chickpea under water-limiting and nonlimiting situations.

Annigeri (o) and JG 74 (•). For TDM: $y = -0.41 (\pm 0.331) + 1.07 (\pm 0.08)$, $r^2 = 0.89$, rse = 0.336;
For seed yield: $y = 0.21 (\pm 0.149) + 0.83 (\pm 0.08)$, $r^2 = 0.82$, rse = 0.138

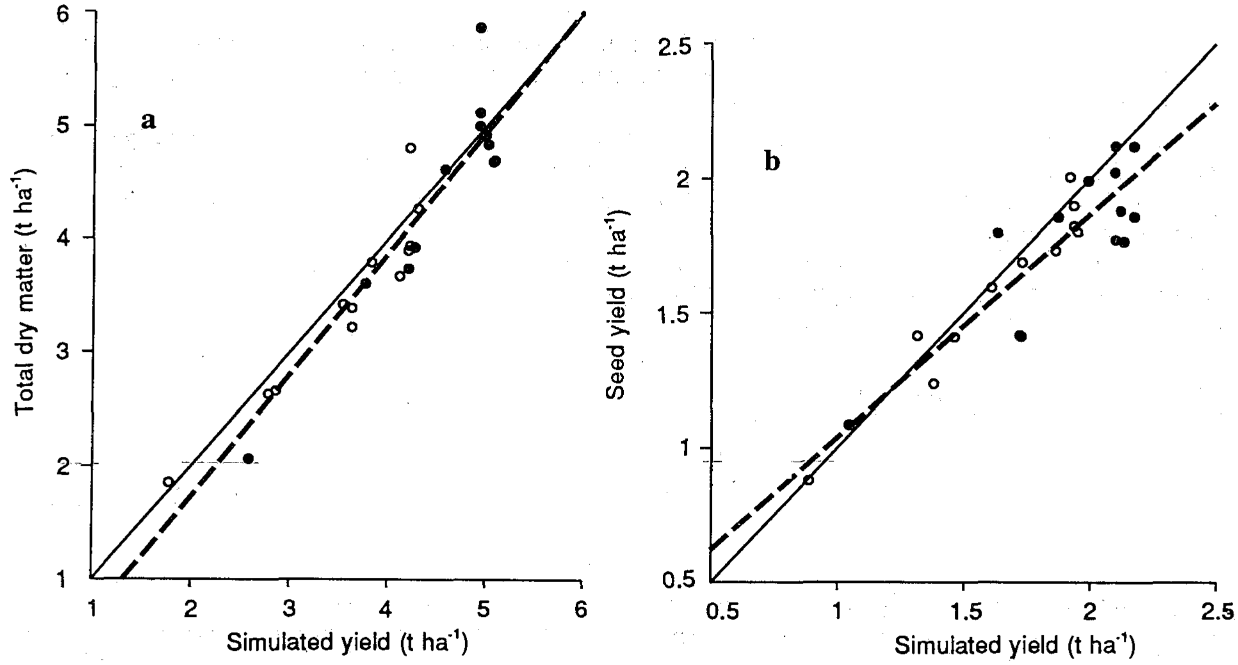


*Figure 3. Simulated versus observed (a) total dry matter (TDM), and (b) seed yields of Annigeri and JG 74.*

## Pigeonpea Modeling

A study was conducted to investigate the effect of agroclimatological factors on phenology, growth, biomass accumulation, and grain yields. The crop growth and development of the extra short-duration (ESD) and short-duration (SD) types was characterized over a range of photothermal environments. Information from partially controlled field studies was used to develop a simulation model applicable to the semi-arid tropics. This model, like the chickpea model, has also been adapted from PNUTGRO. In our initial work, we retained the framework of the groundnut model, while focusing on the crop growth under nonlimiting situations of soil moisture and nutrients.

The potential for introducing ESD and SD pigeonpea types into new agroecological environments or intensifying its production in existing systems has been evaluated. This ex ante analysis using crop growth simulation model could indicate (a) new agroecological environments where existing genotypes might fit well, (b) crop characteristics required to fit a particular environment, and (c) yield gaps between potential and present levels of production. The possibility of extending the ESD and SD pigeonpeas in rainfed environments where the effective length of growing season is short, is examined. It is suggested that the ESD and SD pigeonpeas could find a niche as sole crops in areas with a seasonal rainfall of 500–1000 mm. The expected yield is 1.5–2.0 t $ha^{-1}$. The SD types need about 1400°C d during vegetative and 750°C d during reproductive phases. The crop could, therefore, fit into regions where medium duration (MD) pigeonpeas are not grown, and replace crops such as maize, which have similar agroclimatic requirements. A maize-pigeonpea rotation, which may be most sustainable, may emerge, as the areas under ESD and SD genotypes extend in peninsular, central, and northern Indian rainfed regions.

### Short-duration pigeonpeas: future model development

Once the model accurately predicts potential yield under optimal conditions of growth, it could be further developed to include the effects of nutrient and moisture deficiencies, and waterlogging, on crop growth and yield. In addition, the senescence module of the model needs to be refined.

- The model will have to be developed further to simulate crop growth beyond the 'first flush', especially in the longer-duration types.
- It is essential to have a model which would predict the performance of pigeonpea as a component of cropping systems rather than as a sole crop alone. This is particularly relevant in case of medium duration and perennial types, which are invariably cultivated as intercrops.
- Insect pests pose a major problem in the cultivation of pigeonpea. Other biotic constraints include diseases such as phytophtora blight and nematodes. Hence, the effects of the different biotic constraints on crop growth and yield would also need to be considered in the pigeonpea model, in order to make it applicable under a wider range of conditions.
- The genetic coefficients for different duration types and, within each class, for various genotypes, will need to be estimated, and validated across different agroecological environments.

# Nutrient Management

## Mineral and Mineralizable N in a Vertisol under Different Cropping Systems Rotations

A cropping systems rotation experiment was established in 1983 on a Vertisol to quantify the nitrogen (N) contribution of grain legumes to nonlegumes in the rotation and short-term and long-term changes in soil N fractions. Here, we report results of the treatments; sorghum followed by safflower continuously (S+SF-S+SF), and in rotation with sorghum followed by chickpea (S+CP-S+SF), sorghum/pigeonpea intercrop (S/PP-S+SF), and cowpea/pigeonpea intercrop (C/PP-S+SF).

If N is the limiting nutrient for plant growth and is not fertilized, plant N uptake depends on the mineral N supply by the soil. The mineral N supply by the soil is determined by the mineral N content in the soil at the beginning of the cropping season, and the mineralization/immobilization and N-loss mechanisms effective during the cropping season.

On an average, top soil mineral N content in N-O treatments at the beginning of the growing season was higher in the S/PP-S+SF and C/PP-S+SF years following the legume system (Fig. 4). But only in the S/PP-S+SF treatment was the mineral N content always higher. Differences between rotations in $NH_4$-N content were not significant at any depth and differences in $NO_3$-N content were significant up to 60 cm depth. In the total profile, an additional amount of, on an average, 24 kg N $ha^{-1}$ in the S/PP-S+SF and 16 kg N $ha^{-1}$ in the C/PP-S+SF, was available at the beginning of the cropping season in the years following a legume. Mineralizable N in the topsoil at the beginning of the growing season was also increased in the years following a legume. An additional amount of 4, 8, and

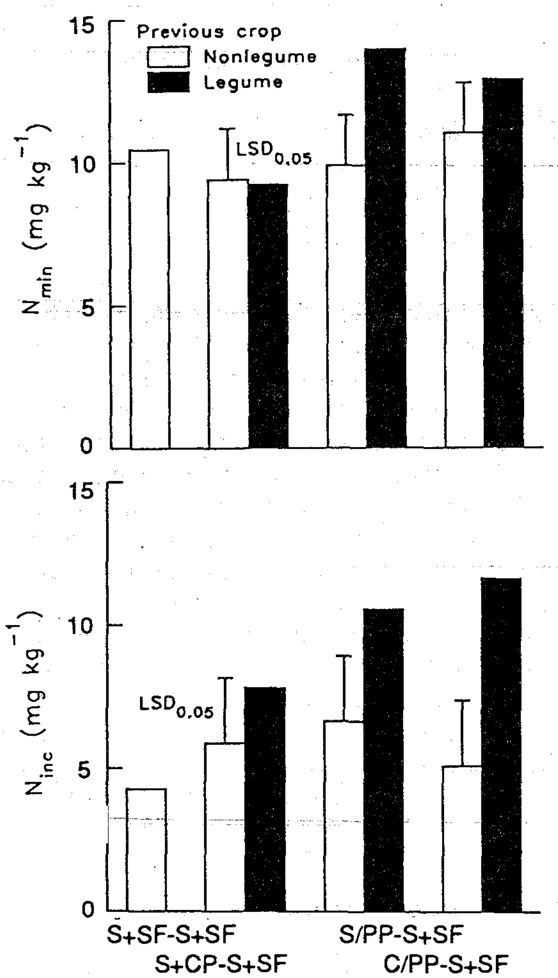


***Figure 4. Mean mineral N ($N_{min}$) and mineralizable N ($N_{inc}$) in the topsoil (0–15 cm) of N-O.***

14 kg N $ha^{-1}$ was found in S+CP-S+SF, S/PP-S+SF, and C/PP-S+SF.

For the evaluation of the long-term effects of rotations on the soil mineral N content, the treatment and its mirror image (i.e., S/PP-S+SF and S+SF-S/PP) was averaged. In the long term, mineral N content fluctuated, but no consistent trend for any rotation became obvious (Fig. 5). However, the mineralizable N in the top soil showed some clear treatment effects after 10 years. The C/PP-S+SF treatment resulted in the highest mineralizable N (19 mg $kg^{-1}$), followed by S/PP-S+SF (12 mg $kg^{-1}$). The S+CP-S+SF treatment recorded 11 mg $kg^{-1}$ of soil. The nonlegume treatment (S+SF-S+SF) had the lowest mineralizable N content of 6 mg $kg^{-1}$ soil.

The relationship between mineral N and mineralizable N at the beginning of the cropping season and N uptake of sorghum is shown in Figure 6. With a linear regression which seemed appropriate owing to the low amount of N in the N-O treatments, mineral N explained only 30% of N treatments, uptake, and mineralizable N explained 34% of N treatments uptake. Using these two parameters in a multiple linear regressior model did not improve the prediction of N uptake. We concluded that mineralization, which is not correctly reflected in the measured mineralizable N at the beginning of the growing season and N loss mechanisms, must play an important role for N availability in these soils and cropping systems.

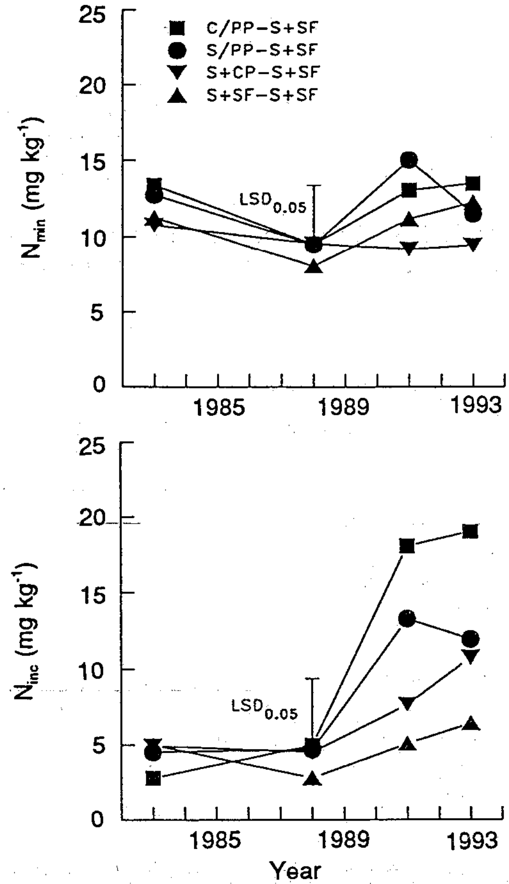


***Figure 5. Mineral N ($N_{min}$) and mineralizable N ($N_{inc}$) in the topsoil (0–15 cm) of N-O treatments.***

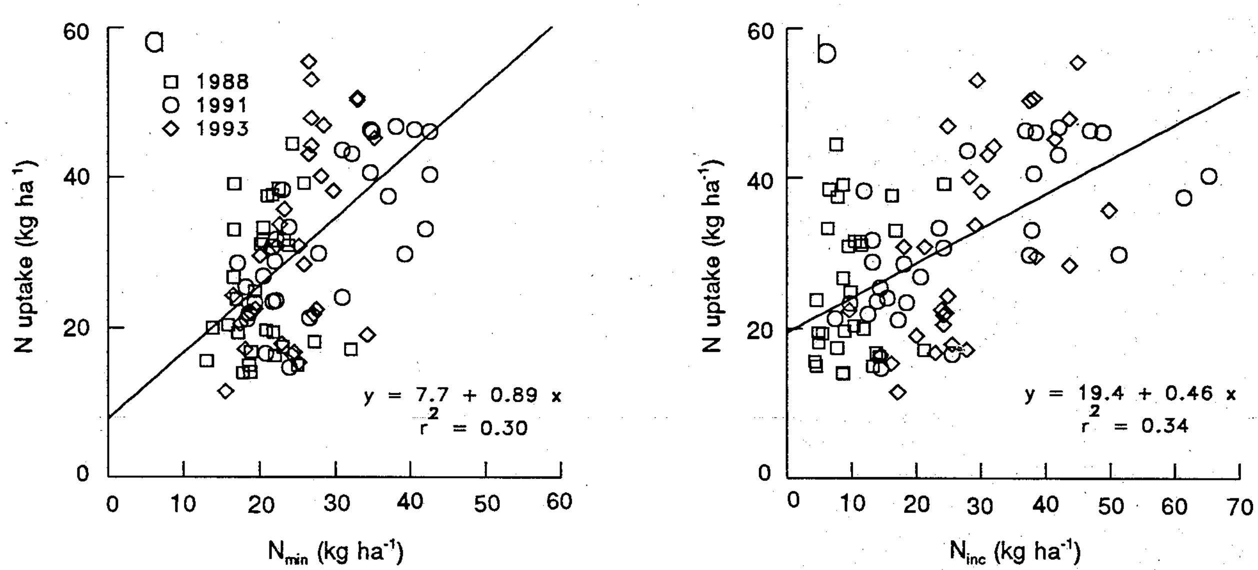


***Figure 6. Relationship between mineral N (a) and mineralizable N (b) at the beginning of the cropping season in N-O treatments and N uptake of sorghum.***

## Residual Effects of Legumes

Legumes grown as intercrops or in rotation with cereals often increase the yield of a subsequent cereal crop grown on the same soil, as compared with the yield of a cereal grown after a nonlegume crop. Such increased nonlegume yields following legume crops have been attributed to the N contributed by the legumes and non-N rotational effects of legumes.

The effect of different cropping systems, from a long-term rotation experiment, on sorghum yield and behavior of soil and applied N was studied, by using sorghum as a test crop in a greenhouse experiment. The soils used in this study were from the long-term rotation experiment on a Vertisol at IAC. The experiment was started in the 1983 rainy season. Eight cropping systems with 2-year rotations were selected.

1. Two rows of sorghum intercropped with one row of pigeonpea every year (S/PP-S/PP).
2. Two rows of cowpea intercropped with one row of pigeonpea followed by sorghum in the rainy season and safflower in the postrainy season (COP/PP-S+SF).
3. S/PP in the first season followed by sorghum in the next rainy season and then chickpea in the postrainy season (S+CP).
4. S/PP-S+SF.
5. S+CP-S+CP.
6. S+CP-S+SF.
7. S+SF-S+SF.
8. Fallow in the rainy season followed by sorghum in the postrainy season (F+S)-F+S.

All the crops were rainfed, and no mineral nitrogen was applied to any plot during the study. All the crops received 20 kg P ha$^{-1}$ per season.

### Sorghum grain and plant biomass production

Sorghum grain yield was significantly ($P \leq 0.001$) affected by the previous cropping history (Fig. 7). A maximum grain yield of 8.6 g per pot was observed in case of COP/PP-S+SF treatment soil and followed by S/PP-S+CP, S/PP-S/PP, S/PP-S+SF > S+CP-S+SF, S+SF-S+SF, and S+CP-S+CP. Grain yield in case of COP/PP-S+SF treatment was 63% higher than that of the sorghum grown in S+SF-S+SF treatment. In other pigeonpea-based cropping systems, grain yield was 36–56% higher than S+SF-S+SF plots. In chickpea-based cropping systems, sorghum yielded 18–24.5% lower than the S+SF-S+SF plots. Total plant biomass (above ground + roots) of sorghum was also significantly ($P \leq 0.001$) influenced due to cropping history. The highest total plant biomass of 30.2 g per pot was recorded in case of COP/PP-S+SF treatment, followed by S/PP+S+CP, S/PP-S/PP > S/PP-S+SF > S+CP+ S+CP, S+SF-S+SF, and S+CP-S+SF treatments.

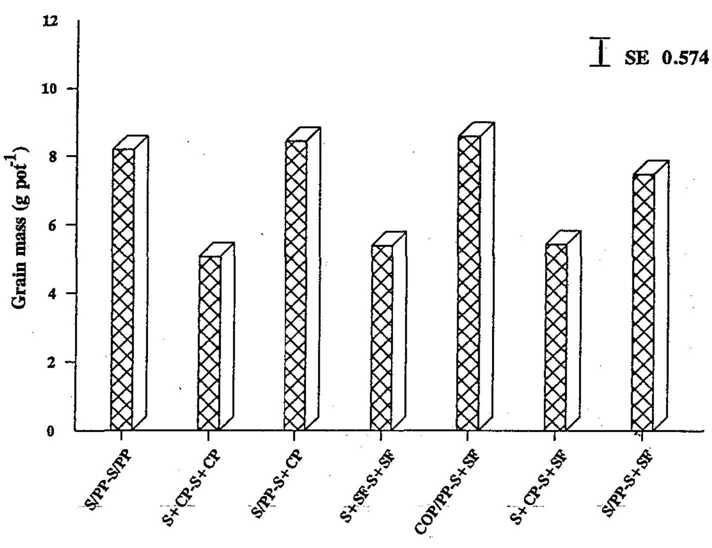


*Figure 7. Grain mass of sorghum grown in surface soil samples collected from different cropping systems plots.*

## Shoot:root ratio

Shoot:root ratio of sorghum grown in soil samples from all the cropping systems decreased from 0.30 at 30 DAE to 0.13 at 106 DAE. Previous cropping history of the soil had a significant effect on the shoot:root ratio of sorghum. Significantly lower shoot:root ratio was observed in the case of sorghum grown in soil from pigeonpea-based cropping system plots rather than the ones grown in S+SF-S+SF, S+CP-S+CP, and S+CP-S+SF plots.

## Total N uptake

Total plant N uptake of sorghum plants also varied significantly due to the cropping history of the soil (Fig. 8). A maximum total N uptake of 108.2 mg per pot was observed in the case of plants grown in soil from COP/PP-S+SF treatment followed by S/PP-S/PP and S/PP-S+CP > S+CP-S+CP, S/PP+S+SF, S+SF-S+SF, and S+CP-S+SF treatments.

## Residual N in sorghum and 'A' value of soil

The fertilizer N replacement value (FRV) or 'N equivalent' refers to the amount of additional inorganic N required to obtain the same levels of yield from a nonlegume crop which follows another nonlegume crop, as those from one which follows a legume crop. This concept is based on the hypotheses that all the benefits of legumes on the succeeding cereals/nonlegume crop are solely due to N effect, and that further legume N is just as available as fertilizer N. However, recent literature based on $^{15}N$ methodology do not support these hypotheses.

A linear response function was used to relate the observed yield to the expected N requirement, based on the assumption that the N supply alone causes the differences in yields observed between cropping systems. The FRV calculated for different treatments using S+SF-S+SF plot as control varied from 65–161 mg N per pot (11.4–28 kg N $ha^{-1}$ equivalent). Using $^{15}N$, dilution technique with S+SF-S+SF treatment as control, it was estimated that 8.4–20% of the total sorghum plant N, in case of plants grown in soil from pigeonpea-based systems, was derived from the N that was either fixed previously and had accumulated, or from the soil N that became available more readily due to the presence of pigeonpea in the rotation.

