Assessing Joint Research Impacts

International Crops Research Institute for the Semi-Arid Tropics

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Abstract

Pursuit of a joint approach to the assessment of research impact is critical for the continuing viability of national and international research within the global agricultural R&D system. This workshop on "Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics" was organized to achieve three objectives: a) to report results of case studies on adoption and impact undertaken jointly by teams from ICRISAT and the national programs; b) to provide a forum for peer review; and c) identify through working group sessions key issues and priority areas for ICRISAT/NARS research agenda on impact assessment.

The workshop was attended by ICRISAT scientists from all disciplines, by representatives from private and public sector research institutions, the seed sector, and other international research organizations. These proceedings include the presentation of case studies featuring research impact in four areas — genetic enhancement research; resource management options; intermediate products of research; and impact of networks. That adoption is a condition of impact was noted. The efficiency dimension of impact served as a starting point in most analyses. Other dimensions of impact include food security, gender equity, sustainability, human nutrition, employment, and spillover effects. The integration of these dimensions in the research evaluation process was discussed. Peer review was an important feature of this workshop; it served as a basis for the discussions on priorities for the future research agenda on impact assessment.

Résumé

L'évaluation conjointe de l'impact de la recherche: compte rendu d'un atelier international, 2-4 déc 1996, ICRISAT, Patancheru, Inde. La suivie d'une approche conjointe pour l'évaluation de l'impact de la recherche est cruciale pour la viabilité continue de la recherche nationale et internationale au sein du système mondial de recherche et de développement agricole. L'atelier sur "l'Evaluation conjointe de l'impact des technologies SNRA/ICRISAT pour les régions tropicales semi-arides" a été organisé en vue de réaliser trois objectifs principaux: a) faire un compte rendu des résultats des études de cas sur l'adoption et l'impact entreprises conjointement par les équipes de l'ICRISAT et des programmes nationaux; b) servir de forum pour la revue par les spécialistes (peer review); et c) identifier, à travers des sessions de groupes de travail, les thèmes clés ainsi que les domaines de priorité pour le programme de recherche des Systèmes nationaux de recherche agricole (SNRA)/ICRISAT sur l'évaluation de l'impact.

L'atelier a réuni les chercheurs de l'ICRISAT provenant de toutes les disciplines de travail, ainsi que les représentants des institutions de recherche relevant des secteurs public et privé, les représentants du secteur de semences et d'autres organismes de recherche internationaux. Ces comptes rendus comportent la présentation des études de cas traitant de l'impact de la recherche dans quatre domaines — la recherche sur l'amélioration génétique; les possibilités de gestion des ressources; les produits intermédiaires de la recherche; et l'impact des réseaux. La réunion a noté que l'adoption est une condition de l'impact. La dimension de l'efficacité a servi de point de départ pour la plupart des analyses. Les autres dimensions de l'impact comprennent la sécurité alimentaire, l'équité de genres, la durabilité, la nutrition humaine, l'emploi et les retombées secondaires. L'intégration de ces dimensions dans le processus d'évaluation de la recherche a fait l'objet de discussion. La revue par les spécialistes était une charactéristique importante de cet atelier; elle a servi de base pour les discussions sur les priorités pour le programme de recherche future sur l'évaluation de l'impact.

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Introduction

Welcome Address

J G Ryan[1]

Ladies and gentlemen, it is a professional and personal pleasure to welcome all of you to this important workshop. I know that besides colleagues from India, we also have representatives from Indonesia, Nepal, Bangladesh, Sri Lanka, and Africa. I hope I haven't missed any country or regional representation as I welcome visitors to ICRISAT. And to my colleagues at ICRISAT, I also offer a particular welcome. I think it's highly appropriate that this workshop focuses on joint impacts of agricultural research by national agricultural research systems (NARS) and ICRISAT.

As most of you know, it is not easy to differentiate among the various actors in agricultural research in terms of attributing impact to particular inputs. The Consultative Group on International Agricultural Research (CGLAR) and I believe in the NARS, and there has been considerable effort in recent years to act in more collaborative partnerships as we pursue our agendas. I believe this particular approach of collaboration and partnership is going to be an even more important feature of the relationships between ICRISAT and other international centers and NARS in the future. And by national agricultural systems, we should be talking of not only the national publicly-funded research institutions such those here in India, but also universities, the private sector, government organizations, and farm associations. After all, it is the farmers who are the ultimate focus of what we are all about — if we don't satisfy their expectations and needs, then both publicly and privately funded R&D activities in agriculture have no use.