The N-supplying capacity of the soil 'A' value of these soils varied significantly ($P \leq 0.001$) with the cropping history. Results showed that increased sorghum yields from the pigeonpea-based cropping systems over the S+SF-S+SF system were not solely due to the increased N availability. Further, the FRV method overestimated N contribution of pigeonpea by 150%, based on $^{15}N$-based methods.

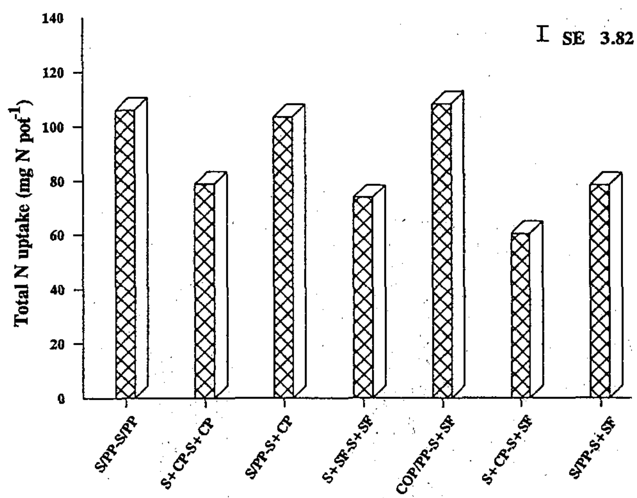


*Figure 8. Total N uptake by sorghum plants grown in surface soil samples collected from different cropping systems.*

## Grain N content, $^{15}N$ atom percentage excess, and $^{15}N$ recovery

At harvest stage, N content in grains, shoots and roots was significantly higher in case of pigeonpea-based treatments than in others. Grain N content in pigeonpea-based treatments was 1.4–1.9 times higher than grain N content in the S+SF-S+SF treatment.

The $^{15}N$ atom percentage excess in grain and shoots from the pigeonpea-based systems was lower than in other treatments. The percentage of $^{15}N$ recovery in grains from pigeonpea-based treatments was 1.3–1.72 times higher than the $^{15}N$ recovery in grains from the S+SF-S+SF treatment. The total $^{15}N$ fertilizer recovery in plants was 33% in COP/PP-S+SF, and varied up to 24.7% in the S+CP-S+SF treatment. The amount of $^{15}N$ translocated to grains varied from 43.8% in the S+SF-S+SF treatment to 61.6% in the COP/PP-S+SF treatment.

## N during crop growth

Mean mineral ($NO_3$+$NH_4$)N in soil decreased from 8.5 µg $g^{-1}$ soil to 5.9 µg $g^{-1}$ soil at 30 days after emergence (DAE) and further decreased to 3.7 µg $g^{-1}$ soil at 58 DAE. At harvest 106 DAE, mean mineral N content in soil was 3.3 pg $g^{-1}$ soil (Fig. 9). The mineral N content was highest in case of the S/PP-S+SF treatment, and lowest in the S+CP-S+CP rotation plots. Mean net N mineralization in soil was similar with samples collected before sowing and at 30 DAE, and decreased significantly at 58 DAE, and marginally increased later up to harvest. The mean net N mineralization across the sampling times in pigeonpea-based systems was 9–13.8 times higher (2.10 µg $g^{-1}$ soil per 10 days) than the S+SF-S+SF treatment. Mean microbial N in the soil across the sampling times was maximum (30.2 µg $g^{-1}$ soil) in case of COP/PP-S+SF, and it was followed by S/PP-S+CP > S/PP-S/PP-S/PP-S+SF > S+CP-S+CP, S+SF-S+SF, and S+CP-S+SF (Fig. 10). Mean microbial N across the cropping systems increased significantly at 58 DAE and remained such with a marginal increase at harvest stage. For microbial N, significant interaction between cropping systems and sampling dates was observed. In case of all the pigeonpea-based systems, microbial N increased at 58 DAE and remained such with a marginal increase at harvest, whereas in other soils, microbial N remained similar at 30 to 58 DAE.

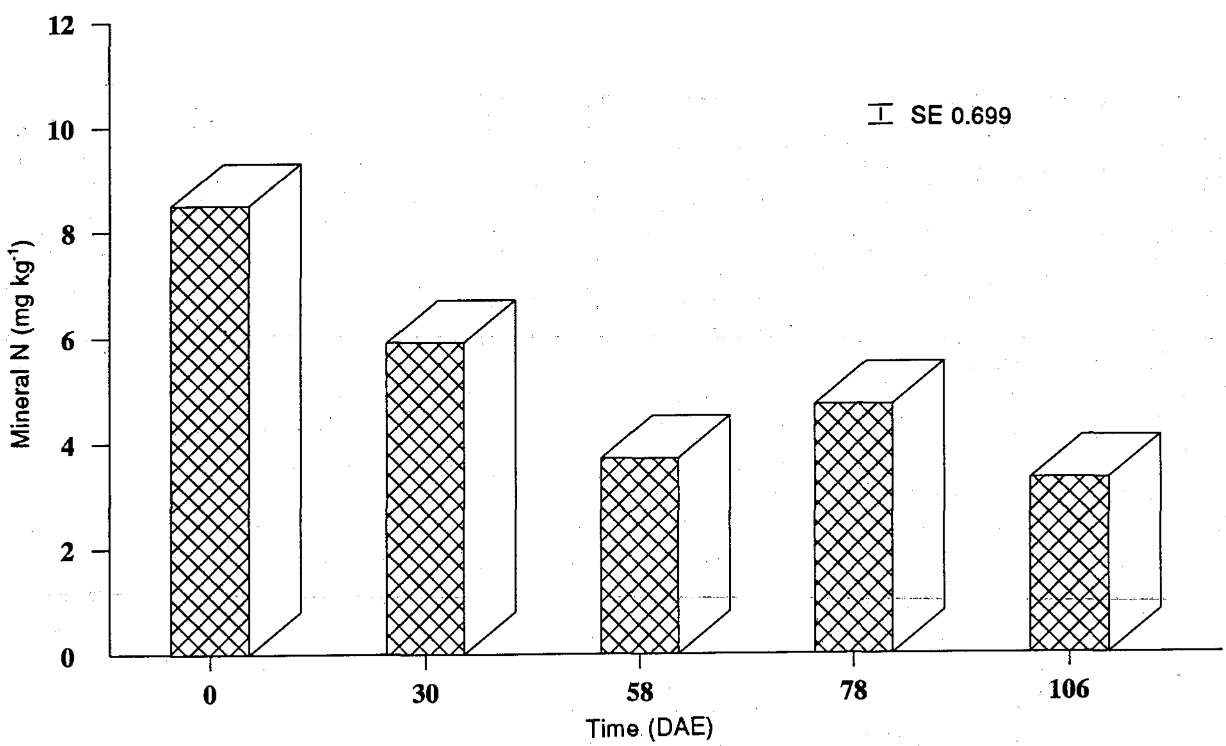


*Figure 9. Mean mineral ($NH_4$+$NO_3$) N content in soil from different cropping systems during sorghum growth.*

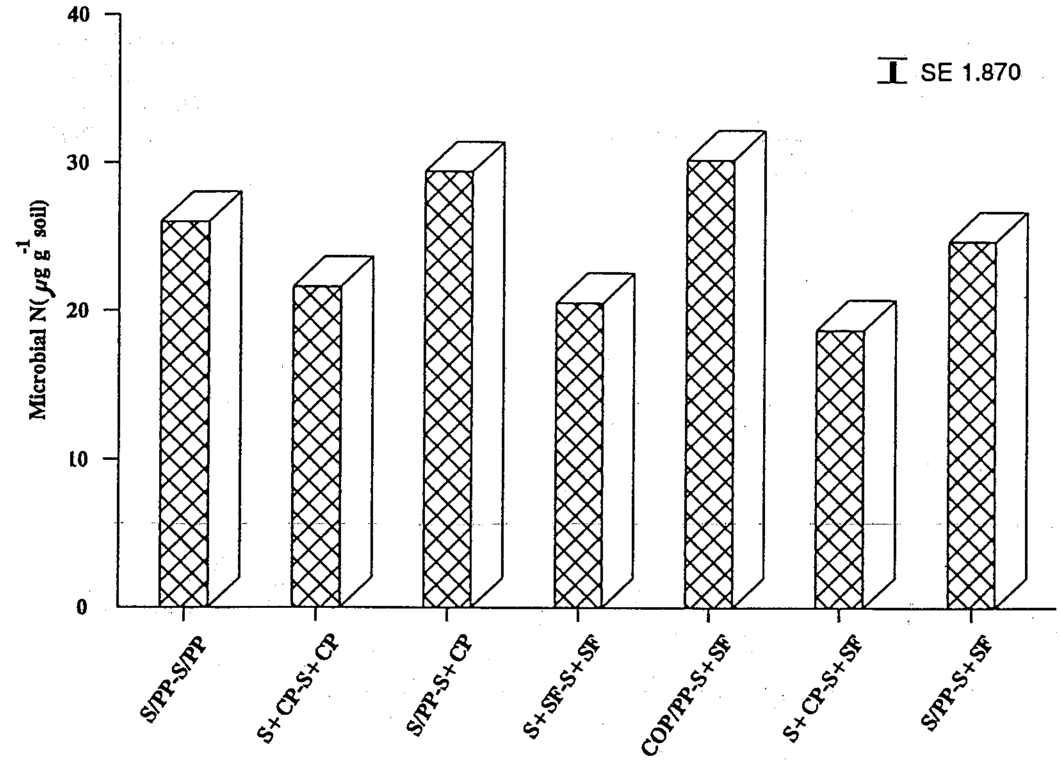


***Figure 10. Mean microbial N in soil from different cropping systems across the four samplings.***

## Mineral and Organic P Sources

An experiment was conducted to determine the feasibility of balance-based fertilizer recommendations in a postrainy-season sorghum system on deep Vertisols. It is often argued that under the receding moisture conditions of a postrainy crop season, fertilizer application does not affect yield to a great extent. A nutrient of relatively low mobility such as P is mainly concentrated in the plowed layer, and this layer dries out quickly. This leaves a relatively short time for the crop to take up the required nutrient. In our experiment, P uptake ceased 75 days after sowing (DAS). But there was no indication that P uptake was slowed down by drying the surface layer, which occurred much before the end of the 75-day period.

However, the basis for the final difference in P uptake and yield between fertilized and nonfertilized sorghum was laid much before that. The P influx, which is the uptake per unit root length or surface area, is nearly equal for both treatments at later stages (Table 2), indicating that the plant adapts its P uptake mechanism to low phosphorus concentrations in the surrounding soil solution. The real difference occurs within the first 3 weeks where the influx is 4.6 times higher in the fertilized treatment. This allowed the plants in the fertilized treatment to grow faster and develop a larger root system. At later stages, uptake of the fertilized treatment was still higher than in the nonfertilized treatment, but that was only due to the greater root length. The influx was the same.

***Table 2. P-influx of sorghum (M 35–1) with P-fertilizer application (P–500: 500 kg P ha$^{-1}$) and without P-fertilizer application (P-O).***

| | P-O | P–500 |
|---|---|---|
| Days after sowing | x $10^{-14}$ mol cm$^{-1}$ s$^{-1}$ | |
| 0 – 26 | 0.11 | 0.47 |
| 26 – 40 | 0.93 | 0.86 |
| 40 – 54 | 1.21 | 1.10 |
| 54 – 75 | 1.13 | 1.80 |

The observed grain yield difference of 1.2 t between the fertilized and the nonfertilized treatment clearly indicates how important sufficient P availability is during the first 3 weeks, even in the postrainy season, under receding moisture conditions. What is sufficient P availability under these conditions? Results indicated that at a soil content greater than 3 mg P $kg^{-1}$ (Olsen-P), fertilizing the amount of P removed by the crop was sufficient to achieve the maximum grain yield of 3.5 t $ha^{-1}$ (Fig. 11).

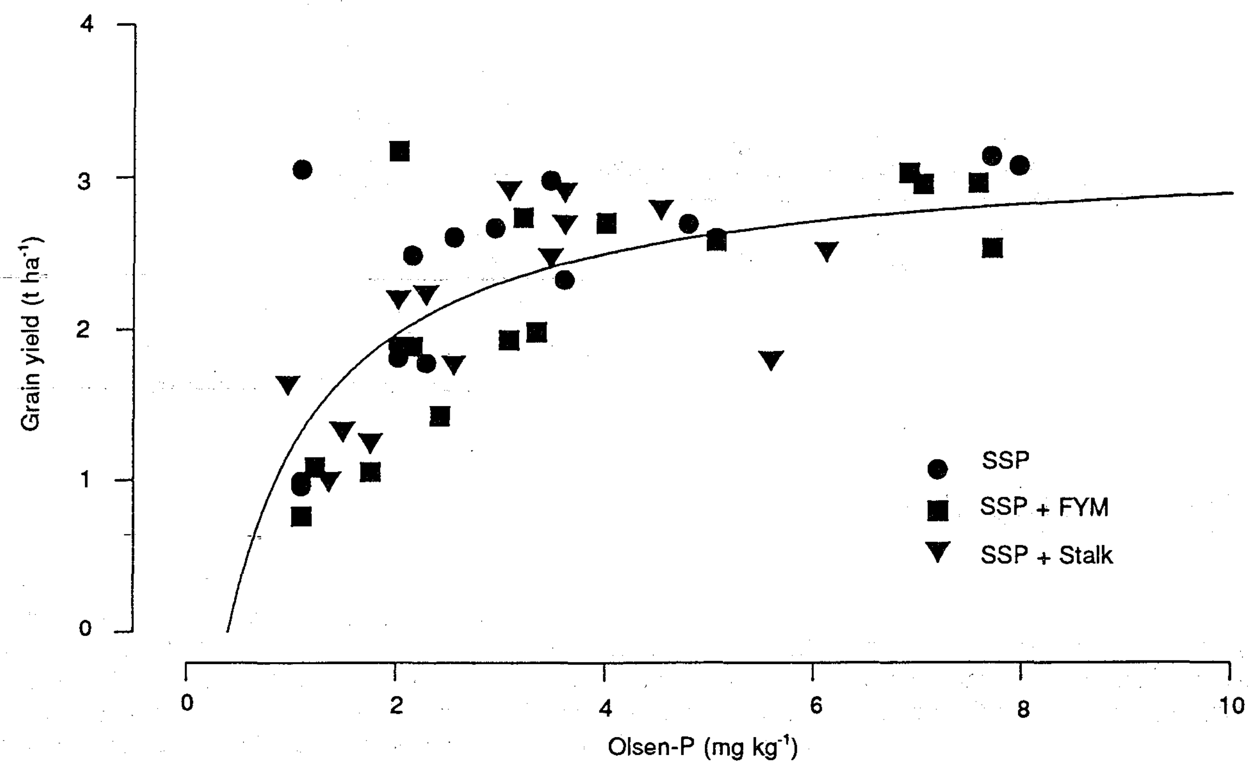


***Figure 11. Grain yield at different soil available P contents (Olsen-P) in treatments receiving the amount of P removed as mineral fertilizer, or in combination with organic amendments.***

There is some indication that organic P is an important source for the nutrition of sorghum under conditions of low P availability. Taking only the inorganic P in soil solution into consideration, it was not possible to simulate P uptake of this crop with the Claassen-Barber nutrient uptake model (Fig. 12). However, a considerable proportion of P in the soil solution is bound to organic molecules, and not accounted for with standard analytical procedures. Taking the organic soil solution P into account improved the fit of the model considerably (Fig. 13). Previous work elsewhere has shown that the concentration of organic P, and as a consequence total P, in the soil solution can be increased by organic matter amendments. (Seeling, B. and Jungk, A. (In press). Influence of plant residues on the mobilization and immobilization of soil phosphorus. Plant and Soil #S124). This is a possibility to increase P availability. These interactions between organic matter amendments and P nutrition will be studied further.

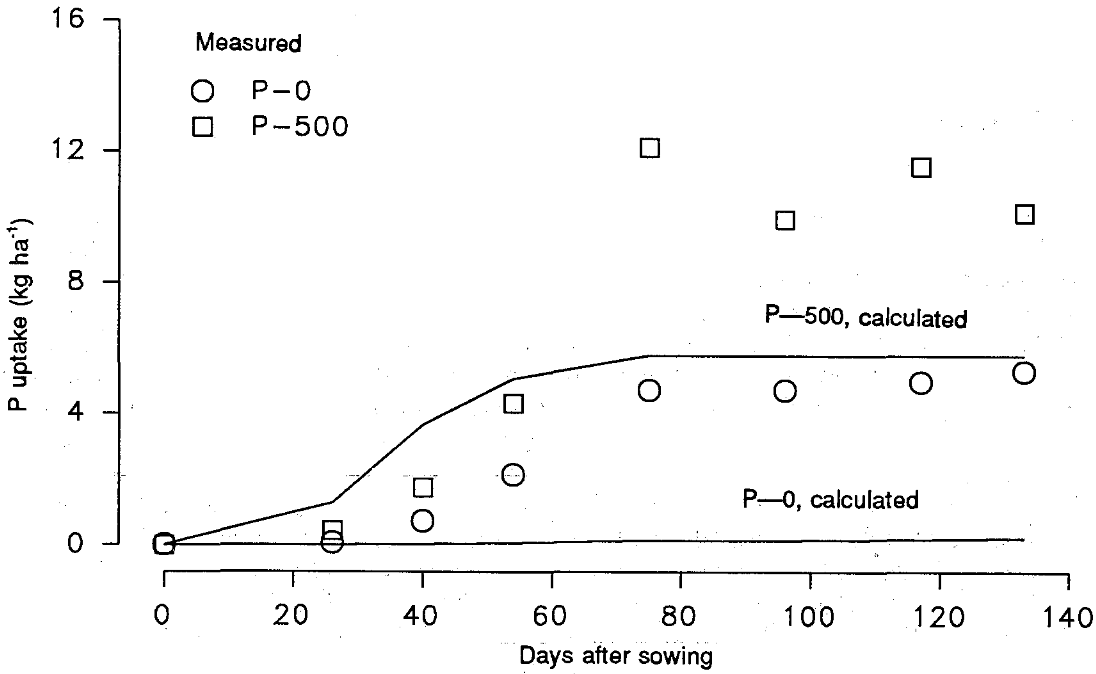


***Figure 12. Measured and predicted P uptake of sorghum (M 35–1). Phosphate uptake calculated without taking organic P in soil solution into account.***

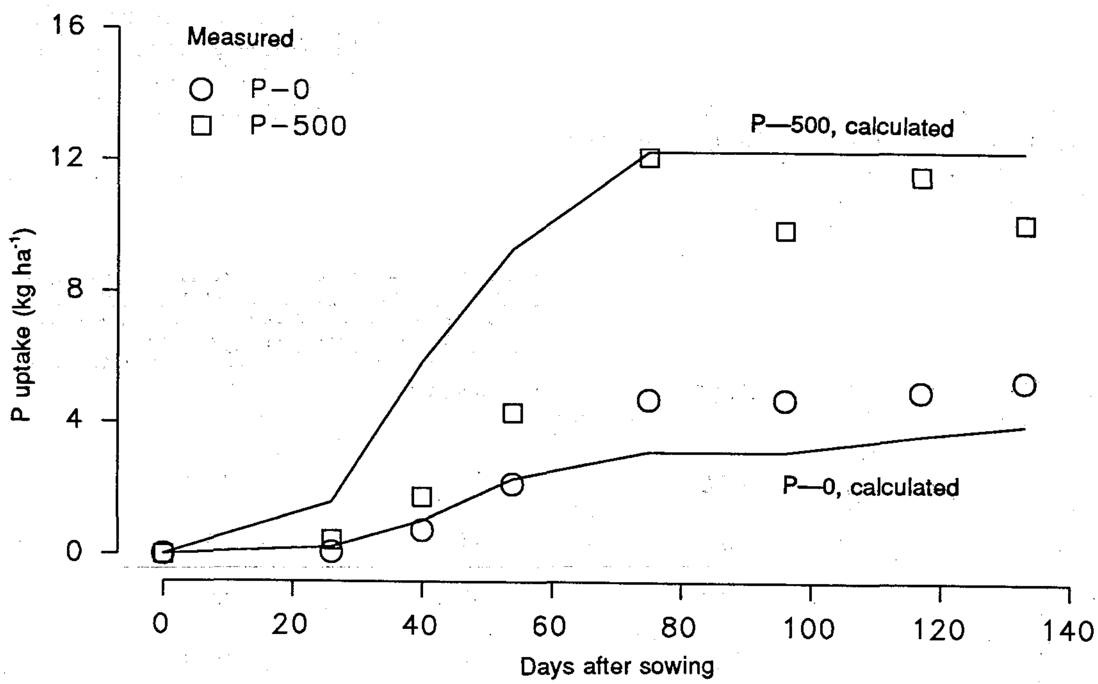


***Figure 13. Measured and predicted P uptake of sorghum (M 35–1). Phosphate uptake calculated by taking organic P in soil solution into account.***

# Soil and Water Conservation/Management

## Water Balance

Seasonal rainfall in RM 15 during the period of the experiment was 655.5 mm in 1991–92, 399.8 mm in 1992–93, 472.8 mm [for castor (C) because it was harvested a week earlier than the other crops], 479.4 mm for the intercrops groundnut/pigeonpea (GN/PP), sorghum/pigeonpea (S/PP), and sole pigeonpea (PP) in 1993–94, and 665.6 mm in 1994–95. The five cropping sequences examined in this experiment were (a) sole castor in one year, followed by sorghum/ pigeonpea intercrop in the other year, (b) groundnut/pigeonpea intercrop followed by sole castor, (c) sole pigeonpea in one year alternating with sole castor, (d) sole castor followed by GN/PP intercrop, and (e) S/PP intercrop followed by sole castor. These cropping sequences greatly influenced runoff ($R_o$), the difference in stored water ($\Delta W$), evapotranspiration (ET), and deep percolation (DP). Because of the effects of the cropping sequence on $R_o$, the proportion of rainfall that infiltrated the soil profile also varied (Table 3). The GN/PP has a 2-tier canopy in which the groundnut covers the soil surface while the pigeonpea shades about 0.6 to >1.0 m from the surface. This provided a good protection against raindrop impact. This architecture therefore ensured that a large fraction of rainfall (>90%) infiltrated into the soil profile (Table 3) to augment soil water used for evapotranspiration. The proportion of rainfall that infiltrated into the soil under sole castor was <90% in 2 out of the 4 years (i.e., 1992/93 and 1994/95) of experimentation. The high $R_o$ in the S/PP plot in 1991/92 resulted in the cropping system with the least infiltration the first year. However, the preceding castor crop provided a rooting system which improved the soil structure and also exhausted the antecedent moisture, resulting in high infiltration in that sequence in the subsequent years.

There was no consistent trend in the cumulative evapotranspiration of the cropping systems. In 1991/92, ET was in the order GN/PP > C > PP > S/PP. In 1992/93, it was C > S/PP > GN/PP while in the 1993/94 it was PP > C > GN/PP > S/PP and in 1994/95, ET was S/PP > GN/PP > C. Although rainfall in the 1993/94 season was greater than that in any of the preceding seasons, there was no water percolation beyond 2.0 m depth in any of the cropping sequences studied that year. This was due to good rainfall distribution in 1993/94, compared with that during 1992/93. However, except in 1991/92, there was more deep percolation beyond 2.0 m depth in the GN/PP than in either the C or the S/PP systems, indicating that though PP was common to both intercrops, sorghum appears to utilize the excess internal water better than does groundnut.

***Table 3. Proportion of rainfall that infiltrated through soil under the different cropping systems.***

| | Rainfall that infiltrated soil profile (%) | | | |
|---|---|---|---|---|
| Crop sequence[1] | 1991/92 | 1992/93 | 1993/94 | 1994/95 |
| C | 92.3 | 84.9 | 97.2 | 86.2 |
| GN/PP | 92.8 | 92.3 | 98.3 | 93.1 |
| S/PP | 87.8 | 92.8 | 95.9 | 93.3 |
| PP | 91.5 | - | 97.9 | - |

1. C = Castor; GN/PP = Groundnut/Pigeonpea; S/PP = Sorghum/Pigeonpea; and PP= Pigeonpea.

## Waterlogging

### Genotypic differences in waterlogging tolerance of short-duration pigeonpea

Using the pot screening method developed at IAC, about 60 pigeonpea lines of extra-short- and short-duration groups for tolerance to waterlogging were screened. The tolerant (ICP 8379 and ICP 14199) and susceptible (ICP 7035) control genotypes proved consistent in their response to waterlogging. Waterlogging for 8 days resulted in significant reduction in shoot dry mass (mean 24.4%), roots + nodule dry mass (mean 63.8%), and total plant biomass (mean 32.4%) of pigeonpea lines tested. About 20 genotypes were found tolerant to waterlogging. Among them, three genotypes—ICPL 87113, ICPL 91031, and ICPL 84023, were found promising as they suffered relatively less loss in plant dry matter, compared with other tolerant genotypes. Some of the single plant selections of the tolerant genotypes were grown to maturity and selfed seed collecting for further studies. The breeders have made crosses to transfer the tolerance to waterlogging from identified sources to some of their elite lines. It is proposed to test the selfed seed of those single plant selections for tolerance to waterlogging.

## Water Harvesting and Supplemental Irrigation

Paradoxically, although crop yields in the dryland farming areas are constrained by water deficits, a significant portion of rainwater escapes as runoff from these areas. This runoff water could be harvested and stored in a farm reservoir which could be used later for supplemental irrigation. The feasibility of providing irrigation from stored runoff in a farm reservoir was studied in this ICAR-ICRISAT Collaborative research project conducted in Anantapur, Akola, and Hyderabad.

We completed the analysis for the probabilities of getting 40, 60, 80, and 100 mm of water from the tank for supplemental irrigation under various conditions at Akola and Hyderabad. We also calculated the conditional probabilities of water availability in the tank for irrigation during drought periods.

For Hyderabad and Akola centers, we completed part of the analysis of probabilities of getting certain amount of water for supplemental irrigation during droughts. The probabilities of the occurrence of drought stress during three crop growth stages : growth stage 1 (GS1, sowing to panicle initiation), growth stage 2 (GS2, panicle initiation to anthesis) and growth stage 3 (GS3, grain filling stage) were estimated. In addition, the probabilities of obtaining 40 mm of water for irrigation from the experimental tanks during the drought stress period for each crop growth stage were calculated. For Akola, it was found that the chances of 40 mm of water being available from the tank during drought periods of GS2 and GS3 exceeded 95% compared with 63% for GS1. For Hyderabad, the chances of 40 mm of water being available from the tank during drought periods of GS2 and GS3 exceeded 88% compared with 45% for GS1. Considering the various losses in the tank water storage system, the tank water use efficiency was found to be highest in Akola, compared with those at Hyderabad and Anantapur.

Indications are that considerable information on various aspects of water storage in tanks can be obtained by using the water harvesting model developed at IAC. The model can estimate the probability of water availability in a tank when long-term daily rainfall and open pan evaporation records, along with certain crops and soils information, are used as input data. The chances of adequate stored runoff water being available for supplemental irrigation during drought stress periods can also be determined.

## Effect of Erosion by Water on the Productivity of an Alfisol

Soil erosion reduces productivity of soils through a variety of ways, e.g., by selectively removing finer particles, thus reducing the overall fertility or the available water capacity. It may also produce physical effects such as crusting, compaction, or increased soil strength. We initiated this study on the Effect of Erosion by water on the productivity of an Alfisol in 1988 to (a) quantify the relationship between soil erosion and groundnut yield; and (b) measure changes in soil properties that are associated with erosion.

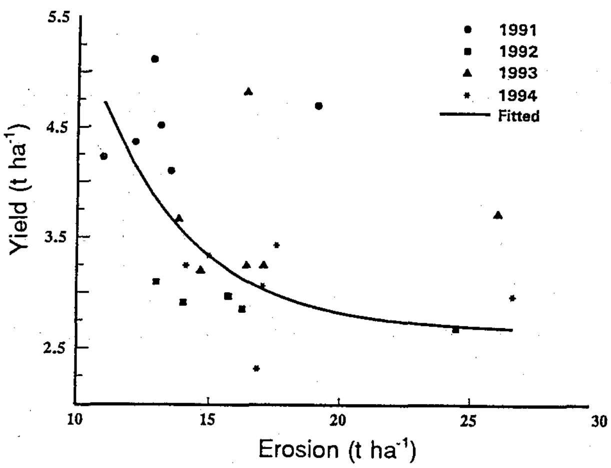


***Figure 14. Yield of groundnut pods and haulms versus cumulative erosion in NF– plots.***

During the first 2 years (1988 and 1989) of the study, six main levels of erosion (with four replications) were induced naturally by stretching over 24 Wischmeier-type erosion plots (25 m × 3 m), plastic meshes of different size apertures. By the end of this controlled erosion period, the plots had suffered markedly different degrees of erosion which in turn affected the productive potential of the soil. In June 1990, an equal number of additional plots were desurfaced to simulate six levels of erosion from 3 to 320 t ha$^{-1}$, corresponding to depths from 0.2 to 20 mm. We have, since 1990, been cropping both the naturally eroded and desurfaced plots to determine if any relationship exists between yield of groundnut (var. Robut-1) and cumulative erosion. One half of each plot was fertilized each year with 100 kg ha$^{-1}$ diammonium phosphate (DAP).

Seasonal rainfall during the period of experimentation was 548.3 mm in 1991, 486.1 mm in 1992, 449.1 mm in 1993, and 595.7 mm in 1994. The mean yield ($Y_t$) of groundnut pods and haulms from the naturally eroded nonfertilized (NF-) plots decreased rapidly as the cumulative erosion by water increased (Fig. 14). In the case of the NF+ plots, the rapid rate of decline had decreased at erosion rates greater than 12 t ha$^{-1}$. It was postulated that addition of fertilizers would mask the yield decline due to erosion. Therefore, this relationship was unexpected and appears to indicate that either the fertilizer rate was not sufficient to offset the decline due to erosion or that other factors such as lower water content resulting from loss of clay may be involved. This hypothesis would be examined when particle size distribution measurements are examined in future. There was no consistent yield decline due to erosion in the desurfaced plots. In the desurfaced plots which were not fertilized (DF-), total yield was almost constant over erosion rates ranging from 6 to 325 t ha$^{-1}$. The high groundnut yield in 1993 does not reflect the total quantity of rainfall but its good distribution, because the rainfall amount was in the order 1994 > 1991 > 1992 > 1993.

We hypothesized that because runoff often selectively removes the clay fraction, the clay content of the plots would decrease with time, while the proportion of sand would correspondingly increase. The results of the particle size analysis indicate that with the exception of NF- plots, clay content decreased. The silt content, in all treatments increased by 1993. The sand content, however, decreased slightly in NF+, DF-, and DF+ treatments. There was an increase in the NF- plots between 1991 and 1992, but a drastic decrease by 1993. These results lead to the inference that clay and probably fine sand were eroded, while surprisingly, silt was not eroded.

There was a drastic decrease in total nitrogen content of the soil by 1993 due to erosion (Fig. 15).

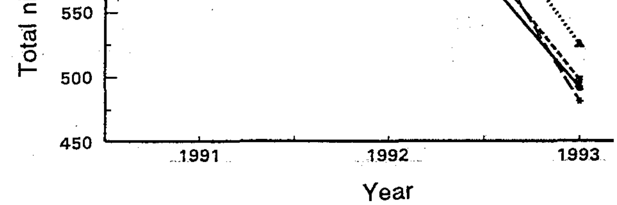


***Figure 15. Mean nitrogen content (six values) of different erosion treatments versus time.***

With the exception of DF- plots which had slight increase in total nitrogen, there was no significant difference in total nitrogen content of the other treatments by 1993. Available phosphorus for the nonfertilized plots (i.e., NF- and DF-) was lower than that in the NF+ and DF+ plots. By 1993, there was no difference in available phosphorus in the NF- and DF- plots. There was a large increase of available phosphorus in 1992 in the NF+ and the DF+ plots. This increase could not be explained. The exchangeable potassium in all the treatments increased in 1992. The exchangeable potassium for the nonfertilized plots (NF- and DF-) was similar and greater than that for the fertilized plots (NF+ and DF+). It appears that phosphorus application, promoted utilization of more potassium by plants in the fertilized than in the nonfertilized plots.

## Vegetative Barriers for Erosion Control

In this experiment, we studied the effect of porous barriers (vetiver, lemon grass, and stone bund) on runoff and soil loss from plots with two land slopes (2.8% and 0.6%) on an Alfisol site. During summer, vegetative barriers suffered from prolonged drought. With rainfall in June, we observed faster recovery of vetiver compared with lemon grass. The data presented in Table 4 show that vetiver hedges were very effective in reducing runoff and soil loss from both 2.8 and 0.6% slope plots. Stone bund and lemon grass hedges were not effective in reducing runoff from 2.8% slope plots, but were very effective on 0.6% slopes. All barriers were effective in reducing soil loss on both 2.8 and 0.6% slopes. Multiple regression analysis with the data from all years showed that the rainfall amount and 30 min intensity and age of the barrier are important variables contributing to runoff.

***Table 4. Effect of porous and vegetative barriers on runoff and soil loss on two land slopes on an Alfisol site during 1994.***

| | | Runoff (mm) | | Soil loss (t $ha^{-1}$) | |
|---|---|---|---|---|---|
| | | Slope (%) | | | |
| Treatment (barriers) | Rainfall (mm) | 2.8 | 0.6 | 2.8 | 0.6 |
| Control (no barrier) | 591 | 281 | 222 | 8.15 | 1.95 |
| Lemon grass hedge | 591 | 247 | 54 | 4.99 | 0.62 |
| Stone bund | 591 | 239 | 87 | 3.29 | 0.70 |
| Vetiver hedge | 591 | 123 | 48 | 2.04 | 0.54 |

# Soil Management Effects on Physical and Biological Processes

## Soil Structure

The project 'Response of soil processes to modification of soil structure' was started in 1988 in collaboration with the Queensland Department of Primary Industries (QDPI), Australia, to assess the effect of some tillage, organic, and biological systems on soil structure and related processes. The systems include three tillage depths (0,10, and 20 cm deep) and three amendments (bare, 15 t $ha^{-1}$ per year farmyard manure (FYM), and 5 t $ha^{-1}$ per year rice straw) in a factorial combination, and six perennial systems with perennial pigeonpea, *Cenchrus ciliaris*, and *Stylosanthes hamata* as sole and mixtures. The beneficial effect of perennial systems on soil structure has been monitored since 1992 by returning the plots to annual cropping.

*Table 5. Effect of soil management on runoff and sorghum yields during 1994.*

| Treatment[1] | Runoff (mm) | Grain (t ha$^{-1}$) | Drymatter (t ha$^{-1}$) |
|---|---|---|---|
| ZTB | 159 | 2.60 | 4.56 |
| ZTF | 84 | 2.55 | 7.90 |
| ZTS | 52 | 3.52 | 7.35 |
| STB | 126 | 2.32 | 4.14 |
| STF | 84 | 2.70 | 8.08 |
| STS | 77 | 3.60 | 7.64 |
| DTB | 108 | 2.34 | 4.45 |
| DTF | 50 | 2.83 | 8.02 |
| DTS | 54 | 3.47 | 6.83 |
| P | 91 | 3.13 | 6.86 |
| PSt | 58 | 3.51 | 6.13 |
| PCSt | 71 | 3.22 | 5.94 |
| C | 83 | 3.20 | 6.38 |
| CSt | 90 | 3.41 | 6.63 |
| St | 68 | 3.39 | 6.19 |
| SEd | 17.8 | 0.37 | 0.51 |
| CV (%) | 22.4 | 12.9 | 8.33 |

1. ZT = Zero tillage; ST = Shallow tillage; DT = Deep tillage; B = Bare; F = FYM about 15 t ha$^{-1}$ per year; S = Straw about 5 t ha$^{-1}$ per year; P = Pigeonpea; C = *Cenchrus ciliaris*; and St = *Stylosanthes hamata*.

During 1994, all the plots were cropped with sorghum. The trends in runoff and grain and dry-matter yields were similar to those observed in earlier years (Table 5). Runoff was significantly low in all plots amended with FYM or straw and prior perennials compared with nonamended bare plots. The benefit was about 70–100 mm. Grain yields were higher in plots amended with straw and prior perennials. Grain yields from FYM-amended plots were very similar to those in bare plots. However, dry-matter yields were significantly higher in FYM-amended systems compared with bare systems. This is attributed to the rainfall at the time of flowering. Sorghum in FYM-amended systems flowered a week earlier than in other systems.

An analysis of previous years data was done to quantify the changes in infiltration and runoff with time under different management options. The effect of tillage on infiltration and runoff was directly related to the rainfall since tillage. A sharp reduction in infiltration and increase in runoff was observed with the first 100 mm rainfall since tillage. Tillage benefits disappeared with about 350 mm rainfall since tillage. A gradual reduction in runoff was observed in the systems amended with FYM, suggesting the structural buildup. Runoff from prior perennial plots was found to increase with time ever since their return to annual cropping. This is probably an indication of the structural degradation in these systems.

### Modeling

A simulation model PERFECT (Productivity Erosion Runoff Functions to Evaluate Conservation Techniques) was calibrated and validated using the data from the project. With some modifications, the model was able to predict well, the effects of soil management on runoff. The values of root mean square error for the 1:1 line ranged from 4 to 6. The model explained 70–88% variation in daily runoff volume.

## Soil Management and Earthworm Biomass in Alfisols

The earthworms collected across 15 soil management treatments in an Alfisol during 1989–93 belonged to two species; *Octochaetona phillotti* (Michaelson) and *Lampito mauritii* (Kinberg), the former being dominant. They were of endogenic nature. The earthworms collected from the nearby undisturbed natural revegetation area belonged to three species including the above two, and the other being *Octonochaeta rosea* (Stephenson), which was bigger and deeper burrowing than the other two. The species composition of earthworms did not differ across these soil management treatments for the past 5 years.

There was very little or no earthworm biomass from September 1989 to September 1991 in the annual treatments, except in zero-tillage with FYM treatment. However, there was no such variation in biomass in perennial treatments. The biomass was significantly higher during the 1992 cropping season, compared with that of earlier 3 years

(1989–91) and that of 1993 (Fig. 16). The decrease in biomass under the annual treatments and during the earlier years was most probably due to the synergetic effects of carbofuran and herbicides applied during July 1989, which probably suppressed the biomass till September 1991. The biomass could recover from the ecotoxic effects of the pesticides after 3 years.

The biomass of earthworms was significantly lower ($P \leq 0.05$) in the annual treatments with tillage and organic amendments, compared with those of the perennial ley treatments during all the 5 years, although there was little discernible difference among the tillage treatments (Fig. 16). The average biomass during the five crop seasons across the 15 treatments significantly differed ($P \leq 0.01$), indicating the distinct effects of all the soil management treatments on the biomass. The increased biomass in the perennial leguminous cover-crop treatments was probably a result of the increased amount of plant residue on the soil surface with higher nitrogen content in soil; also, the cover crops reduced the chance for dry soil period that limits the earthworm activity.

The monthly average biomass of earthworms in the natural revegetation area (75.9 g $m^{-2}$) was several-fold higher compared with those under soil management treatments during 1992 and 1993. It was >29 times higher compared with the zero-tillage bare treatment, and >4 times higher than that of the *S. hamata* treatment. This showed a distinct impact of soil management practices on the earthworm biomass. The biomass under the arable area was low, probably due to the small size of the earthworms, compared with that of the natural revegetation area. The decline in biomass under arable land, particularly under the tillage, compared with the undisturbed areas, may be attributable to the mechanical damage during cultivation. Thus, it was concluded that soil managements such as tillage and application of agrochemicals had deleterious effects on earthworm biomass, while the cover-crop treatments showed positive effects.