Let me illustrate the emphasis that will be given by ICRISAT and the other international centers to collaborative relationships in the future. At the recent International Centers Week in Washington, two days were devoted to a global forum on agricultural research, and that forum was led by the NARS and regional organizations such as APAARI (Asia-Pacific Association of

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Agricultural Research Institutions); ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa); SACCAR (Southern Africa Centre for Cooperation in Agricultural Research); and WCASRN (West and Central African Sorghum Research Network).

That forum was an extremely important renewal of the CGIAR system to illustrate the sense of partnership with NARS that will be a hallmark of future relationships. The other major reason why this meeting is appropriate concerns the total resources devoted to agricultural R&D in the developing world. The international centers' research represents only about 4%, so the other 96% comes from other actors in the agricultural R&D spectrum. And that includes public sector funding as well as private and voluntary funding of agricultural R&D.

So I believe for these types of reasons that it is not appropriate for us in the international centers to be talking about our impacts separately from joint impacts with our NARS partners. I believe that all of us in the global agricultural research system are facing a support environment that is being subjected to many dynamics, such as the debates over intellectual property rights and constrained resources for agricultural research, particularly in the public sector, and competition in the private sector. It is also a challenge to harness research resources in pursuit of private sector objectives that complement objectives of public sector institutions.

One of the major purposes of joint impact assessment is to measure and document, and I stress document, joint development of what we might call intermediate scientific output. The quality and quantity of these is often an important ingredient to acknowledge the scientific contributions of a group of scientists working in an institution or a number of institutions. Thus intermediate outputs are necessary, but obviously not sufficient in most instances to justify continued financial support to the agricultural research agendas of other public or private sector institutions.

We should also use opportunities such as this workshop to look at how we can more accurately assess and document joint impact in terms of socioeconomic parameters that contribute to economic progress. The one that is most common is benefit-cost assessment, and here is where the issue arises of deciding who has actually contributed and for how long. Most of the benefit-cost studies that pertain to agricultural research — either individual projects, an institution, a program, or an entire national effort — show extremely high internal rates of return to the investment. Critics conclude that costs are being underestimated and benefits overestimated. Those who respond would say this is an indication of underinvestment in agricultural research because we still have a great opportunity for further investment to get very high rates of return. The truth may lie somewhere in between.

Another element of measuring and documenting the socioeconomic impact of public sector institutions such as ICRISAT is what share of benefits from joint activities is attributed to the core research. Also important is the gender perspective in those benefit streams. Have women in particular been participating in the gains from the enhanced income streams generated from agricultural research and development activities?

A fourth issue is the implications of research activities in terms of enhancing the environment or natural resource base on which most agricultural endeavors depend. Many methodological challenges still remain. In the past, there wasn't much emphasis on natural resource management research as is currently the case. There may be methodological difficulties in deciding who is responsible for generating natural resource management research, how much is indigenous knowledge, and how much is modern science. There are many methodological questions that surround the natural resource management agenda.

Measuring the joint impact of agricultural R&D is very important to justify future investments in agricultural research and development. Stakeholders want to know what has been accomplished in the past, and what are the prospects for future socioeconomic improvements. Accountability is alive and well in agricultural R&D, and this provides another reason why we need, as we say in India, *pukka* impact assessments, not *kucha.* And that is why I am delighted that we have some key reviewers in this room who can contribute to the refinement of impact assessments undertaken thus far.

We need to be looking at joint measures of impact so we can set future priorities in a more informed way. Impact studies should not be used solely to look at a final rate of return, but also to understand the process to guide future endeavors and provide more explicit justification for future support.

The more we expose our impact studies, the better job we will do at ex-ante priority setting. As this cycle continues, planning and methodology will improve, and we will do a better job of informing our stakeholders of the R&D agenda. These joint exercises are also important to reach an agreement among NARS, international centers, and other actors for a future complementary agenda.

I am confident this workshop will be successful, and I very much look forward to the outcome of this continuing process.