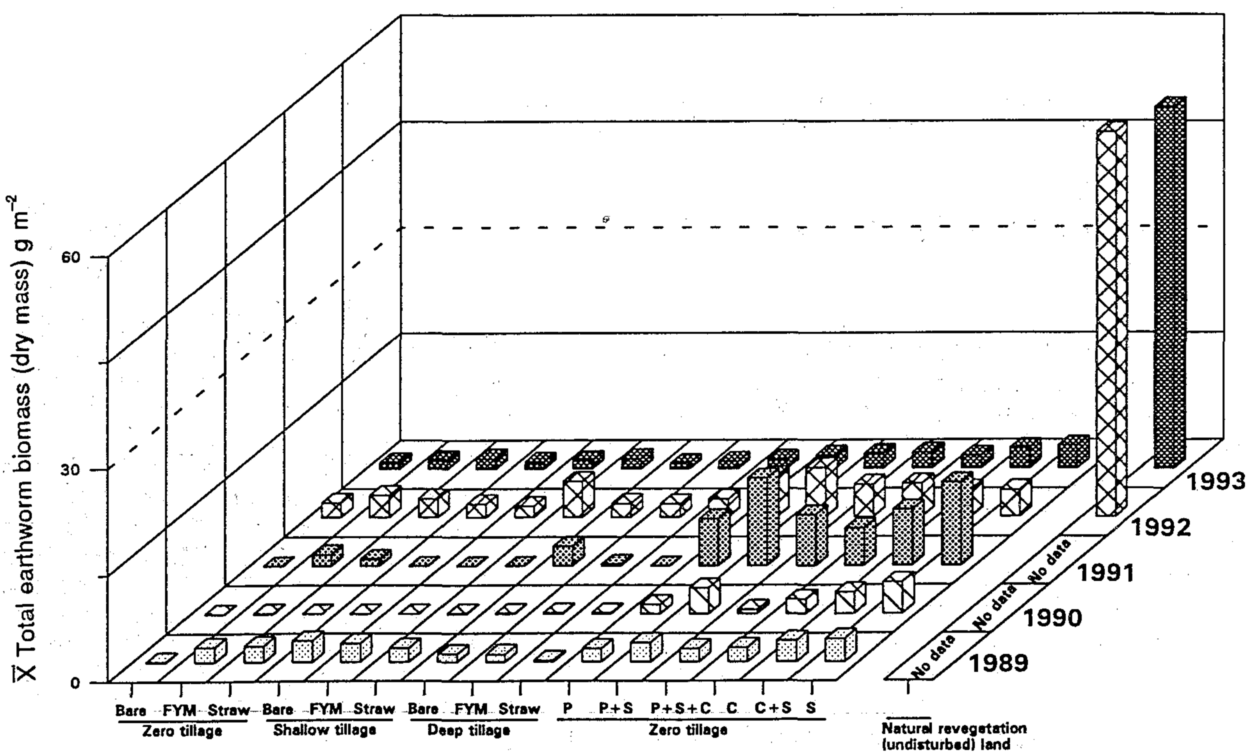


***Figure 16. Biomass (X̄) of earthworms across 15 soil management treatments and in the natural revegetation undisturbed area (P =** **Perennial pigeonpea,** ***S =*** **Stylosanthes hamata,** ***and C =*** **Cenchrus ciliaris*).**

## Soil Surface Management and Microorganisms

Soil productivity greatly depends on the balance between physical, chemical, and biological properties of soil. Soil management has a great impact on biological properties through changes in soil environment, addition of energy source for soil biota, and interaction among members of soil biota. A project was established in 1988 at IAC by ICRISAT and QDPI, to study the response of soil processes to the modification of soil structure of an Alfisol (for details refer to SACD - Soil Structure). As the experiment in the project has various soil surface amendment treatments which include different tillages and organic amendments, it was thought that the project could provide a research topic on the effect of soil amendment on soil microorganisms with a long-term objective to interrelate soil microbial activities with soil processes.

In 1994, we analyzed and compiled the data of soil microbial biomass C and N, and vesicular-arbuscular (VA) mycorrhiza collected in 1991–1993 from selected treatments in the project experiment. Soil and root samples were collected from zero tillage with no amendment (bare) (ZTB), zero tillage with 15 t $ha^{-1}$ FYM (ZTF), zero tillage with 5 t $ha^{-1}$ rice straw (ZTS), 20 cm deep tillage with no amendment (bare) (DTB), 20 cm deep tillage with 15 t $ha^{-1}$ FYM (DTF), 20 cm deep tillage with 5 t $ha^{-1}$ rice straw (DTS), a perennial grass *Cenchrus ciliaris* without tillage (C) and a perennial crop *Stylosanthes hamata* without tillage (S). Pearl millet in 1988, sorghum in 1989 and 1990, and maize in 1991 were sowed in all the tillage treatments except perennial treatments. In 1992, all treatments including perennial treatments were sowed to maize, and to sorghum in 1993.

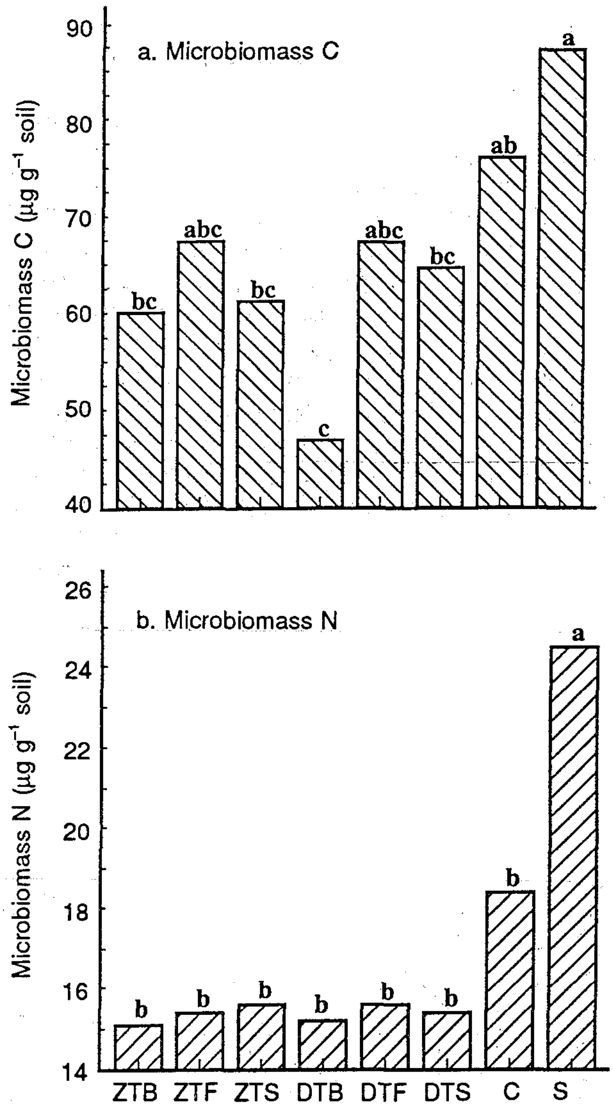


***Figure 17. Soil microbial biomass C and N. Values are the mean of three samplings during 1991, 1992, and 1993. Means followed by different letters are significantly different (P ≤0.05). [ZTB = Zero tillage with no amendment (bare), ZTF = Zero tillage with farmyard manure (FYM), ZTS = Zero tillage with rice straw, DTB = Deep tillage with no amendment (bare), DTF = Deep tillage with FYM, DTS = Deep tillage with rice straw, C =* Cenchrus ciliaris*, S =* Stylosanthes hamata*].***

The means of soil microbial biomass C, measured one time each year for 3 years, are shown in Figure 17. The trend that perennial treatments have higher biomass C was found, but it was not statistically significant. Biomass C was significantly lower in deep tillage with no amendment treatment than in any other treatment. Figure 17 shows the means of soil microbial N for 3 years, which was significantly higher in the *S. hamata* treatment than in any other treatments. Like biomass C, biomass N was also higher in perennial treatments. Generally, soil microbial biomass has been reported to be higher in zero-tillage or in straw application. In this study, biomass N was not affected by tillage or organic material treatments, although there was a trend that biomass C was the lowest in zero tillage without organic material addition.

Soil microbial biomass was measured around 50% inflorescence stage of maize and sorghum each year in this study. In the terminal review of QDPI-ICRISAT project in March 1994, it was mentioned that tillage effect diminished in a short period because of the intensive rainfall and soil structure. This quick diminishment of tillage effect may have resulted, at least in part, in no-tillage effect on soil microbial biomass. In the case of straw application, we observed that much of the straw applied had been carried away by termites before the straw was decayed by microorganisms. It is likely that much of organic fraction has not entered the soil due to termite activity.

One of the perennial treatments—*S. hamata* treatment—caused the largest increase in soil biomass C and N. Several other studies have shown that soil biomass levels are higher in the treatments sown to leguminous pasture, regardless of nutrient managements. It is surmised that *S. hamata* have some effects on increased soil microbial biomass like other leguminous pastures.

It is well recognized that soil microorganisms contribute to soil aggregate formation. The ICRISAT-QDPI project studied the effect of all 15 soil management treatments on the abundance of aggregates larger than 2 mm. Among the eight treatments selected in this study, the percentage in aggregates larger than 2 mm was the highest in *S. hamata* treatment, followed by *C. ciliaris* treatment. As mentioned earlier, soil microbial biomass C and N were the highest in *S. hamata* treatment, followed by *C. ciliaris* treatment. Further study is required to delineate the relationship between aggregates abundance and soil microbial biomass.

The means of VA mycorrhizal infection are shown in Figure 18. Contrary to biomass C and N, the VA-mycorrhizal infection trend was lower in perennial treatments. Deep tillage treatments except the one with FYM showed higher mycorrhizal infection. It has been often reported that VA mycorrhiza infection was higher in crops grown in zero-tillage soil than in disturbed soil, and that FYM application stimulated VA mycorrhiza. Contrary to these reports in this study, the two deep tillage treatments, with no amendment and with straw application, tended to increase VA mycorrhizal infection, and perennial treatments which are considered as zero tillage, tended to cause the decrease in VA mycorrhizal infection. There was no effect of FYM on VA mycorrhiza, either. At present, we cannot explain the difference seen in our observations as against general observations. However, it may be possible that increased VA mycorrhizal infection in deep tillage treatments is associated with increased dispersal of infective hyphae or propagules by disturbing the soil.

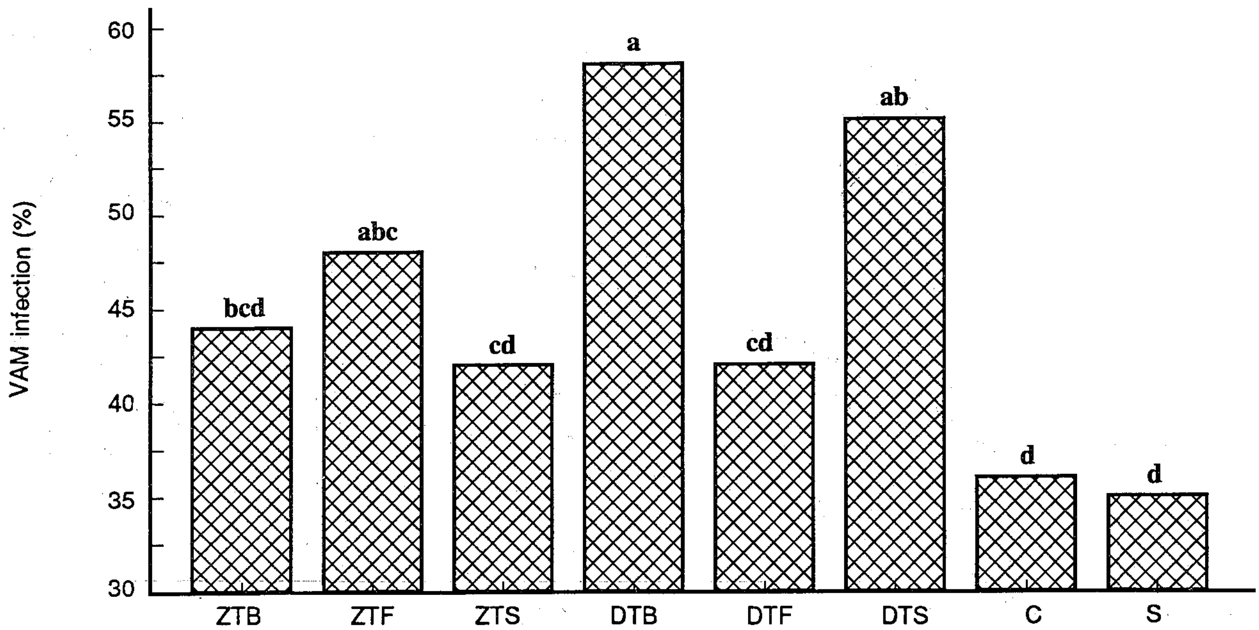


***Figure 18. Vesicular-arbuscular mycorrhizal infection. Values are the means of three replications. Means followed by different letters are significantly different (P ≤0.05). [ZTB = Zero tillage with no amendment (bare), ZTF = Zero tillage with farmyard manure (FYM), ZTS = Zero tillage with rice straw, DTB = Deep tillage with no amendment (bare), DTF = Deep tillage with FYM, DTS = Deep tillage with rice straw, C =*** **Cenchrus ciliaris,** ***S =*** **Stylosanthes hamata*****].***

## Variation in Soil Factors and their Effect on Crop Establishment

Experiments were conducted in the laboratory to study compaction characteristics of an Alfisol and a Vertisol, and the effects of compaction on imbibition of groundnut (in Alfisol) and chickpea (in Vertisol).

Alfisol samples (from RW 3 field) at different moisture contents (range 6–11%) were compressed with different levels of pressure (0.2–1.1 kg $cm^{-2}$), to determine their compaction response. It was found that soil bulk density increased with increase in applied pressure. Soil samples at higher moisture contents attained a higher bulk density compared with soil samples at lower moisture contents for the same level of applied pressure. The relationship between soil bulk density and applied pressure was represented by a power function having $R^2$ greater than 0.93 (Fig. 19). Soil samples (from BW 5 field) at different moisture contents (range 12–22%) were compressed with different levels of pressure (0.1–1.4 kg $cm^{-2}$). It was observed that soil bulk density increased with increase in applied pressure. Soil samples at a higher moisture content attained higher bulk density than soil samples at lower moisture content for the same level of applied pressure. The relationship between soil bulk density and applied pressure was represented by a power function having $R^2$ greater than 0.90.

Imbibition of groundnut seeds was studied by keeping the seeds in the soil (moisture content 6%, 8%, and 11%), and then compressing the soil to different levels of bulk density in the range of 1.2–1.4 g $cm^{-2}$. We observed that increase in seed moisture content was greater for seeds kept in soil having higher bulk density compared with seeds kept in soil at lower bulk density. Moisture gained by seeds at 24 h of hydration period was significantly higher ($P \leq 0.05$) at higher bulk densities than at lower bulk densities for all the soil moisture levels. However, at 48 h of hydration the differences in seed moisture (due to difference in soil density) were significant for soil samples having moisture contents of 6% and 8% only. The effect of soil compaction on imbibition of chickpea seeds was studied by keeping the seeds in soil (collected from BW 5) at different moisture contents (10.6–24.5%) and then compressing the soil to different levels of bulk density. We observed that moisture gained by seeds was greater at higher bulk density compared with those at lower bulk density for soils at 20.3 and 24.5% moisture contents. Differences in the seed moisture due to density effect were significant ($P \leq 0.05$), at 48 h for soil at 24.5% moisture, and at 72 h for soil at 20.3% moisture. However, the soil density effect on moisture gained by chickpea seeds was not significant for soils at 10.6 and 16.9% moisture, throughout the hydration period.

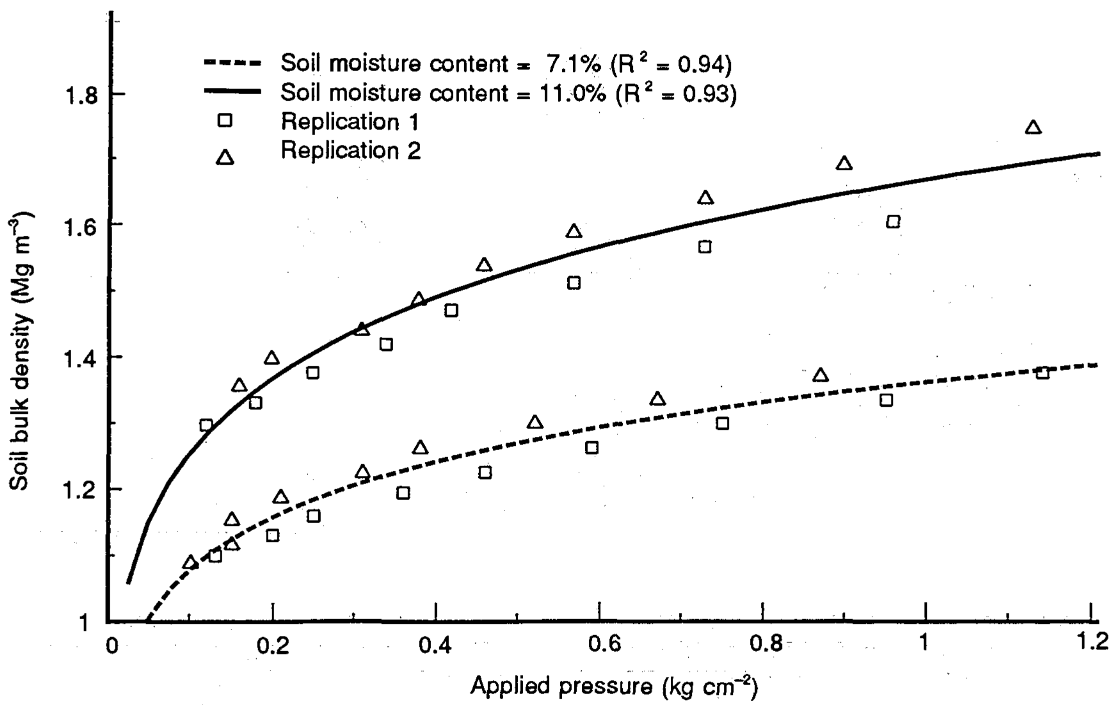


***Figure 19. Compaction response of Alfisol samples.***

## Soil Compaction and Penetration Resistance

Soil compactibility and penetration resistance of soil has, in the past, been used to study soil management effects on agricultural soils. Experiments were conducted to study compactibility and needle penetrometer resistance of soil, taken from different plots of an experimental field (RM19B), which have been under combination of two tillage treatments (no till, and tillage to two depths at 100 and 200 mm), and two management practices (no FYM and 15 t $ha^{-1}$ FYM), for the last 5 years.

Soil was passed through a 2-mm sieve, and samples were prepared for soil compressibility test. The test samples were compressed under a plunger in a cylinder. The force needed for compression and the corresponding displacement of the plunger were measured, and used to draw graphs between applied pressure and the density of soil samples. Results show that the soil with no FYM has higher compressibility than the soil that received FYM at a rate of 15 t $ha^{-1}$, under both the tillage treatments. The differences in bulk density (wet basis) of soil under different treatments are statistically significant at higher levels of applied pressure.

The sieved soil was used to prepare samples at three density levels (1.34, 1.46, and 1.62 Mg $m^{-3}$) having 4% and 8% moisture contents for the needle penetration test. The force needed for the penetration of needle penetrometer and the corresponding depth of penetration were recorded. Results show that addition of FYM increased penetration resistance (at 15 mm depth) of the soil under deep and shallow tillage. This is in agreement with our earlier observations, indicating that the soil with no FYM offers a lesser resistance to compression than the soil that received FYM at a rate of 15 t $ha^{-1}$, under both the tillage treatments. It was also observed that the needle penetration resistance of soil containing FYM increased with increase in intensity of tillage. The soil samples taken from shallow tillage had higher penetration resistance than those from zero tillage, but lower penetration resistance than those from deep tillage at all the density levels.

# CLAN - GIS - PQU - TAFP

# Research Support and Network

# Cereals and Legumes Asia Network (CLAN)

*The Cereals and Legumes Asia Network (CLAN) is a collaborative research and technology exchange network. ICRISAT provides the Coordination Unit, and also the technical and backup support on ICRISAT mandate crops (sorghum, pearl millet, chickpea, pigeonpea, and groundnut). CLAN works closely with the scientists at ICRISAT Asia Center (IAC) and in the national programs as equal partners in planning, experimentation, monitoring, and evaluation of approved collaborative research endeavors. Currently, CLAN activities are concentrated in Bangladesh, China, India, Indonesia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam.*

## Review and Work Plan Meetings

Review and Work Plan meetings are held every 1 or 2 years in each member country to review the past research results, identify future research needs and priorities, and to prepare a work plan for collaborative research. The work plan contains details of administrative procedures and protocols, and agreed experimental plans, material, and staff exchange, training, etc. During 1994, review and work plan meetings were held in Indonesia (19 Jan), Thailand (22 Jan), Myanmar (18–20 May), Nepal (16–17 Jun), and China (1–2 Jul), and collaborative work plans were developed with each country.

## Consultation with Asian NARS

A consultation meeting with senior research administrators from Bangladesh, China, India, Indonesia, Nepal, and Thailand was held during 9–10 Jun at IAC.

The purpose of the consultation was to interact with the National Agricultural Research Systems (NARS) to solicit their comments and suggestions on ICRISAT's medium-term plan (MTP) projects' formulation. Senior administrators from NARS expressed their satisfaction on the project planning exercise, which was based on priority themes and production systems concept. The participants suggested that consultation should be extended to scientists in the national programs.

Subsequently, consultation meetings with scientists were organized in Bangladesh, India, Myanmar, Nepal, Thailand, and Vietnam during Sep-Oct to discuss detailed project proposals. The feedback, comments, and suggestions were incorporated and the projects were revised.

## Working Group Meetings

A Working Group consists of scientists who have expressed interest and commitment to work together to address and solve high-priority regional problems. Each working group's activities (as agreed to at the meetings) are facilitated by a Technical Coordinator. CLAN supports the working groups by providing administrative and logistic support to the Technical Coordinator, and to the working group members. Two working group meetings were held during the reporting period:

- Third groundnut bacterial wilt working group meeting was held 4–5 Jul at Wuhan, China, to review the results of past research on bacterial wilt pathogen, its detection and diagnosis, host-plant resistance, cultural and biological control, and to prepare plans for future research on groundnut bacterial wilt in Asia.
- A consultative meeting was organized at IAC, 26–27 Jul to review the current research on cytoplasmic male sterility (CMS) in pigeonpea, develop research strategies to achieve viable CMS systems, and to establish a collaborative work plan for future research. ICRISAT Asia Center was requested to coordinate the activities of the working group.

## Monitoring of Network Collaborative Activities

Regular visits to on-station and on-farm experiments are essential to monitor the progress of research, obtain feedback, and assist in mid-term corrections if required, in on-farm trials. Such visits are usually undertaken by NARS scientists. Joint (IAC and NARS staff) monitoring tours were conducted in Bangladesh, Indonesia, Myanmar, Nepal, Sri Lanka, and Vietnam, during the cropping season to facilitate interaction and exchange of ideas among the national scientists, extension officials and IAC scientists, and with farmers regarding on-farm research trials.

### Asian Grain Legumes On-Farm Research (AGLOR)

Asian Grain Legumes On-Farm Research is a component of FAO/RAS Project and is being implemented since 1990 in Indonesia, Nepal, Sri Lanka, and Vietnam. The main objective of the AGLOR project is to generate and evaluate high-yield technology options in farmers fields, with the active participation of farmers. During the initial years of the project (1990–1993), single-factor diagnostic trials were evaluated, and subsequently, during 1993–95, a combination of two or more factors which could increase yields were tested. For example, in Indonesia, the high-yield technology was tested in large areas (up to 5 ha) in Tuban (East Java) and Subang (West Java). In Tuban, improved practices gave a pod yield of 1.68 t $ha^{-1}$ compared with 0.88 t $ha^{-1}$ using the traditional farmers' practices, while in Subang, improved practices gave a pod yield of 2.08 t $ha^{-1}$ compared with 1.41 t $ha^{-1}$ using farmers' practices.

### Special Pigeonpea Production Projects

***Sri Lanka.*** The Asian Development Bank (ADB) approved the second phase of the pigeonpea project, which became operational in Jan 1994. The Resident Scientist took up his position in August to assist the execution of the project (detailed report given elsewhere).

***Thailand.*** A trilateral project (involving Field Crops Research Institute, Bangkok; Siamati Ltd., Bangkok; and ICRISAT) was started in 1992 to commercially produce pigeonpea in northern Thailand (Chiang Rai, and Chiang Mai) in about 100 ha. A short-duration pigeonpea variety ICPL 151 gave up to 3 t $ha^{-1}$ in farmers' fields, when sown in the second week of July. Medium-duration lines (intercropped with maize) yielded around 2.5 t $ha^{-1}$ Saimati Ltd. processes the pigeonpea procured from farmers for export of *dhal* to other countries.

### Human Resource Development

The CLAN Coordination Unit facilitated the training of technicians and scientists from member countries [details in Training and Fellowships Program (TAFP) report].

A special training course on Diagnosis and Detection of *Pseudomonas solanacearum* and for Resistance Screening Against Groundnut Bacterial Wilt was organized during 6–9 Jul, Wuhan, China. Thirteen scientists from China, two from Vietnam, and one each from Malaysia and Thailand attended the course. The trainees were provided hands-on training on isolation, identification, and differentiation of biovars of *Pseudomonas solanacearum* using conventional techniques, and detection and identification using the enzyme-linked immunosorbent assay (ELISA), polymerase chain reaction (PCR), bacterial identification (BACTID), and Biolog techniques.

### Exchange of Scientists' Visits

Exchange of visits of scientists from NARS and IAC enhances interaction and exchange of research results and information, and assists in formulation of future joint research activities. Eighty-seven scientists from 10 Asian countries spent 555 person days visiting IAC, and/or participating in workshops and meetings. On the other hand, 60 IAC scientists visited 11 Asian countries and spent 650 days to participate in various technology exchange activities.

## Visits to Asia by ICRISAT Management

- ICRISAT's Director General (DG) visited Bangladesh and Nepal to visit the collaborative research activities, and for discussions with NARS administrators and Agriculture Ministry officials.
- The DG and Deputy Director General (DDG) visited China to participate in the China-CLAN/ICRISAT Review and Planning Meeting, and the Groundnut Bacterial Wilt Working Group Meeting. The DDG also visited the groundnut farmers' fields in Shandong Province, and the Shandong Peanut Research Institute, Laixi.
- Executive Director (ED), IAC, visited Nepal to participate in a Rice-Wheat Consortium Meeting, and later visited the legume research stations of Nepal Agricultural Research Council at Rampur and Parwanipur.
- The ED also visited Laos and held discussions with Senior Administrators to identify the needs of the NARS for ICRISAT's support in research and training.

## Pigeonpea in Sri Lanka

On the request of the Government of Sri Lanka, the second phase of pigeonpea research and development was initiated in Jan 1994, with technical support from ICRISAT and financial support from the ADB.

During 1993/94, a series of multilocational trials were conducted to identify high-yielding lines, better than the control ICPL 87. Determinate lines ICPL 85010 (1.1 t $ha^{-1}$), 88001 (0.8 t $ha^{-1}$), and MPG 537 (0.8 t $ha^{-1}$), and indeterminate lines ICPL 88028 (0.8 t $ha^{-1}$), 88034 (1.3 t $ha^{-1}$), and 89113 (1.2 t $ha^{-1}$) were identified for testing at many locations in the national coordinated varietal trial.

At present, short-duration pigeonpea variety ICPL 87 is being recommended for cultivation in Sri Lanka. This variety is however, susceptible to pod borers, especially *Maruca testulalis*. We compared yields of a newly bred *Maruca*-tolerant line MPG 537 with ICPL 87 in the on-farm trials (Table 1). Considering its performance over 2 years, MPG 537 (1.21 t $ha^{-1}$) was found to be 80.6% superior to ICPL 87 (0.67 t $ha^{-1}$) in seed yield. Seed of MPG 537 was multiplied for further testing.

***Table 1. Yield (t $ha^{-1}$) of MPG 537 and control ICPL 87 in on-farm varietal trials, 1992/93 and 1993/94 Maha seasons (main rainy seasons) in Sri Lanka.***

| Village | MPG 537 | ICPL 87 |
|---|---|---|
| 1992/93 | | |
| Iththawewa 1 | 0.50 | 0.43 |
| Iththawewa 2 | 0.89 | 0.84 |
| Iththawewa 3 | 0.67 | 0.28 |
| Ihalawewa | 0.57 | 0.15 |
| Bulankulama | 0.48 | 0.41 |
| Kurundankulama | 0.46 | 0.39 |
| Mean | 0.591 | 0.410 |
| 1993/94 | | |
| Thalagalla | 1.82 | 1.14 |
| Imbulgodaygama | 2.93 | 0.93 |
| Iththawewa | 1.15 | 0.74 |
| Mean | 1.834 | 0.931 |
| Overall mean | 1.213 | 0.671 |

**Processing and Utilization.** Considering the difficulties for *dhal* processing in Phase I of the project, the development of a suitable milling machine was given very high priority at the inception of the second phase. A consultant from India spent 10 days in Sri Lanka to assess the locally available machines and to make recommendations on the need to modify the existing machines, or fabricating new machines. Subsequently, an Engineer and a Food Technologist spent 3 weeks in India to study pigeonpea processing technology. The Indian prototypes imported under the Phase I, were carefully studied to ascertain the reasons for their frequent breakdowns.

Major changes in the design were incorporated to develop a small, efficient machine for use at the village level. Six new prototypes of the modified version were fabricated at the Farm Mechanization Research Centre, Maha Illuppallama. Preliminary field testing of these machines indicated that the modified versions produced better quality *dhal*. We plan to deploy these machines in the field for community level *dhal* milling in 1995.

In order to identify commercial processing machines to cater to the future needs of large-scale production, a survey was conducted in Colombo, Trincomalee, and Badulla districts. Of the 17 mills visited, 'Barik Mills' in Colombo, using pressure-type discs, was found to be the one with the most potential. Pigeonpea seeds processed in this mill gave good quality *dhal*. We plan to provide technical assistance to this mill in installing grading and separation facilities to improve processing efficiency and recovery of *dhal*.

A survey conducted to study the feasibility of selling pigeonpea *dhal* in three districts revealed that 48% of the hoteliers and 38% of the grocers had previous knowledge of pigeonpea consumption and marketing. Most respondents believed that pigeonpea *dhal* could be sold at a price higher than that of cowpea, black gram, yellow peas and green gram, and for large-scale consumption, pigeonpea *dhal* needs to compete with lentil.

# Geographic Information Systems (GIS)

Geographic Information Systems (GIS) became a support facility under the Regional Executive Director (RED), with a mandate of 50% support and 50% service. Eight PC-based Arc/info GIS licenses were distributed on loan to various Divisions in the Institute. The custodians of the GIS licenses for the respective Divisions comprises the GIS User's Committee, with L J Haravu (Senior Manager, Library and Documentation Services) as the Chairman.

## Support

### Corporate

- Maps of West, Central, southern, and eastern Africa; Southeast Asia; China; and Korea were plotted with country names for the use of Deputy Director General's office.
- Slides of the soil degradation maps of Australia for the Director General's office.
- A Zone map of Africa was produced at the request of the Information Management and Exchange Program for a workshop presentation.

### Agronomy Division

- The *mandal* map of Andhra Pradesh was digitized for the Indo-Swiss collaborative project for the Agronomy Division (Production Agronomy).
- The soil map of Vietnam was prepared from the FAO soils database for Do Thi Dzung, Research Scholar. Other databases from Vietnam brought by her were analyzed to help her in her Phd thesis.
- A few old graphs were digitized and their original values obtained.

### Crop Protection Division

- A global map showing *Sclerotium rolfsii* induced stem and pod rots in groundnut.
- Distribution of nematodes in Uttar Pradesh, India.
- Map showing *Helicoverpa* resistance nurseries in the world.

### Farm and Engineering Services Program

- Atlas GIS was loaded in the GIS facility to help FESP transfer some of their database files and obtain color hard copy outputs using the HPDesignjet 650C plotter.

### Socioeconomics and Policy Division

- Agroecological Zones (AEZ) maps for Asia were digitized. The percentage of the respective AEZ's in each district in India was calculated using GIS and dBASE.
- A cover page was designed and printed for the medium-term plan project proposals, using GIS and Corel graphics.
- *Heliothis* migration map in Andhra Pradesh was produced, and a copy of the map in Tiff format was provided.

### Soils and Agroclimatology Division

- Transparencies of ICRISAT mandate crops, Production Systems of India, and the state map of India were provided for a project formulation meeting.

## Projects Completed

- Productivity and stability of groundnut in Vietnam (a case study), Do Thi Dzung.
- Spread of pearl millet downy mildew, R Bandyopadhyay, Nandini Dendukuri.
- Quantifying levels of chemical spray from varying distances, C S Pawar.

## Interactions with the National Agricultural Research Systems

- The Central Research Institute for Dryland Agriculture (CRIDA) was assisted in converting their crop database into Arc/info-compatible format for trend analysis.

## Training Course

- A training course on basic GIS, digitization, and Arc/view was conducted for 19 staff members from 12–19 Sep 1994.

## Development and Initiation

- A software module to determine the heat unit availability in the rainy season for crops, based on their specific base temperature was developed and demonstrated to scientists.

  Using this module, scientists can determine graphically where their varieties can be released and what kind of varieties should be developed to target niche areas to meet cropping system demand, based on heat units at first approximation.
- Quick reference maps for Production Systems 1–10 for India have been made available to ICRISAT scientists as an internal publication, to help them to develop their project proposals. The publication shows maps depicting soil types, soil texture, slope phases, climate, distribution of ICRISAT mandate crops, and the districts within each production system.

# Plant Quarantine Unit (PQU)

## Exchange of Seed and Other Material

During the year, the Unit assisted the Plant Quarantine Regional Station of the National Bureau of Plant Genetic Resources (NBPGR) in clearing 42 086 seed samples of ICRISAT mandate crops comprising breeding lines and germplasm accessions, for export to 78 countries (Table 1).

The NBPGR released 2946 accessions of imported seeds (seedlings in case of groundnut) from 19 countries to grow in the Post Entry Quarantine Isolation Area (PEQIA).

Seed samples exported to cooperators or mentor institutes for laboratory studies were:

Sorghum : 3 seed samples for Restriction Fragment Length Polymorphism (RFLP) studies.
Pearl millet : 3179 seed samples for RFLP and for seed coat color variation studies.
Chickpea : 1 seed sample for RFLP.
Groundnut : 1 seed sample for greenhouse studies.

Besides, soil samples, leaf powder, and rhizobial agar slopes were exported to cooperators.

### Seed Health Testing

The seed samples for export were subjected to seed health tests for storage insect pests and pathogens. Thirteen seed samples of sorghum, 7 of chickpea, 25 of pigeonpea, and 89 seed samples of groundnut infested with storage insect pests were salvaged. One-hundred-and-one seed samples of sorghum, 21 of pearl millet, 97 of chickpea, 119 of pigeonpea, 127 of groundnut, and 10 seed samples of a minor millets were detained by NBPGR due to association of pathogens with seeds.

### Post Entry Quarantine Isolation Area

The imported seed samples, after their seed health tests by NBPGR, Hyderabad, were released for growing one generation in PEQIA, an isolated area in the southeast corner of IAC. This 'grow-out' serves as an additional check to intercept any exotic pathogen that may have escaped earlier tests. Sowing of imported seed samples (2946 seed samples imported, Table 1) continued the year round, as and when seed samples were released by NBPGR, in the presence of scientists from NBPGR, PQU staff, and the concerned scientist who imported the seeds. Crops were jointly inspected by NBPGR and PQU every week, until their harvest. Adequate plant protection measures for local insect pests (*Helicoverpa* in pigeonpea, shoot fly in sorghum, and thrips in groundnut) and diseases (late leaf spot in groundnut, and downy mildew in pearl millet and sorghum) were undertaken. Healthy seeds harvested from the mandate crops were released to scientists for their use. A nearby nethouse facility was used for growing-out tests for seed samples received in a limited quantity.

***Table 1. Cropwise details of seed samples exchanged through IAC and NBPGR during 1994[1].***

| | Number of seed samples | |
|---|---|---|
| Crop | Exports (through IAC) | Imports (through NBPGR) |
| Sorghum | 15 925 | 653 |
| Pearl Millet | 2 177 | 775 |
| Chickpea | 13 618 | 488 |
| Pigeonpea | 3 328 | 341[2] |
| Groundnut | 6 366 | 609[3] |
| Minor Millets | 672 | 80 |
| Total | 42 086 | 2946 |

1. IAC = ICRISAT Asia Center; NBPGR = National Bureau of Plant Genetic Resources.
2. Includes *Rhynchosia* spp.
3. Includes wild *Arachis* spp.

### Computerization of Seed Export Data

The Unit now has a comprehensive database of seed samples of mandate crops exported from 1978.

# Training and Fellowships Program (TAFP)

## HRDP Restructured

Human Resource Development Program (HRDP) was retitled Training and Fellowships Program (TAFP) reflecting a change in the organization and management structure of ICRISAT. Changes were also made in the Fellowship categories. Postdoctoral Fellows are called Research Fellows; and the two categories of Senior Research Fellows and Research Fellows now have one title: Visiting Scholars. There are no changes in the other categories, i.e., Research Scholars, In-Service Trainees, and Apprentices.

## Research Fellows

Pranesh S Badami (India) completed his 2-year Research Fellowship on 30 Jun 1994 in Cellular and Molecular Biology Division (CMBD). His research studies were related to wide hybridization and in vitro studies in *Cicer*.

J J Adu Gyamfi (Ghana), Research Fellow with the Government of Japan Project in Agronomy Division concluded his fellowship on 15 Sep 1994. His work contributed to the understanding of rooting behavior and nitrogen dynamics in sorghum/pigeonpea intercropping in Alfisols.

Eight Research Fellows (Table 1) are continuing their study programs during the second year of their Research Fellowship.

## Visiting Scholars

Thirty-nine scientists from 16 National Programs came for study programs ranging from 2 weeks to 12 months to learn and develop skills in different Research Divisions [Agronomy Division (AD)—4, Genetic Enhancement Division (GED)—10, Genetic Resources Division (GRD)—1, Cellular and Molecular Biology Division (CMBD)—7, Soil and Agroclimatology Division (SACD)—5, Crop Protection Division (CPD)—11, and TAFP—1].

## Research Scholars

Adib Sultana (India) in GRD, N H Nam (Vietnam) in AD, K G Kausalya (India) in CPD, and Uma Chitra (India) in CMBD completed their PhD theses research.

***Table 1. Research Fellows at ICRISAT Asia Center during 1994.***

| Name | Country | Research Division | Program |
|---|---|---|---|
| Sabine D Golembek | Germany | AD | Soil temperature studies on groundnut |
| Erik J van Oosterom | Holland | AD | Drought studies on pearl millet |
| Björn Seeling | Germany | SACD | Soil organic matter studies |
| Susan Cowgill | UK | CPD | Chickpea pest management |
| Mitsuru Yoshida | Japan | CPD | Host-plant resistance to *Helicoverpa* |
| Himani Bhatnagar | India | CPD | Influence of agricultural production systems on plant diseases |
| T Satyanarayana | India | CPD | Studies on plant bud necrosis virus |
| Ali Nur H Duale | Somalia | CPD | Biology and biocontrol potential of *Aprostectus coimbatorensis* |

Elasha E Elasha (Sudan) in AD, A S A B Binjeewad (Yemen) in GED, Claudia Sanetra (Germany) in SACD, and A Swarnalatha (India) in CPD concluded their MSc theses research.

Barbara R M Adolph (Germany) in Socioeconomics and Policy Division (SEPD), Elasha E. Elasha (Sudan) in AD, M Nivedita in SACD, T Rupa Singh and V Anitha in CPD (all from India) started their PhD theses research.