Workshop Overview

M C S Bantilan[1]

Good morning everyone, and welcome to this workshop on "Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics." It is now almost two years since we embarked on an initiative to document the impacts of agricultural research. This is indeed a reunion, because most of you were with us in 1993 when we held a small meeting on agricultural research impact awareness and appreciation. That 1993 meeting was followed by a workshop on methodology, where we presented a wide range of technologies developed through ICRISAT/NARS partnerships, and we discussed approaches to integration of research evaluation efforts of ICRISAT, NARS (national agricultural research systems), and other international research centers.

Our series of joint case studies began in 1995 and 1996. We sustained the initiative within the national programs by training, and on-the-job and field experience among our own and NARS staff in Asia (1995) and Africa (1996). Since then, these study programs have been a regular feature of what has evolved as a global impact team.

The first objective of this workshop is to present results and progress of adoption and impact studies undertaken jointly by teams from ICRISAT and the national programs. Second, this workshop provides a forum where peer reviewers have been invited to give critiques and constructive suggestions that will help improve or refine the adoption and impact analysis. I am thankful to the eminent scientists who have joined us for the next three days to share their expert opinions and perspectives. And lastly, the most important activity of this workshop will be the working group discussions. Following the review of papers, you will have additional opportunities to suggest directions for the future joint research agenda on impact assessment.

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

To give you an overview of our workshop, let me provide a day-by-day outline. After the opening remarks and inspirational talk by Dr Ryan this morning, will be an overview of present technologies in the SAT and a summary of case studies that are underway. This session will present effects of adoption of cereals and legumes genetic enhancement technologies and consequent impact.

Three themes will be covered on day 2 — the impact of resource management technologies, use of ICRISAT intermediate products by NARS and the seed sector, and the impact of networking. An important session at the end of this day will be a forum for peer review where invited reviewers will critique the papers presented during the first two days. During this session, experts will present their opinions on the methods and analysis in the case studies, and provide suggestions to enhance the analysis.

All participants will be involved in working group sessions on day 3. Four working groups are planned. The sessions will provide a venue for more extensive discussion of various aspects of the studies — impact studies of genetic enhancement research; impact studies of resource management research; impact of intermediate products — crop management and screening techniques; and use and value of germplasm and parental materials. These working groups will address key issues on impact assessment in each of these areas and develop a workplan that incorporates suggestions from the peer reviewers. Highlights of the working group discussions and a workshop synthesis report will be presented in the concluding session.

I look forward to your active participation, and thank each of you for the valuable contributions that I know you will make during this workshop.

Joint Impact of Genetic Enhancement Research: Case Studies

Sorghum S 35 in Chad — Adoption and Benefits

A Yapi[1], G Dehala[2], K Ngawara[2], and I Abdallah[3]

A sound policy on science and technology is necessary to resolve most development problems, and thus soon after independence, the government of the Republic of Chad set up a national committee for scientific and technical research under the Ministry of Planning and Development. The objective of the committee was to coordinate all research activities led by different institutions in the country, including the Agronomic Research Center, which later became the Center for Agricultural Research and Technology (CART). Agricultural research developed with major internal and external funding, which led to perfecting certain technologies, including the sorghum variety S 35.

Considering the not insubstantial funds already granted for agricultural research, as well as the bleak possibilities for future financial assistance, it is essential to evaluate the impact of past investments so that research objectives and activities can be organized for greater efficiency.

This study is a combined effort of ICRISAT and CART to evaluate the impact of research and extension of sorghum S 35 in the semi-arid regions of Chad. The two main objectives are:

- to determine the performance and acceptability of S 35 under farm-level conditions based on adoption rates and farmer perceptions in different regions where the technology is applicable; and
- to evaluate the economic impact that the adoption (and the accompanying cultivation techniques) had on the welfare of peasants and consumers.

Other indicators of impact affecting food security, rural poverty, and problems for lasting development will also be discussed based on data collected in major sorghum growing regions.

Yapi, A., Dehala, G., Ngawara, K., and Abdallah, I. 1998. Sorghum S 35 in Chad — adoption and benefits. Pages 11-25 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

ICRISAT Conference Paper No. 1348

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2. Center for Agricultural Research and Technology, BP 441, N'djamena, Chad.
3. Gassi Seed Project, Chad.

Study regions

Chad is one of the largest African countries, with an area of 1 284 000 km^2 and a population of 6.3 million. The cultivable surface area is 20 million ha, of which only 5% is currently exploited. Agriculture and animal breeding represent 43% of the gross national product (GNP) and support 90% of the population (Chad: Ministere du Plan et de la Cooperation 1993). Sorghum, pearl millet, and maize are the staple cereals of the Chadian diet. (Table 1).

Table 1. Cereal consumption in Chad (kg capita^{-1} year^{-1}).

Zone	Pearl millet	Sorghum	Maize	Rice
Sahelian	60	60	30	0.7
Sudanian	40	90	20	30
Country average	50	70	20	10

Source: Chad: Ministere de l' Agriculture, 1996

All three cereals are cultivated (although in varying proportions) throughout the country, with the exception of the extreme north, which is too arid. The three study zones — Guera, Mayo-Kebbi, and Chari-Baguirmi (Fig. 1) — were chosen because they are located in the Sahelian and the Sahelian-Sudanian zones, where climate affects yield and consequently necessitates short-cycle crop varieties such as S 35. Furthermore, these three zones are target and distribution zones for S 35 in Chad.

Guera

Sorghum remains the most cultivated crop in this hilly region. The climate is of the Sahelian type with an annual rainfall of 400-700 mm and a rainy season that can last five months (May-Sep). The dry season is generally Oct-Apr, with a temperature of 42 °C in April. The soil and sub-soil are clay and sandy-clay, permeable, and poor in organic matter, but favorable to the cultivation of cereals such as sorghum and pearl millet. In the mountainous zones (which are unfortunately numerous), the soil has been largely washed away by erosion. Indiscriminate exploitation of the environment and overgrazing aggravate soil degradation.

Off-season cultivation is also possible in this region. Ferralitic soils can be found in certain areas. The vegetation of Guera is characterized by a sparse grassy and woody savannah. There are a number of natural water sources and zones that can be flooded, thus permitting the cultivation of berbere (flood sorghum), which along with S 35, are the only white-grained sorghums in the region. White sorghum (300 CFA coro^{-1}) is more costly in the local market than red sorghum (175 CFA coro^{-1}) local varieties. The 'coro' is a unit of measure used for cereal transactions in Chad, about 2.5 kg. The CFA is the currency used in most of French-speaking Africa, and is pegged to the French franc at 1 ff = 100 CFA. The French franc usually trades at between 5 and 6 to the U.S. dollar.