G Suresh Babu and K L N Prasad, both from India, began their theses research for Masters degree program.

Jayanty S S C M Sastry (India), Do Thi Dung (Vietnam), O P Jhorar (India), and M P K Jayawant (India), worked with the concerned Research Divisions for a few weeks to learn some of the techniques required for their theses research.

## In-Service Trainees

Twenty-eight participants from 20 countries attended the 1994 Rainy Season In-Service Training Program. Nine participants were trained in Cereals Improvement, 3 in Legumes Improvement, 12 in Production Agronomy, and 4 in Resource Management programs. They conducted 64 experiments, analyzed and interpreted the data, and wrote reports summarizing the results from their experiments.

Participants from China(1) and Pakistan(2) spent 10 weeks to learn the research techniques on chickpea improvement and production.

Md Abdul Kyuim (Bangladesh) underwent training in groundnut breeding, Aziz Fouman (Iran) in cereals breeding, Damodar Pokhrel (Nepal) in identification of groundnut pests and diseases, and H M S Bandara (Sri Lanka) underwent training in pigeonpea insect control through Integrated Pest Management procedures.

## Apprentices

Twenty-six Apprentices from Holland(5), India(13), Belgium(2), Ghana(1), UK(2), Australia(1), Japan(1), and Ethiopia(1) worked on different research projects in the various Research Divisions.

## Short Training Courses

A 6-week special training course in Agroclimatology at the request of United Nations Development Program (UNDP) under United Nations-Region for Arab Bureau (UN-RAB) concluded on 19 Jan 1994. Participants from Sudan(2), Syria(1), and Yemen(4) attended the training course. The National Coordinators and the Directors of Research of the member countries appreciated this training effort to their staff and expressed that this training would benefit them in the future.

A short in-country training course on research planning, data handling, and scientific report writing was conducted from 14 to 26 Feb 1994 at Joydebpur, Bangladesh. The course was attended by 60 scientists working with Bangladesh Agricultural Research Institute, and Crop Diversification Program, and was funded by Canadian International Development Agency (CIDA).

## Follow-Up Activities

Three-hundred-and-nine documents related to ICRISAT publications and journal articles, Skill Development Series, and computer-aided lessons in diskette form were distributed at the request of former TAFP participants.

# Information Exchange

ICRISAT works in 48 countries that between them have over 200 languages. Our publications obviously cannot take care of every one, but we are trying.

ICRISAT's identification handbooks—pocket-sized, illustrated books on common pests and diseases—are very popular throughout the semi-arid tropics (SAT). We are trying to make a good product even better, by translating these books into different languages, so that research and extension staff will find them easier to use, and farmers will be able to understand more clearly what our scientists do, and how their work will benefit them. This new publications thrust began with three Information Bulletins dealing with legume crops that are critical to smallholder farmers throughout Asia. Field Diagnosis of Chickpea Diseases and their Control is available in Arabic, Bangla, Chinese, English, Myanma, and Nepali; and the Pigeonpea and Chickpea Insect Identification Handbook in Chinese, English, Myanma, Nepali, Singhalese, and Tamil. Field Diagnosis of Groundnut Diseases is now available in English, Chinese, French, and Vietnamese.

The proceedings of a conference on groundnut bacterial wilt, which is a major disease in China, was published barely 6 months after the conference. This publication is another first for ICRISAT: the first of our publications to carry abstracts in Chinese and English. Groundnut research in China is considerably advanced, and this interaction in publishing can only strengthen scientific linkages between the Institute and research organizations in China.

However, this effort is not limited to Asia. Francophone Africa has long been a priority area in terms of bilingual publishing. All major reports are in both English and French. Translators at IAC and ISC make sure that journal articles, news items, book summaries, etc., are available in both languages. Portuguese is the major language in parts of the Central, Southern, and Eastern Africa (Mozambique, for example). ICRISAT conference proceedings relating to that region carry Portuguese summaries of all papers. An Information Bulletin on web blotch disease of groundnut has been published in Portuguese—the first time ICRISAT has brought out a full publication in that language. Spanish is another important language in the SAT. All ICRISAT publications relevant to Latin America carry Spanish abstracts; and several books are translated in full.

'This is ICRISAT' is a color booklet that describes the Institute's activities conducted at each of our locations around the world. We began with English and French. We have added five Indian languages—Hindi, Kannada, Marathi, Tamil, and Telugu, and a Hausa language version for western and central Africa.

Our in-house typesetting capacity grew considerably in 1994. Until then we could produce camera-ready pages in English, French, Spanish, and Portuguese. Last year we acquired new software that allows us to work in three Indian languages—Hindi, Marathi, and Kannada—and we plan to expand this list further.

Scientists and extension workers in many countries, whatever crops they work on, have one problem in common—improved cultivars or management practices are not adopted by farmers as widely or readily as they should be. One reason is lack of communication; our inability to convince farmers that the new product is in fact an improvement over the old ways. At ICRISAT, we now produce leaflets in Indian languages, explaining the advantages that these new products offer, and what exactly the farmer must do (for example, how far apart rows of plants should be, or what herbicides to apply and when) to maximize benefits. The leaflets are printed in Hindi, Kannada, Marathi, Tamil, and Telugu, and distributed on Farmers Days that the Institute hosts every year. The response has been excellent, and we believe that as local-language publications become more widely available, interactions between scientists, extension staff, and farmers will grow stronger, and that this will be gradually reflected in better farming practices, and higher incomes for smallholder farmers.

## Sharing the News

In 1994, we made a major change in newsletter publishing. The first issue of the Integrated Pest Management Newsletter was produced and circulated from entomologists at IAC. We merged the International Chickpea and International Pigeonpea Newsletters into one annual volume, and added to our list the International Sorghum and Millet that is copublished with Sorghum Improvement Conference of North America (SICNA) and the University of Georgia, USA.

We made conscious efforts to widen the scope of our three international newsletters by enlisting the help of Crop Coordinators in all regions.

We gave bulk copies of back issues of the International Arachis Newsletter to the National Centre for Groundnut, Junagadh, Gujarat, India, and the International Chickpea and International Pigeonpea Newsletters to the Indian Institute of Pulses Research, Kanpur, Uttar Pradesh, India. Our collaborators in these centers have many visitors who will make good use of the back issues, and in turn will help us to boost circulation, and the research centers will supply back issues on request.

All three newsletters will grow in size and circulation in the coming year—evidence that they are internationally recognized as useful vehicles for communication between crop scientists.

# Appendix

# Portfolio of Research Projects

ICRISAT's research portfolio contains 22 multidisciplinary projects—15 commodity projects on five crops (pearl millet, sorghum, chickpea, pigeonpea, and groundnut), 4 integrated systems projects that focus on multi-commodity systems, 2 projects on socioeconomics and impact assessment, and a genetic resources project. All the projects involve close collaboration with NARS and wherever necessary, with mentor institutions that have expertise in basic research. Research activities span a continuum—diagnostic, strategic, applied, and adaptive work. This ensures that our work is focused on our clients (farmers and NARS throughout the SAT), and that technology exchange is rapid and effective.

The broad objectives of our research portfolio are to—

- Develop cultivars resistant/tolerant to the major biotic and abiotic stresses, and well adapted to target production systems.
- Effectively deliver research products and disseminate information through training programs, workshops, seminars, publications, and field days.
- Monitor the adoption of new and existing technologies to ensure that research activities are accurately targeted, and are responsive to the needs of both farmers and the NARS.
- Build upon collaborative research partnerships with NARS to address specific regional concerns, and simultaneously to maximize spillover benefits across the SAT.
- Ensure sustainable improvements in productivity, while conserving the natural resource base and improving the quality of the environment.

## Single Commodity Projects

PM1 Improvement of pearl millet productivity and stability in arid to semi-arid tropical transition environments. Targeting techniques to farmers' needs; developing strategies for management of downy mildew, *Striga*, and insect pests; enhancing productivity and suitability in physically harsh environments; genetic enhancement of grain yield and adaptation; facilitate delivery of new technologies to NARS and farmers. PS 1 (Asia), 13 (WCA), and 19 (SEA), with spillover to 6, 12 (Asia), 14, 15 (WCA), and 20 (SEA).

PM2 Improvement of pearl millet productivity and stability in semi-arid tropical environments. Objectives as for PM1. PS 3, 8 (Asia), 14 (WCA), 20 (SEA) with spillover to 2, 4, 6, 7, 9 (Asia).

PM3 Improvement of pearl millet productivity and stability in long-season semi-arid tropical environments. Objectives as for PM1. PS 15 (WCA) with spillover to 20 (SEA).

SGI Improvement of sorghum productivity and stability in low-rainfall areas. Identifying constraints to sorghum production; integrated management strategies for *Striga*, economically important insects and abiotic stresses; developing improved genetic materials; technology exchange and impact studies. PS 19 (SEA) with spillover to 13, 14 (WCA), and 20 (SEA).

SG2 Improvement of sorghum productivity and stability in medium-rainfall areas. Identifying constraints to sorghum production; integrated management strategies for *Striga*, economically important diseases, insects and abiotic stresses; developing improved genetic materials; technology exchange and impact studies. PS 4, 7, 9 (Asia), 14, 15 (WCA), 20, 21 (SEA) with spillover to 5, 6 (Asia), 27, 29 (LAC).

SG3 Improvement of sorghum productivity and stability in high-rainfall areas. Identifying constraints to sorghum production; integrated management strategies for *Striga*, economically important diseases and insects; developing improved genetic materials; technology exchange; and impact studies. PS 16 (WCA) with spillover to 17 (WCA), 22 (SEA).

SG4 Improvement of sorghum productivity and stability in high altitude/low temperature areas. Identifying constraints to sorghum production; adaptation strategies for low temperature; integrated management strategies for economically important diseases; developing improved genetic materials; technology exchange; and impact studies. PS 23 (SEA) with spillover to 24 (SEA).

SG5 Improvement of sorghum productivity and stability in postrainy-season production. Objectives as for SG1. PS 7, 8 (Asia), with spillover to 6 (Asia).

GN1 Improvement of medium- and long-duration rainfed groundnut productivity and stability. Development of varieties resistant to biotic and abiotic constraints; understanding the epidemiology of the diseases; development of integrated management strategies for biotic and abiotic constraints. PS 6, 8, 9, 11 (Asia), 13, 14 (WCA), 20 (SEA) with spillover to 2, 3 ,5, 7 (Asia), 15, 16, 18 (WCA), 22 (SEA).

GN2 Improvement of short-duration rainfed groundnut productivity and stability. Objectives as for GN1. PS 5, 6, 8, 9, 10, 11 (Asia), 13 (WCA), 22 (SEA), with spillover to 2, 3, 7 (Asia), 14 (WCA), 21 (SEA).

GN3 Improvement of irrigated postrainy-season groundnut productivity and stability. Objectives as for GN 1. PS 5, 9, 10, 11 (Asia) with spillover to 2, 3, 4, 6, 7, 8 (Asia).

PP Enhancement of productivity, stability, and adoption of short-duration pigeonpea, and technology transfer in medium- and long-duration pigeonpeas. Short-duration pigeonpea research will include development and study of physiologically and morphologically efficient plant types, cytoplasmic and genetic male sterility for development of hybrids, identification, characterization, and incorporation of resistance/tolerance to biotic and abiotic stresses, integrated pest management and strategic adoption of enhanced short-duration germplasm in new environments and cropping systems. The medium- and long-duration pigeonpea research will focus on transfer of the enhanced genetic material to NARS for maintenance and utilization, multilocational adaptative testing with NARS of most promising disease and pod fly resistant material, and IPM. PS 2, 3, 7, 8, 9 (Asia), 20, 21 (SEA), and with spillover to 4, 5, 6, 10 (Asia), 15, 16 (WCA), 20, 21, 22, (SEA), 25, 27, 28 (LAC).

CP1 Chickpea improvement and management in dry and hot environments. Genetic enhancement; development of cultivars resistant to biotic and abiotic stresses; identification and intragression of desirable genes into chickpea. PS 4, 5, 6, 7, 8, 9, 11, 12 (Asia), 20, 21, 22, (SEA), 27 (LAC) with spillover to 1, 2, 3, 12 (Asia).

CP2 Chickpea improvement and management in moderately dry and cool environments. Genetic enhancement; development of cultivars resistant to biotic and abiotic stresses. PS 1, 2, 3, 10, 11 (Asia) with spillover to 4, 5, 6, 7, 8, 9, 12 (Asia), 17 (WCA), 19, 20 (SEA), 25 (LAC).

CP3 Chickpea improvement and management in moderately dry and cold environments. Genetic enhancement; development of cultivars resistant to biotic and abiotic stresses suitable for winter- and spring-sown chickpeas in WANA. PS 12 (Asia) with spillover to 1, 2, 3, 11 (Asia), 26 (LAC).

## Integrated Systems Projects

ISP1 Strategies for enhanced and sustainable productivity in rainfed short-season (60–100 days), millet/legume based production systems. Diagnosis of constraints, integration of technologies, improved genotypes into systems; strategies to enhance the availability and utilization of water and nutrients; strategies to reduce pests, diseases, and weed losses; resource management and modelling of component systems; technology exchange; impact assessment. PS 1 (Asia), 13 (WCA), 19 (SEA) with spillover to 12 (Asia), 14 (WCA), 20 (SEA).

ISP2 Strategies for enhanced and sustainable productivity in short- to intermediate-season (100–125 days) rainfed millet/sorghum/legume based production systems. Characterization of the environment; development of improved management strategies and improved cropping systems/land-use systems leading to improved productivity and sustainability; special focus on sorghum and groundnut-based production systems on sandy soils. The project is a vehicle to promote collaborative research between NARS, NGOs, and IARCs for the benefit of farmers in the domain. PS 9 (Asia), 14 (WCA), 20 (SEA) with spillover to 6 (Asia), 13 and 15 (WCA).

ISP3 Strategies for enhanced and sustainable productivity in low- to intermediate-rainfall (90–150 days) production systems in the SAT. Objectives as for ISP2. PS 7, 8 (Asia), 15, 18 (WCA), 21 (SEA) with spillover to 14, 16 (WCA), 20 (SEA).

ISP4 Legume-based technologies for rice and/or wheat production systems in South and Southeast Asia. This project is a vehicle for eco-regional research and is a means to demonstrate concentrated, efficient, and cooperative efforts by IRRI, ICRISAT, CIMMYT, NARSs, and other agencies to the benefit of farmers in the region by improving both productivity and sustainability through the development of improved legume-based technology. PS 2, 3, 5 (Asia) with spillover to 4, 10, 11 (Asia).

## Socioeconomic and Impact Projects

ECON1 Research evaluation and impact assessment (REIA). Systematic and comprehensive assessment of the benefits generated through ICRISAT research and their impact in farmers' fields. Global.

ECON2 Markets and policy. Examine production, utilization trends and impact of specific market policies on the trade and prices of ICRISAT mandate crops and review factors influencing the competitive position of these crops in national, regional and world economies; examine policy and infrastructural factors influencing the availability and use of inputs required for production, particularly seed. Global.

## Genetic Resources Project

GR Genetic resources assembly, evaluation, and management for conservation and utilization. Germplasm collection, evaluation, characterization, maintenance, distribution, impact assessment, and biodiversity studies. Global.

# Key Production Systems

## Asia

1. Transition zone from arid rangeland to rainfed, short-season millet/pulse/livestock. Eastern margins of the Thar Desert.
2. Subtropical lowland rainy and postrainy season, rainfed, mixed cropping. Central/eastern Indo-Gangetic Plains.
3. Subtropical lowland rainy and postrainy season, irrigated, wheat-based. Western Indo-Gangetic Plains.
4. Tropical, high-rainfall rainy plus postrainy season, rainfed, soybean/wheat/chickpea. Central India.
5. Tropical, lowland, rainfed/irrigated, rice-based. Eastern India, Myanmar, Thailand, Southeast Asia.
6. Tropical, lowland, short rainy season, rainfed, groundnut/millet. Saurastra Peninsula.
7. Tropical, intermediate rainfall, rainy season, sorghum/cotton/pigeonpea. Eastern Deccan Plateau, central Myanmar.
8. Tropical, low-rainfall, primarily rainfed, postrainy season, sorghum/oilseed. Western Deccan Plateau.
9. Tropical, intermediate-length rainy season, sorghum/oilseed/pigeonpea interspersed with locally irrigated rice. Peninsular India.
10. Tropical, upland, rainfed, rice-based. Eastern India, Southeast Asia.
11. Subtropical, major groundnut and sorghum. China.
12. Subtropical, intermediate elevation, winter rainfall and rainfed, wheat-based. West Asia and North Africa.

## West Africa

13. Transition zone from arid rangeland to short season (less than 100 days), rainfed, millet/cowpea/livestock. Sahelian western Africa, and southern margins of the Sahara Desert.
14. Intermediate season (100–125 days), rainfed, millet/sorghum/cowpea/groundnut-based. Northern Sudanian Zone.
15. Intermediate season (125–150 days), rainfed, mixed, sorghum-based. Southern Sudanian Zone.
16. Long season (150–180 days), rainfed, mixed, maize-based. Northern Guinean Zone.
17. Humid, bimodal rainfall, mixed, root-crop based. Southern Guinean and Forest Zones.
18. Low-lying areas prone to inundation, postrainy season, sorghum/millet/groundnut-based. Sahelian and Sudanian Zones.

## Southern and Eastern Africa

19. Lowland, rainfed, short season (less than 100 days), sorghum/millet/rangeland. Sahelian eastern Africa, and margins of the Kalahari Desert.
20. Semi-arid, intermediate season (100–125 days), sorghum/maize/rangeland. Eastern Africa and parts of southern Africa.
21. Intermediate season (125–150 days), sorghum/maize/finger millet/legumes. Eastern and southern Africa.
22. Lowland, subhumid, mixed, rice/maize/groundnut/pigeonpea/sorghum. Coastal areas of eastern and southern Africa.
23. Highland, rainfed, long season, (150–180 days), sorghum/maize/teff. Highland zones of northeastern and eastern Africa.
24. Highland, semi-arid, rainfed, intermediate season (100–120 days), mixed maize/sorghum/wheat/barley/pastoral. Highland zones of eastern and southern Africa.

## Latin America

25. Tropical, upland, rainfed, maize/sorghum intercropping. Central America and Hispaniola.
26. Tropical, intermediate elevation, subtropical summer rainfall, rainfed and irrigated, sorghum. Inland valleys of Mexico and Colombia, northern Argentina.
27. Tropical and subtropical coastal plains, rainfed/irrigated. Mainly Pacific coast of Central America.
28. Tropical, subhumid, rainfed, acid-soil savanna. Llanos of Colombia and Venezuela.
29. Intermediate-elevation, semi-arid, rainfed, acid soil. Northeastern and central Brazil.

# Workshops, Meetings, and Conferences

***Workshops, meetings, and conferences organized or sponsored by ICRISAT in the Asia region during 1994.***

| Date | Name of the Workshop/Meeting | Location | Cosponsors[1] |
|---|---|---|---|
| 19 Jan | Indonesia-CLAN/ICRISAT Review and Work Plan Meeting | Bogor (Indonesia) | CRIFC |
| 22 Jan | Thailand-CLAN/ICRISAT Review and Work Plan Meeting | Bangkok (Thailand) | FCRI |
| 1–5 Mar | Review and Planning Meeting on Water-Use Efficiency Project | Bombay (India) | BARC, ACIAR |
| 15–18 Mar | FAO-ICRISAT Expert Consultancy Workshop on "Genetic manipulation of crop plants to enhance integrated nutrient management in cropping systems. 1: phosphorous" | IAC | FAO |
| 21–26 Mar | ICRISAT Project Planning Meeting | IAC | |
| 18–19 May | Myanmar-CLAN/ICRISAT Review and Work Plan Meeting | Yezin (Myanmar) | MAS |
| 9–10 Jun | NARS Consultation on ICRISATs MTP Research Project Formulation | IAC | |
| 16–17 Jun | Nepal-CLAN/ICRISAT Review and Work Plan Meeting | Rampur (Nepal) | |
| 1–2 Jul | China-CLAN/ICRISAT Review and Work Plan Meeting | Beijing (China) | CAAS |
| 4–5 Jul | Third Groundnut Bacterial Wilt Working Group Meeting | Wuhan (China) | CAAS |
| 26–27 Jul | Consultative Group Meeting on Cyto-plasmic Male Sterility in Pigeonpea | IAC | ICAR |
| 5–6 Sep | Consultation with NARS on Sorghum Project Formulation | Hyderabad (India) | NRCS/ ICAR |
| 14–15 Sep | CRIDA Plant Protectionists Meeting | IAC | CRIDA/ICAR |
| 15–18 Sep | Consultation with NARS on Chickpea Pigeonpea Project ISP4 Project Formulation | Bikaner (India) | IIPR ICAR |
| 20 Sep | Consultation with NARS on ICRISAT Project Formulation | Kathmandu (Nepal) | NARC |
| 20 Sep | Consultation with NARS on ICRISAT Project Formulation | Bangkok (Thailand) | FCRI |

*Continued*

**Workshops, Meetings, and Conferences** (contd.)

| Date | Name of the Workshop/Meeting | Location | Cosponsors[1] |
|---|---|---|---|
| 21 Sep and 27 Sep | Consultation with NARS on ISP3 Project Formulation | Hyderabad (India) | CRIDA ICAR |
| 21 Sep | Consultation with NARS on ICRISAT Project Formulation | Hanoi (Vietnam) | MAFI |
| 22 Sep | Consultation with NARS on ICRISAT Project Formulation | Bogor (Indonesia) | CRIFC |
| 22 Sep | Consultation with NARS on ICRISAT Project Formulation | Joydebpur (Bangladesh) | BARI |
| 27 Sep | Consultation with NARS on ICRISAT Project Formulation | Yangon (Myanmar) | MAS |
| 18–19 Oct | Consultation with NARS on Pearl Millet Project Formulation | Pune (India) | AICPMIP/ ICAR |
| 7–11 Nov | Increasing Biological Nitrogen Fixation and Yield of Grain Legumes in Asia | IAC | FAO IAEA UNDP |
| 21–25 Nov | Dynamics of Roots and Nitrogen in Cropping Systems of the Semi-Arid Tropics | IAC | JIRCAS |
| 28 Nov–2 Dec | The Analysis and Exploitation of Plant Adaptation in Agricultural Crop Improvement Programs | IAC | IRRI |
| 14–16 Dec | Integration of Research Evaluation Efforts of ICRISAT with NARS and Other International Research Institutions | IAC | ACIAR AIDAB |

1. ACIAR = Australian Centre for International Agricultural Research; AICPMIP = All India Coordinated Pearl Millet Improvement Program; AIDAB = Australian International Development Assistance Bureau; BARC = Bhabha Atomic Research Center; BARI = Bangladesh Agricultural Research Institute; CAAS = Chinese Academy of Agricultural Sciences; CRIDA = Central Research Institute for Dryland Agriculture; CRIFC = Central Research Institute for Food Crops; FAO = Food and Agriculture Organization of the United Nations, FCRI = Field Crops Research Institute; IAEA = International Atomic Energy Agency; IAC = ICRISAT Asia Center; ICAR = Indian Council of Agricultural Research; IIPR = Indian Institute of Pulses Research; IRRI = International Rice Research Institute; JIRCAS = Japanese International Research Center for Agricultural Sciences; MAFI = Ministry of Agriculture and Food Industry; MAS = Myanmar Agriculture Service; MTP = Medium-Term Plan; NARC = National Agricultural Research Council; NARS = National Agricultural Research System(s); NCL = National Chemical Laboratory; NRCS = National Research Centre on Sorghum; UNDP = United Nations Development Program.

# Publications by the staff of the Asia region during 1994

## Summary Proceedings

**Bantilan, M.C.S.,** and **Joshi, P.K.** (eds.) 1994. Evaluating ICRISAT research impact: summary proceedings of a Workshop on Research Evaluation and Impact Assessment, 13–15 Dec 1993, ICRISAT Asia Center, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 148 pp. ISBN 92–9066–302–2.

**Gowda, C.L.L.,** and **Ramakrishna, A.** 1994. Working Groups on Biological Nitrogen Fixation in Legumes. Pages 6–10 *in* Linking Biological Nitrogen Fixation Research in Asia: Report of a meeting of the Asia Working Group on Biological Nitrogen Fixation in Legumes, 6–8 Dec 1993, Patancheru, A.P. 502 324, India. International Crops Research Institute for the Semi-Arid Tropics.

**Reddy, L.J.,** and **Nigam, S.N.** 1994. Germplasm enhancement in groundnut. Pages 38–42 *in* Evaluating ICRISAT research impact: summary proceedings of a workshop on Research Evaluation and Impact Assessment. 13–15 Dec 1993, ICRISAT Asia Center, India (Bantilan, M.C.S., and Joshi, P.K., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

**Rupela, O.P., Kumar Rao, J.V.D.K., Wani, S.P.,** and **Johansen, C.** (eds.) 1994. Linking biological nitrogen fixation research in Asia: Report of a meeting of the Asia Working Group on Biological Nitrogen Fixation in Legumes, 6–8 Dec 1993, ICRISAT Asia Center, India, Patancheru 502 324, Andhra Pradesh, India. 140 pp.

**Sharma, S.B.,** and **McDonald, D.** (eds.) 1994. International agricultural research on diseases caused by nematodes—needs and constraints: Summary and recommendations of a satellite meeting of the International Congress of Plant Pathology, 6 Aug 1993. Montreal, Canada, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 24 pp. Order Code: CPE 093.

**van Rheenen, H.A.** 1994. Recent advances in chickpea improvement. Pages 225–235 *in* Proceedings of Plant Breeding Symposium on Crop Breeding in India: Current Status and Future Strategy. Pantnagar, 2–4 Nov 1992.

**Virmani, S.M.** and **Chavez, L.T.** (Conveners). 1994. Soil Technology for Sustainable Agriculture. Transactions, Volume 7a, Commission VI: Soil Technology for Sustainable Agriculture, 15th World Congress of Soil Science, 10–16 Jul 1994, Acapulco, Mexico. International Society of Soil Science and The Mexican Society of Soil Science. 137 pp.

**Wright, G.C.,** and **Nageswara Rao, R.C.** (eds.) 1994. Selection for water-use efficiency in grain legumes. Report of a Workshop held at ICRISAT Center, Andhra Pradesh, India, 5–7 May 1993. ACIAR Technical Report no.27. Canberra, Australia: Australian Centre for International Agricultural Research. 70 pp.

## Books

**Intal, P.S.,** and **Bantilan, M.C.S.** (eds.) 1994. Understanding poverty and inequity in the Philippines: A compendium of policy and methodological researches. UNDP/NEDA Publication. United Nations Development Program/National Economic and Development Authority. 411 pp. ISBN 971–8535–04–7.

**Sehgal, J., Batta, R.K., Virmani, S.M., Nagabhushana, S.R.,** and **Sarma, V.A.K.** (eds.) 1994. International Seminar on Managing Red and Lateritic Soils for Sustainable Agriculture—Highlights, 24–28 Sep 1993, Bangalore, India. New Delhi, India: Oxford and IBH Publishing Co. 72 pp.

**Virmani, S.M., Katyal, J.C., Eswaran, H., and Abrol, I.P.** (eds.) 1994. Stressed ecosystems and sustainable agriculture. Proceedings of an International Symposium on Agroclimatology and Sustainable Agriculture in Stressed Environments, 15–20 Feb 1993, ICRISAT Asia Center, Patancheru, India. New Delhi, India: Oxford and IBH Publishing Co. 441 pp.

## Book Chapters

**Isleib, T.G., Wynne, J.C., and Nigam, S.N.** 1994. Groundnut breeding. Pages 552–623 *in* The groundnut crop. A scientific basis for improvement (Smartt, J., ed.). London, UK: Chapman and Hall. (JA 1466)

**Laryea, K.B., Cogle, A.L., and Pathak, P.** 1994. Tillage problems in rainfed soils: relevance to sustained productivity. Pages 119–134 *in* Soil management for sustainable agriculture in dryland areas. New Delhi, India: Indian Society of Soil Science. (CP 828)

**Middleton, K.J., Pande, S., Sharma, S.B., and Smith, D.H.** 1994. Diseases. Pages 336–394 *in* The groundnut crop. A scientific basis for improvement (Smartt, J., ed.). London, UK: Chapman and Hall. (JA 1468)

**Sharma, H.C.** 1994. Insect plant relationships. Pages 1–13 *in* Recent Advances in Insect Physiology and Toxicology (Gujar, G.T., ed.). New Delhi 110 024, India: Agricole Publishing Academy. (JA 1088)

**Singh, A.K., and Simpson, C.E.** 1994. Biosystematics and genetic resources. Pages 96–137 *in* The groundnut crop. A scientific basis for improvement (Smartt, J., ed.). London, UK: Chapman and Hall. (JA 1455)

**Subbarao, G.V., and Johansen, C.** 1994. Physiological mechanisms relevant to genetic improvement of salinity tolerance in crop plants. Pages 807–831 *in* Handbook of plant and crop physiology (Pessarakli, M., ed.). New York, USA: Marcel Dekker, Inc. (JA 1463)

**Subbarao, G.V., and Johansen, C.** 1994. Potential for genetic improvement in salinity tolerance in legumes: pigeonpea. Pages 581–595 *in* Handbook of plant and crop physiology (Pessarakli, M., ed.). New York, USA: Marcel Dekker, Inc. (JA 1428)

**Subbarao, G.V., and Johansen, C.** 1994. Strategies and scope for improving salinity tolerance in crop plants. Pages 559–579 *in* Handbook of plant and crop physiology (Pessarakli, M., ed.). New York, USA: Marcel Dekker, Inc. (JA 1462)

**Subbarao, G.V., Johansen, C., and Nageswara Rao, R.C.** 1994. Transpiration efficiency: avenues for genetic improvement. Pages 785–806 *in* Handbook of plant and crop physiology (Pessarakli, M., ed.). New York, USA: Marcel Dekker Inc. (JA 1609)

**Talukdar, B.S., Singh, S.D., and Hash, C.T.** 1994. Breeding for resistance to diseases in pearl millet. Pages 176–185 *in* Crop breeding in India (Singh, H.G., Mishra, S.N., Singh, T.B., Hari Ram, and Singh, D.P., eds.). Pantnagar, India: G.B. Pant University of Agriculture and Technology. (CP 846)

**Wightman, J.A., and Ranga Rao, G.V.** 1994. Groundnut pests. Pages 396–479 *in* The groundnut crop. A scientific basis for improvement (Smartt, J., ed.). London, UK: Chapman and Hall. (JA 1472)

**Wright, G.C., and Nageswara Rao, R.C.** 1994. Groundnut water relations. Pages 281–335 *in* The groundnut crop. A scientific basis for improvement. (Smartt, J., ed.) London, UK: Chapman and Hall. (JA 1457)

## Journal Articles

**Awadhwal, N.K., and Babu, M.M.** 1994. A multi-row bullock drawn planter for groundnut and some other dryland crops. Agricultural Engineering Journal 3(1 and 2):69–76. (JA 1668)

**Bidinger, F.R., Weltzien R.E., Mahalakshmi, V., Singh, S.D., and Rao, K.P.** 1994. Evaluation of landrace topcross hybrids of pearl millet for arid zone environments. Euphytica 76:215–226. (JA 1575)

**Butler, D.R.** 1994. Reply: comment on the paper "Daily patterns of dew-point temperature in a semiarid climate". Agricultural and Forest Meteorology 68:113–115. (Misc)

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## Breeders' Material Exchange during 1994 at ICRISAT Asia Center.

| Crop/ Country | Trials and nurseries: Sets | Entries | Breeder seed | Advanced lines | Segregating populations | Released material | Germplasm accessions | Others | Total |
|---|---|---|---|---|---|---|---|---|---|
| | No. of samples | | | | | | | | |
| **Sorghum** | | | | | | | | | |
| ***Asia*** | | | | | | | | | |
| China | 2 | 52 | 0 | | 76 | | 0 | 0 | 128 |
| India | 26 | 148 | 53 | | 2992 | | 2603 | 4 | 5800 |
| Indonesia | 6 | 113 | 0 | | 48 | | 0 | 0 | 161 |
| Iran | 2 | 150 | 0 | | 165 | | 96 | 10 | 421 |
| Lao, PDR | 1 | 26 | 0 | | 0 | | 0 | 0 | 26 |
| Myanmar | 6 | 135 | 0 | | 320 | | 0 | 0 | 455 |
| Pakistan | 27 | 511 | 0 | | 0 | | 0 | 0 | 511 |
| Saudi Arabia | 2 | 101 | 0 | | 0 | | 78 | 0 | 179 |
| Syria | 7 | 133 | 0 | | 0 | | 0 | 0 | 133 |
| Thailand | 12 | 220 | 0 | | 77 | | 8 | 2 | 307 |
| Vietnam | 3 | 63 | 0 | | 0 | | 0 | 0 | 63 |
| Yemen | 3 | 51 | 0 | | 128 | | 33 | 0 | 212 |
| ***Africa*** | | | | | | | | | |
| Benin | 1 | 25 | 0 | | 0 | | 0 | 0 | 25 |
| Botswana | 0 | 0 | 0 | | 27 | | 0 | 0 | 27 |
| Burkina Faso | 3 | 70 | 0 | | 0 | | 0 | 0 | 70 |
| Cameroon | 3 | 50 | 0 | | 0 | | 0 | 0 | 50 |
| Egypt | 16 | 317 | 0 | | 115 | | 1094 | 0 | 1526 |
| Ethiopia | 15 | 275 | 0 | | 16 | | 0 | 0 | 291 |
| Ghana | 3 | 70 | 0 | | 0 | | 0 | 0 | 70 |
| Kenya | 3 | 78 | 500 | | 100 | | 1017 | 0 | 1695 |
| Mali | 10 | 70 | 0 | | 0 | | 5 | 0 | 75 |
| Mozambique | 1 | 25 | 0 | | 0 | | 0 | 0 | 25 |
| Nigeria | 10 | 70 | 0 | | 120 | | 7 | 0 | 197 |
| Rwanda | 1 | 25 | 0 | | 0 | | 0 | 0 | 25 |
| Sudan | 14 | 221 | 0 | | 705 | | 11 | 0 | 937 |
| Togo | 2 | 45 | 0 | | 0 | | 0 | 0 | 45 |
| Uganda | 0 | 0 | 0 | | 0 | | 70 | 0 | 70 |
| Zambia | 23 | 70 | 0 | | 0 | | 1500 | 0 | 1570 |
| ***Europe*** | | | | | | | | | |
| Belgium | 0 | 0 | 0 | | 0 | | 2 | 1 | 3 |
| Germany | 0 | 0 | 0 | | 0 | | 34 | 0 | 34 |
| Italy | 0 | 0 | 0 | | 16 | | 45 | 0 | 61 |
| UK | 0 | 0 | 0 | | 3 | | 11 | 0 | 14 |
| ***The Americas*** | | | | | | | | | |
| Argentina | 1 | 25 | 0 | | 0 | | 0 | 0 | 25 |
| Canada | 0 | 0 | 0 | | 0 | | 353 | 0 | 353 |
| Dominican Republic | 0 | 0 | 0 | | 0 | | 0 | 24 | 24 |
| El Salvador | 1 | 25 | 0 | | 0 | | 0 | 0 | 25 |

*Continued*

Breeders' Material Exchange (contd.)

| Crop/ Country | No. of samples: Trials and nurseries: Sets | Entries | Breeder seed | Advanced lines | Segregating populations | Released material | Germplasm accessions | Others | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Sorghum** | | | | | | | | | |
| ***The Americas*** | | | | | | | | | |
| Mexico | 2 | 45 | 0 | | 0 | | 40 | 0 | 85 |
| Paraguay | 0 | 0 | 0 | | 6 | | 0 | 0 | 6 |
| Peru | 0 | 0 | 0 | | 61 | | 30 | 10 | 101 |
| Uruguay | 0 | 0 | 0 | | 0 | | 30 | 0 | 30 |
| USA | 0 | 0 | 0 | | 0 | | 445 | 0 | 445 |
| ***Oceania*** | | | | | | | | | |
| Australia | 1 | 25 | 0 | | 0 | | 0 | 0 | 25 |
| Total | 207 | 3234 | 553 | | 4975 | | 7512 | 51 | 16325 |
| **Pearl Millet** | | | | | | | | | |
| ***Asia*** | | | | | | | | | |
| Bangladesh | 0 | 0 | 0 | | 6 | | 0 | 0 | 6 |
| India | 54 | 981 | 462 | | 4500 | | 1216 | 0 | 7159 |
| Israel | 0 | 0 | 0 | | 0 | | 20 | 0 | 20 |
| Nepal | 1 | 28 | 0 | | 0 | | 0 | 0 | 28 |
| Pakistan | 7 | 199 | 0 | | 0 | | 0 | 0 | 199 |
| South Korea | 0 | 0 | 0 | | 41 | | 0 | 0 | 41 |
| Thailand | 0 | 0 | 0 | | 0 | | 2 | 0 | 2 |
| Yemen | 0 | 0 | 0 | | 16 | | 0 | 0 | 16 |
| ***Africa*** | | | | | | | | | |
| Algeria | 0 | 0 | 0 | | 0 | | 5 | 0 | 5 |
| Egypt | 2 | 51 | 0 | | 14 | | 0 | 0 | 65 |
| Ethiopia | 3 | 75 | 0 | | 11 | | 0 | 0 | 86 |
| Kenya | 1 | 28 | 0 | | 79 | | 0 | 0 | 107 |
| Niger | 0 | 0 | 0 | | 19 | | 21 | 0 | 40 |
| Sudan | 0 | 0 | 0 | | 21 | | 0 | 0 | 21 |
| Zimbabwe | 0 | 0 | 0 | | 4 | | 0 | 0 | 4 |
| ***Europe*** | | | | | | | | | |
| France | 0 | 0 | 0 | | 0 | | 39 | 0 | 39 |
| Italy | 0 | 0 | 0 | | 0 | | 11 | 0 | 11 |
| Netherlands | 0 | 0 | 0 | | 1857 | | 0 | 0 | 1857 |
| UK | 0 | 0 | 0 | | 1210 | | 0 | 672 | 1882 |
| ***The Americas*** | | | | | | | | | |
| Canada | 0 | 0 | 0 | | 0 | | 201 | 0 | 201 |
| Colombia | 0 | 0 | 0 | | 42 | | 0 | 0 | 42 |
| Mexico | 0 | 0 | 0 | | 0 | | 19 | 0 | 19 |
| Paraguay | 0 | 0 | 0 | | 30 | | 0 | 0 | 30 |
| USA | 0 | 0 | 0 | | 4 | | 5 | 0 | 9 |
| Total | 68 | 1362 | 462 | | 7854 | | 1539 | 672 | 11889 |