Over an area of 59 950 km^2, Guera has a population of 306 653 (43 959

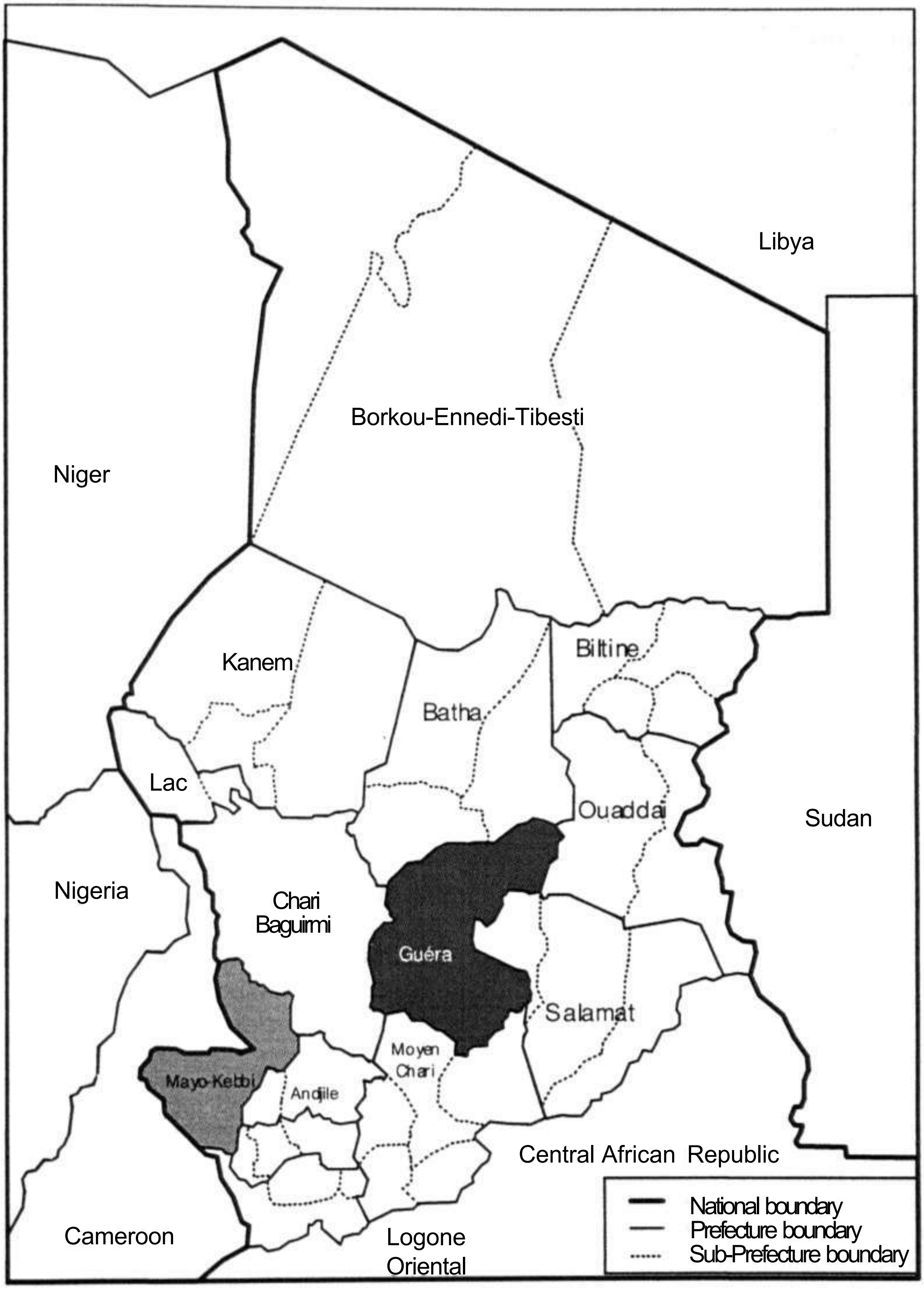

Figure 1. Map of Chad showing the study zones.

urban and 219 884 rural), with 42 810 who are resident nomads (Chad: Ministere du Plan et de la Cooperation 1993). Guera's population is 55% women. The most widespread crops are sorghum, pearl millet, groundnut, and berbere. Cowpea, sesame, potatoes, cassava, and vegetables are also cultivated.

Mayo-Kebbi

Mayo-Kebbi is situated in southwest Chad on the Cameroon border, has an area of 30 105 km^2, and a population of 799 543 (94 001 urban and 705 542 rural). Women are 52% of the population. Mayo-Kebbi is only 240 km (starting from Bongor) from the capital, N'djamena, but in the rainy season, the larger part of Mayo-Kebbi becomes inaccessible, which is a drawback for integration into the national economy.

Opening up this region is thus imperative in order to develop natural resources, improve services for the population, and provide a better infrastructure for commercialization of agriculture.

The average annual temperature is 23°C in Mayo-Kebbi, with daily variations of 20°C in the dry season (Oct-Apr) and 9°C in the rainy season (May-Sep). The average rainfall varies from 1 100 ram in the south to 800 mm in the north. In the last few years, a rainfall deficit of 20% has been noted.

Mayo-Kebbi is divided into drained zones in the southwest and inundation zones in the Logone basin, with a variation in altitude from 340 m in the south to 310 m in the north. Erosion is a serious problem.

Chari-Baguirmi

The Chari-Baguirmi region is characterized by both Sahelian and Sudanian-Sahelian climates, differentiated mainly by rainfall — 400-600 mm in the Sahelian zone, and 600-800 mm in the Sudanian-Sahelian zone. The climate includes a humid season (mid-Jun to mid-Oct), as well as a dry season with a cool period (mid-Oct to mid-Feb) and a hot period (mid-Feb to mid-Jun). Two major rivers, the Logone and the Chari, cross the region, and their waters collect in the northern part of N'djamena in Lake Chad. Chari-Baguirmi covers an area of 83 000 km^2. The soils of the region are particularly varied.

In 1993, the population of Chari-Baguirmi was estimated to be 1 251 906, which is a density of about 15 inhabitants km^{-2} (Chad: Ministere du Plan et de la Cooperation 1993). The urban population is estimated to be 605 212, of whom 88% live in the capital, N'djamena.

Sorghum S 35 in Chad

After the civil war of 1979-81, the country needed to reconstruct its genetic resources and stabilize seed production. Research efforts were first aimed at extrapolating results from agronomic research in neighboring countries (Cameroon, Nigeria, Niger, etc.) with similar agroclimatic conditions, and also with national and international agronomic research organizations such as ICRISAT, SAFGRAD (Semi-Arid Food Grain Research and Development), and IITA (International Institute of Tropical Agriculture). It is in this capacity that S 35 was introduced in 1986 at the Gassi research station in Chad from the Institut de Recherche Agronomique (IRA)-Maroua research station in Cameroon. Base materials of S 35 was bred at ICRISAT in India (Rao 1983) and introduced at Maroua in 1981 from the Samaru research station in Nigeria, hence its prefix 'S'. Table 2 summarizes the stages of research and extension of S 35 technology in Chad.

The variety was earlier officially released in rural areas in the far north of Cameroon, chiefly due to its high yield, especially in a dry year, and also due to its resistance to *Striga,* diseases, and insect pests. In 1983, a year that proved to be drier than usual in the far north of Cameroon, S 35 was superior to all experimental varieties in 10 of the 13 research zones where annual rainfall was lowest (300800 mm). In 1984, a

Table 2. Research and extension periods for S 35 sorghum in Chad.

Institution	Research began	Research ended	Extension began	Extension ended
Gassi Station	1986	1989	1990	1995
AICF			1989	1991
ONDR			1989	Ongoing

Source: Discussions with staff.

year that was even drier, research conducted in rural areas by SAFGRAD at 93 sites in Cameroon, showed that S 35 was even more effective than local and other tested varieties, with an 85% edge in grain yield (S 35 had an average yield of 1 330 kg ha^{-1} compared to 720 kg ha^{-1} for the local variety) (Kamuanga and Fobasso 1994).

Soon after its introduction in Chad in 1986, adaptive research was conducted on S 35 with tests at local research stations and in rural areas. Most of the research activity at the Dougui center (which does not have an irrigation network) was shifted to the Gassi Seed Center so that the Dougui center would

Table 3. Characteristics of S 35.

Character	Description
Pedigree	M 91019-6-1-1-2
Type	Dura
Photoperiodism	Non-sensitive
Panicle	Semi-compact
Grain color	Ivory white
Plant height	1.7-2.1 m
Mean panicle length	24 cm
1 000-seed mass	25-30 g
Mean grain yield potential on-station	2.8 t ha^{-1} without mineral fertilizer, 4.5 t ha^{-1} with mineral fertilizer
Vegetative duration (heading)	60 days
Semi-maturity duration	95-110 days
Drought tolerance	Very good
Foliar disease tolerance	Good
Striga tolerance	Very good
Grain mold tolerance	Mediocre
Recommended cropping area	With 300-800 mm rainfall

Source: IRA 1993; Centre Semencier de Gassi 1989.

serve as a site for S 35 technology tests (Table 3).

Research at the station

S 35 was evaluated in a series of tests at the station in Dougui between 1986 and 1989 (Table 2). The aim of these tests was to compare yield and behavior of S 35 to local varieties and others already in the seed production project at Gassi. Tests conducted at the Dougui station in 1988 showed the superior grain yield of S 35 (Table 4). In fact, the yield of S 35 surpassed that of Samboul by 731 kg ha^{-1} (39%). Zergay was the best local variety (2 463 kg ha^{-1}) compared to Samboul (1 870 kg ha^{-1}), but Zergay is sensitive to smut whereas Samboul has the advantage of being resistant to this disease and harmful insects.

When compared to introduced varieties (E 38-3 and ICSU 1002N), S 35 produces a higher yield and is also resistant to diseases and insect pests. E 38-3 produced a commendable yield but is sensitive to long smut. Despite its good grain yield during tests, E 38-3 was progressively withdrawn due to its sensitivity to long smut. The variety ICSU 1002N is susceptible to stem borer. Long smut and stem borer are two enemies of sorghum in the semi-arid region of Chad.