*Continued*

**Breeders' Material Exchange** (contd.)

| Crop/ Country | No. of samples: Trials and nurseries: Sets | Entries | Breeder seed | Advanced lines | Segregating populations | Released material | Germplasm accessions | Others | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Minor Millets** | | | | | | | | | |
| ***Asia*** | | | | | | | | | |
| Bhutan | 0 | 0 | 0 | | 0 | | 17 | 0 | 17 |
| China | 0 | 0 | 0 | | 0 | | 7 | 0 | 7 |
| India | 0 | 0 | 0 | | 0 | | 3230 | 0 | 3230 |
| Malaysia | 0 | 0 | 0 | | 0 | | 117 | 0 | 117 |
| ***Africa*** | | | | | | | | | |
| Kenya | 0 | 0 | 0 | | 0 | | 500 | 0 | 500 |
| ***The Americas*** | | | | | | | | | |
| Canada | 0 | 0 | 0 | | 0 | | 1 | 0 | 1 |
| ***Oceania*** | | | | | | | | | |
| Australia | 0 | 0 | 0 | | 0 | | 40 | 0 | 40 |
| Total | 0 | 0 | 0 | | 0 | | 3912 | 0 | 3912 |
| **Chickpea** | | | | | | | | | |
| ***Asia*** | | | | | | | | | |
| Bangladesh | 13 | 231 | 0 | | 1 | | 3 | 0 | 235 |
| Bhutan | 7 | 121 | 0 | | 0 | | 0 | 0 | 121 |
| China | 0 | 0 | 0 | | 16 | | 10 | 0 | 26 |
| India | 107 | 1965 | 0 | | 71 | | 81 | 498 | 2615 |
| Iran | 6 | 102 | 0 | | 0 | | 0 | 0 | 102 |
| Israel | 0 | 0 | 0 | | 0 | | 4 | 0 | 4 |
| Japan | 0 | 0 | 0 | | 7 | | 0 | 0 | 7 |
| Laos | 0 | 0 | 0 | | 7 | | 0 | 3 | 10 |
| Lao, PDR | 2 | 36 | 0 | | 0 | | 0 | 0 | 36 |
| Myanmar | 19 | 361 | 0 | | 0 | | 0 | 0 | 361 |
| Nepal | 3 | 57 | 0 | | 0 | | 0 | 36 | 93 |
| Pakistan | 48 | 854 | 0 | | 49 | | 0 | 0 | 903 |
| Philippines | 10 | 190 | 0 | | 0 | | 0 | 0 | 190 |
| Saudi Arabia | 1 | 17 | 0 | | 10 | | 0 | 0 | 27 |
| Sri Lanka | 1 | 19 | 0 | | 2 | | 0 | 0 | 21 |
| ***Africa*** | | | | | | | | | |
| Egypt | 4 | 76 | 0 | | 0 | | 0 | 0 | 76 |
| Ethiopia | 9 | 171 | 0 | | 0 | | 0 | 0 | 171 |
| South Africa | 4 | 60 | 0 | | 0 | | 0 | 0 | 60 |
| Sudan | 2 | 38 | 0 | | 0 | | 0 | 0 | 38 |
| Tchad | 1 | 16 | 0 | | 0 | | 0 | 0 | 16 |
| Uganda | 12 | 107 | 0 | | 0 | | 0 | 0 | 107 |
| Zimbabwe | 11 | 201 | 0 | | 0 | | 0 | 0 | 201 |

*Continued*

| Crop/ Country | No. of samples: Trials and nurseries: Sets | Entries | Breeder seed | Advanced lines | Segregating populations | Released material | Germplasm accessions | Others | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Chickpea** | | | | | | | | | |
| ***Europe*** | | | | | | | | | |
| Belgium | 0 | 0 | 0 | | 0 | | 0 | 2 | 2 |
| Czechoslovakia | 0 | 0 | 0 | | 0 | | 20 | 0 | 20 |
| France | 0 | 0 | 0 | | 10 | | 0 | 0 | 10 |
| Germany | 0 | 0 | 0 | | 2 | | 0 | 0 | 2 |
| Italy | 0 | 0 | 0 | | 0 | | 2 | 0 | 2 |
| Portugal | 9 | 145 | 0 | | 0 | | 0 | 0 | 145 |
| Slovakia | 0 | 0 | 0 | | 77 | | 0 | 0 | 77 |
| Spain | 0 | 0 | 0 | | 2 | | 1 | 0 | 3 |
| UK | 0 | 0 | 0 | | 1 | | 0 | 0 | 1 |
| ***The Americas*** | | | | | | | | | |
| Canada | 0 | 0 | 0 | | 50 | | 0 | 0 | 50 |
| Colombia | 0 | 0 | 0 | | 0 | | 20 | 0 | 20 |
| Honduras | 0 | 0 | 0 | | 15 | | 0 | 0 | 15 |
| Mexico | 2 | 38 | 0 | | 0 | | 0 | 0 | 38 |
| USA | 2 | 38 | 0 | | 1 | | 9 | 0 | 48 |
| ***Oceania*** | | | | | | | | | |
| Australia | 12 | 204 | 0 | | 40 | | 1 | 2 | 247 |
| Total | 285 | 5047 | 0 | | 361 | | 151 | 541 | 6100 |
| **Pigeonpea** | | | | | | | | | |
| ***Asia*** | | | | | | | | | |
| Bahamas | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 4 |
| Bangladesh | 0 | 0 | 0 | 12 | 0 | 3 | 1 | 0 | 16 |
| Bhutan | 4 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |
| Cambodia | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 4 |
| India | 17 | 321 | 0 | 179 | 177 | 79 | 2151 | 91 | 2998 |
| Indonesia | 3 | 48 | 0 | 2 | 0 | 0 | 0 | 0 | 50 |
| Israel | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 5 |
| Japan | 0 | 0 | 0 | 3 | 0 | 2 | 5 | 0 | 10 |
| Laos | 0 | 0 | 0 | 3 | 0 | 3 | 0 | 0 | 6 |
| Malaysia | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| Myanmar | 3 | 16 | 0 | 2 | 1 | 1 | 2 | 6 | 28 |
| Nepal | 5 | 66 | 0 | 25 | 9 | 3 | 10 | 6 | 119 |
| Pakistan | 2 | 30 | 0 | 5 | 0 | 1 | 1 | 0 | 37 |
| Republic of Palau | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 3 |
| Saudi Arabia | 4 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |
| Syria | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 4 |

*Continued*

| Crop/ Country | Trials and nurseries Sets | Entries | Breeder seed | Advanced lines | Segregating populations | Released material | Germplasm accessions | Others | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Pigeonpea** | | | | | | | | | |
| ***Africa*** | | | | | | | | | |
| Burkina Faso | 0 | 0 | 0 | 10 | 0 | 0 | 5 | 0 | 15 |
| Ethiopia | 2 | 27 | 0 | 6 | 0 | 2 | 0 | 0 | 35 |
| Guinea Bissau | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 1 | 4 |
| Kenya | 3 | 32 | 0 | 1 | 0 | 0 | 932 | 0 | 965 |
| Lao, PDR | 0 | 0 | 0 | 8 | 0 | 4 | 0 | 0 | 12 |
| Malawi | 3 | 32 | 0 | 1 | 0 | 0 | 11 | 0 | 44 |
| Mali | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 3 |
| Niger | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 3 |
| South Africa | 0 | 0 | 0 | 0 | 0 | 0 | 500 | 0 | 500 |
| Sudan | 2 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 30 |
| ***Europe*** | | | | | | | | | |
| Italy | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 5 |
| ***The Americas*** | | | | | | | | | |
| Bolivia | 0 | 0 | 0 | 6 | 0 | 1 | 1 | 2 | 10 |
| Dominican Republic | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 1 | 5 |
| Honduras | 0 | 0 | 0 | 6 | 9 | 0 | 10 | 0 | 25 |
| Mexico | 1 | 16 | 0 | 5 | 0 | 1 | 0 | 0 | 22 |
| Trinidad and Tobago | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 10 |
| USA | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 4 |
| ***Oceania*** | | | | | | | | | |
| Australia | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 8 |
| West Samoa | 0 | 0 | 0 | 0 | 0 | 0 | 35 | 0 | 35 |
| Total | 49 | 738 | 0 | 308 | 196 | 112 | 3680 | 108 | 5142 |
| **Groundnut** | | | | | | | | | |
| ***Asia*** | | | | | | | | | |
| Bangladesh | 1 | 15 | 0 | 29 | 16 | 0 | 0 | 0 | 60 |
| China | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Combodia | 1 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 15 |
| India | 13 | 203 | 296 | 751 | 109 | 92 | 1342 | 12 | 2805 |
| Indonesia | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| Japan | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 4 |
| Korea | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 20 |
| Lao, PDR | 3 | 53 | 0 | 20 | 0 | 0 | 0 | 0 | 73 |
| Myanmar | 5 | 87 | 0 | 10 | 0 | 0 | 0 | 0 | 97 |
| Pakistan | 2 | 39 | 0 | 0 | 5 | 0 | 0 | 0 | 44 |

Header note: "No. of samples" spans all sample columns.

*Continued*

**Breeders' Material Exchange** (contd.)

| Crop/ Country | No. of samples | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Trials and nurseries | | | | | | | | |
| | Sets | Entries | Breeder seed | Advanced lines | Segregating populations | Released material | Germplasm accessions | Others | Total |
| **Groundnut** | | | | | | | | | |
| ***Asia*** | | | | | | | | | |
| Philippines | 4 | 67 | 0 | 40 | 0 | 0 | 0 | 0 | 107 |
| Saudi Arabia | 1 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 24 |
| Sri Lanka | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 |
| Syria | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 5 |
| Taiwan | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 5 |
| Thailand | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 10 |
| Vietnam | 0 | 0 | 0 | 107 | 23 | 0 | 323 | 151 | 604 |
| Yemen | 1 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 24 |
| ***Africa*** | | | | | | | | | |
| Botswana | 1 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 15 |
| Ethiopia | 6 | 92 | 0 | 0 | 0 | 0 | 0 | 0 | 92 |
| Kenya | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 |
| Malawi | 0 | 0 | 0 | 0 | 0 | 0 | 2011 | 0 | 2011 |
| Namibia | 2 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 30 |
| South Africa | 3 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 45 |
| Uganda | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 |
| Zimbabwe | 0 | 0 | 0 | 221 | 0 | 0 | 0 | 0 | 221 |
| ***Europe*** | | | | | | | | | |
| Germany | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 8 | 14 |
| UK | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 8 |
| ***The Americas*** | | | | | | | | | |
| Brazil | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 0 | 30 |
| Canada | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Chile | 0 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 25 |
| Honduras | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 13 |
| USA | 0 | 0 | 0 | 81 | 0 | 0 | 40 | 3 | 124 |
| ***Oceania*** | | | | | | | | | |
| West Samoa | 3 | 53 | 0 | 0 | 0 | 0 | 0 | 0 | 53 |
| Total | 46 | 762 | 296 | 1335 | 153 | 92 | 3772 | 186 | 6596 |
| **Grand total** | **655** | **11143** | **1311** | **15386** | | | **20566** | **1558** | **49964** |

Note: The total includes samples exchanged within India by the Research Divisions, besides those handled by Genetic Resources Division (GRD).

# ICRISAT Asia Center - Senior Staff as of 31 Dec 1994

(The countries of internationally recruited staff are italicized)

**Asia Regional Program**

Charles Renard, *Belgium*, Executive Director

**Administration**

P M Menon, Manager
Prashant Bhardwaj, Security Officer
P V Gopiramanan, Finance Officer
M L Hussain, Senior Security Supervisor
K Jagannadham, Senior Transport Officer
T Kulashekar, Administrative Officer
Samiran Mazumdar, Assistant Manager (Food Services)
Y Muralikrishna, Administrative Officer
A Baby Philip, Catering Officer
A J Rama Rao, Personnel Officer
Debendranath Sar, Catering Officer
K K Sood, Chief Security Officer
P Suryanarayana, Assistant Personnel Manager
N Surya Prakash Rao, Chief Medical Officer

**Cereals and Legumes Asia Network (CLAN)**

C L L Gowda, *India*, Principal Coordinator
A Ramakrishna, Scientist (Agronomy)

**Farm and Engineering Services Program (FESP)**

D S Bisht, *India*, Program Leader
Y Chiranjeevi Rao, Engineer (Electrical)
S C Gupta, Engineer (Greenhouse and Controlled Environment)
K Hanmanth Rao, Agricultural Officer (Irrigation)
G Krishna, Head Supervisor (Carpentry)
Ch Malathi, Agricultural Officer(Labor and Farm Maintenance)
Shiva K Pal, Manager (Plant Protection)
R Parameswaran, Senior Engineer (Automobile)
Akbar Pasha, Engineer (Farm Development)
S John Peter, Head Supervisor (Plumbing)
Marri Prabhakar Reddy, Assistant Manager (Irrigation, Labor, and Farm Maintenance)
N S S Prasad, Chief Engineer (General Engineering Services)
Raghuraj Singh, Agricultural Officer (Plant Protection)
C Ram Reddy, Agricultural Officer (Plant Protection)
P Rama Murthy, Senior Administrative Officer
K Ramesh Chandra Bose, Senior Engineer (Civil)
Ramesh C Sachan, Assistant Manager (Greenhouse and Controlled Environment, Training and Documentation)

M C Ranganatha Rao, Deputy Chief Engineer
(Farm Development and Construction)
K Ravindranath, Manager (Farm Machinery and
Mechanical Engineering Services)
Abdul Samad, Senior Foreman (Farm Machinery)
N V Subba Reddy, Senior Horticultural Officer
V Sitaramdas, Agricultural Officer (Plant Protection)

**Geographic Information Systems (GIS)**

P Mohan Rao, Scientist (GIS)

**Plant Quarantine Unit (PQU)**

A M Ghanekar, Chief Plant Quarantine Officer
A Surender, Senior Research Associate

**Training and Fellowships Program (TAFP)**

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S K Dasgupta, Senior Training Officer
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# Acronyms

| | |
|---|---|
| AB | Ascochyta blight |
| AB | Alternate branching |
| ABN | Ascochyta Blight Nursery |
| ACIAR | Australian Centre for International Agricultural Research |
| AD | Agronomy Division |
| ADB | Asian Development Bank |
| AEZ | Agroecological zone |
| AGLOR | Asian Grain Legumes On-farm Research |
| AICPIP | All India Coordinated Pulse Improvement Project |
| AICPMIP | All India Coordinated Pearl Millet Improvement Project |
| AICSIP | All India Coordinated Sorghum Improvement Project |
| AMMI | Additive main effects and multiplicative interaction |
| APAU | Andhra Pradesh Agricultural University |
| Asl | Above sea level |
| AYT | Advanced yield trial |
| BACTID | Bacterial identification |
| BBF | Broadbed and furrow |
| BG | Black gram |
| BGM | Botrytis gray mold |
| BWYV | Beet Western Yellows Virus |
| CAAS | Chinese Academy of Agricultural Sciences |
| CCDV | Chickpea Chlorotic Dwarf Geminivirus |
| CCSHAU | Chaudhary Charan Singh Haryana Agricultural University |
| CENARGEN | Centro Nacional de Pesquisa de Recursos Géneticos e Biotechnologia |
| cfu | Colony forming units |
| CGIAR | Consultative Group on International Agricultural Research |
| CGR | Crop growth rates |
| CIAT | Céntro Internacional de Agricultura Tropical |
| CLAN | Cereals and Legumes Asia Network |
| CMBD | Cellular and Molecular Biology Division |
| CMS | Cytoplasmic male sterility |
| CP | Coat protein |
| CPD | Crop Protection Division |
| CpLV | Chickpea luteoviruses |
| CRIDA | Central Research Institute for Dryland Agriculture |
| DAE | Days after emergence |
| DAP | Diammonium phosphate |
| DAS | Days after sowing |
| DFARS | Dryland Farming Agricultural Research Station |
| DM | Downy mildew |
| DR | Damage rating |
| DS | Date of sowing |
| EHiTIP | Early high-tillering population |
| ELS | Early leaf spot |
| ELISA | Enzyme-linked immunosorbent assay |
| EMBRAPA | Empresa Brasileira de Pesquisa Agropecuaria |
| ESD | Extra short duration |
| FAO | Food and Agriculture Organization of the United Nations |
| FAO/RAS | Food and Agriculture Organization/Region Asia |

| | |
|---|---|
| FESP | Farm and Engineering Services Program |
| FQS | Fodder quality score |
| FRV | Fertilizer N replacement value |
| FYM | Farmyard manure |
| GBPUAT | Gobind Ballabh Pant University of Agriculture and Technology |
| GCA | General combining ability |
| GED | Genetic Enhancement Division |
| GG | Green gram |
| GIS | Geographic Information Systems |
| GPT | Groundnut Production Technology |
| GRD | Genetic Resources Division |
| GSS | Grain setting score |
| GTZ | Deutche Gesellschaft für Technische Zusammenarbeit |
| GY | Grain yield |
| HI | High inputs |
| HYV | High-yielding varieties |
| IAC | ICRISAT Asia Center |
| IARC | International Agricultural Research Center |
| IBPGR | International Board for Plant Genetic Resources |
| ICAR | Indian Council of Agricultural Research |
| ICARDA | International Center for Agricultural Research in the Dry Areas |
| ICIPE | International Center of Insect Physiology and Ecology |
| ICPL | ICRISAT Pigeonpea Line |
| ICSDN | International Chickpea Stunt Disease Nursery |
| IF | Infection frequency |
| IFDRGVT | International Foliar Diseases Resistance Groundnut Varietal Trial |
| IFPRI | International Food Policy Research Institute |
| IGER | Institute of Grassland and Environmental Research |
| IMGVT | International Medium-duration Groundnut Varietal Trial |
| IIPR | Indian Institute of Pulses Research |
| IP | Incubation period |
| IPCV | Indian Peanut Clump Virus |
| IPM | Integrated Pest Management |
| IPMDMVN | International Pearl Millet Downy Mildew Virulence Nursery |
| IRRI | International Rice Research Institute |
| ISC | ICRISAT Sahelian Center |
| ISVHAT | International Sorghum Variety and Hybrid Adaptation Trial |
| ISGVT | International Short-duration Groundnut Varietal Trial |
| JIC | John Innes Centre |
| JNKVV | Jawaharlal Nehru Krishi Vishwa Vidyalaya |
| KARI | Kenya Agricultural Research Institute |
| KSSC | Karnataka State Seeds Corporation |
| LAD | Leaf area damage |
| LD | Lesion diameter |
| LI | Low inputs |
| LLS | Late leaf spot |
| LSGP | Large-seeded Gene Pool |
| LASIP | Latin American Sorghum Improvement Program |
| MAI | Moisture availability index |
| MAS | Months after sowing |
| MET | Multi-environment trial |
| MPG | Maha Illuppallama Pigeonpea Germplasm |

| | |
|---|---|
| MSSC | Maharashtra State Seeds Corporation |
| MTP | Medium-Term Plan |
| NARS | National Agricultural Research Systems |
| NBPGR | National Bureau of Plant Genetic Resources |
| NF | Nonfertilized |
| NF+ | Naturally eroded fertilized |
| NGO | Nongovernmental Organization |
| NPV | Nuclear Polyhedrosis Virus |
| NRCS | National Research Center for Sorghum |
| NRI | Natural Resources Institute |
| PBND | Peanut bud necrosis disease |
| PBNV | Peanut bud necrosis virus |
| PCR | Polymerase chain reaction |
| Peanut CRSP | Peanut Collaborative Research Support Program |
| PEQIA | Post-Entry Quarantine Isolation Area |
| PGR | Plant Genetic Resources |
| PKV | Punjabrao Krishi Vidyapeeth |
| PRA | Participatory rural appraisal |
| PY | Plot yield |
| PYT | Preliminary yield trial |
| QDPI | Queensland Department of Primary Industries |
| QTL | Quantitative trait loci |
| RAPD | Random Amplified Polymorphic DNA |
| RED | Regional Executive Director |
| REIA | Research Evaluation and Impact Assessment |
| RF | Ridge and furrow |
| RFLP | Restriction fragment length polymorphism |
| RH | Relative humidity |
| RLD | Root length density |
| RT-PCR | Reverse transcription-polymerase chain reaction |
| SACD | Soils and Agroclimatology Division |
| SADC | Southern African Development Community |
| SAT | Semi-arid tropics |
| SB | Sequential branching |
| SC | Seed colonization |
| SCRI | Scottish Crop Research Institute |
| SD | Short duration |
| SE | Standard Error of Mean |
| SEA | Southern and Eastern Africa |
| SEPD | Socioeconomics and Policy Division |
| SGRP | Systemwide Genetic Resources Program |
| SI | Seed infection |
| SI | Sporulation index |
| SICNA | Sorghum Improvement Conference of North America |
| SMC | Soil moisture content |
| SMD | Sterility mosaic disease |
| SPGRC | SADC Plant Genetic Resources Centre |
| SWC | Soil and water conservation |
| SY | Stover yield |
| TAFP | Training and Fellowships Program |
| TDM | Total dry matter |
| TF | Time to 50% flowering |

| | |
|---|---|
| TGMR | Threshed grain mold ratings |
| TNAU | Tamil Nadu Agricultural University |
| TSWV | Tomato spotted wilt virus |
| VA | Vesicular-arbuscular |
| WSM | Watershed management |
| WUE | Water-use efficiency |

# About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 16 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank.

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