Adaptive research on S 35 also targeted local regions during 1988/1989 in Guera, Mayo-Kebbi, and Chari-Baguirmi (Table 5). In Guera, S 35 fared well compared to other varieties, but in Chari-Baguirmi, S 35 was inferior to other varieties. The yield of S 35 in Guera did not surpass that of the best local variety (Akoulmout).

Table 4. Results of S 35 trials at Dougui Research Station, 1988.

Variety	50% heading (d)	50% mature (d)	Physiological maturity (d)	Drought resistance	Disease/insect suscep-tibility	Stem height (cm)	Stem taste	Grain color	Grain yield (kg ha^{-1})
Zergay (local)	66	86	101	Resistant	Smut	185	Sweet	Red	2 463
E 38-3	76	98	106	Resistant	Smut	230	Sweet	Cream	1 816
S 35	76	96	106	Resistant	Resistant	235	Sweet	Cream	2 602
White Nadj-dadja	88	111	126	Susceptible	Resistant	310	Not sweet	White	1 298
Red Nadj-dadja	88	111	126	Susceptible	Resistant	310	Not sweet	Red	1400
Samboul	74	96	106	Resistant	Resistant	320	Not sweet	White	1870
ICSU 1002N	82	106	111	Resistant	Stem borer	245	Sweet	White	1966

Source: Progress Report 1988/89, Seed Project, Gassi.

Table 5. Yield comparison of multi-locational trials, 1988/89 (Data for Mayo-Kebbi are not available.)

Sorghum variety	Yield (kg ha^{-1})		
	Guera	Chari-Baguirmi	Mean
S 35	1 416	830	1 123
E 38-3	1 411	1408	1409
White Nadj-dadja	686	534	610
Red Nadj-dadja	610	1036	823
Akoulmout	1 851	846	1015

Source: Progress Report, 1988/89, Seed Project, Gassi.

Farm-level research

Tests on S 35 at the farm level started in 1989, chiefly in Guera, which was the site most favorable to this variety. Most tests were conducted at Mongo and Mangalme by officials of AICF, a French non-governmental organization (NGO). 'Mini doses' of 250 g and 500 g of seed were distributed under a supervision scheme that followed a calendar of pre-arranged visits. In 1994, for example, with 12 workers in the Guera prefecture, ONDR (Office national de developpement rural), could train a minimum of 1 200 farmers distributed in 120 villages.

The distribution method adopted by AICF is similar to that of ONDR, but apart from training farmers, AICF also increased the amount of seed distributed to farmers in targeted villages.

It is interesting to note that all the farmers who were trained sowed at a later date (end-Jun to early-Jul) compared to the usual sowing period of local varieties (generally, end-May to early-Jun) (Table 6). As a short-duration variety, the later sowing period is recommended for S 35 to reduce bird damage and avoid grain mold when the rains have not stopped at harvest time. AICF workers have also insisted on the importance of seedling density (about 100 g 0.01 ha^{-1}) and immediate harvest at maturity. When the field is sown in Jun-Jul at the recommended seedling density, weeded properly, and harvested promptly at the beginning of October, the farmer has a good possibility of getting an average yield of 1 200 kg ha^{-1}, even if less than 30% of the field is sown in rows (Table 6). According to surveys by AICF workers, more than 70% of the trained farmers favor introduction of S 35 in the Guera region.

Study methodology

A study to determine adoption levels and benefits from use of sorghum S 35 in different areas of Chad was conducted.

Primary data collection

Agricultural statistics were reviewed to identify areas with a high production of rainfed sorghum where improved varieties were distributed. This approach targeted potential adoption zones for S 35. Workers from ONDR and AICF made reconnaissance visits in the areas to determine homogeneity and select representative sub-prefectures. Mongo and Bitkine (in Guera), Bongor (in

Table 6. On-farm trials of S 35 carried out by AICF, Arenga (Guera), 1988/89.

Village	No. of farmers and mini-doses	Sowing date	Row sowing (%)	Emergence (%)	Field cleanliness (%)	Harvest date	Production (kg) Total	Production (kg) Mean	Mean yield (kg ha^{-1})
Arenga	5	27 and 28 Jun	Yes 40 No 60	Very good 80 Good 20	Clean 80 Dirty 20	2 or 12 Nov	561	112	1 771
Mankous-sine	2	26 Jun 3 Jul	Yes 50 No 50	Good 100	Clean 100	11 and 14 Nov	219	109	1 588
Male	3	26 Jun and 3 Jul	No 100	Bad 100	Clean 50 Dirty 50	26 Oct and 4 Nov	53	18	983
Doyo II	2	29 Jun and 4 Jul	Yes 100	Very good 50 Bad 50	Clean 50 Dirty 50	25 Oct and 3 Nov	105	53	1 050
Total Bitkine	12	26 Jun- 4 Jul	Yes 42 No 58	Very good 42 Good 25 Bad 33	Clean 73 Dirty 27	25 Oct- 14 Nov	937	78	1 348
Niergui	6	10-29 Jun	No 100	Good 83 Bad 17	Clean 33 Dirty 67	26 Sep- 15 Nov	123	21	1 060
Total Guera	18	10 Jun- 4 Jul	Yes 28 No 72	Very good 28 Good 22 Bad 50	Clean 64 Dirty 38	26 Sep- 15 Nov	1 060	59	1 204

Source: AICF, Extension Work Progress Report, Aranga, Bitkine, Guera.

Mayo-Kebbi) and Mand61ia (under the rural sub-prefecture of N'djamena) were selected, with 28 villages in 17 districts chosen in the 4 sub-prefectures. These villages and districts were chosen to be representative of each of the study zones. A total of 152 farmers participated in the study, with about 6 farmers chosen randomly from each village.

A formal questionnaire was used to ask farmers after harvest in 1994/95 about production systems, their opinion of S 35, and post-harvest conditions.

S 35 is also grown in the regions of Salamat, Moyen Chari, western and eastern Logone, Tandjile, Ouaddai, and Biltine, but not as widely because this is a higher rainfall area. Nevertheless, with a view to covering all production zones, an informal inquiry was carried out by farm extension workers residing in these regions. Based on the opinions of regional extension experts, the adoption of S 35 in these secondary regions was estimated to be 3-6%.

Economic surplus approach was the analytical method used in this study to calculate the economic impact of research and distribution of S 35 in Chad. This method is based on the idea that the usage of a new technology can potentially change the structure of production costs and market prices, and thus improve conditions for farmers as well as consumers (Akino and Hayami 1975, Bantilan 1996, Masters et al. 1995).

Adoption of the new technology increased production efficiency so that despite the additional expenses of adopting a new technology, production gains offset the additional expenses.

In Chad, like most other Sahelian countries, cereals such as sorghum are produced by thousands of small farmers for both home consumption and urban markets, and thus the distinction between producers and consumers is often blurred.

Adoption study

Surveys in rural areas collected information on the adoption rate of S 35, reasons for adoption, and constraints to adoption.

Adoption rate

The adoption rate (%) in each of the three study regions was calculated by dividing the area growing S 35 by the total area under rainfed sorghum in the sample area (Table 7). The adoption rate is clearly higher in Guera than the two other regions because Guera is the zone most suited to cultivation of S 35, and most S 35 grown at Gassi between 1987 and 1989 was distributed in the Guera zone. Table 8 presents production and

Table 7. Adoption rate (%) of S 35 in regions under study in Chad, 1990-95.

Year	Guera	Mayo-Kebbi	Chari-Baguirmi	Average of three regions
1990	17	7	0	7
1991	22	8	0	8
1992	23	10	14	14
1993	28	17	21	20
1994	32	22	22	24
1995	38	27	24	27

Source: Formal on-farm survey, ICRISAT/DRTA, 1994/95.

Table 8. Distribution of mini-doses of S 35 at Gassi, 1987-95.

Year	Seed (t)
1987	0.5 [1]
1988	0.6 [1]
1989	0.9
1990	1.4
1991	4.0
1992	4.0
1993	4.2
1994	5.8
1995	6.3 [2]

1. Multiplication and distribution of S 35 was barely documented in the first few years (1987-89) because seeds were not sold but rather distributed to seed-growing farmers through extension agents for large-scale multiplication. The 1987-89 quantities are estimated based on informal discussions with authorities at the Gassi Research Station and ONDR staff.
2. The quantity of S 35 seed reported for 1995 is an estimate based on sales of 4 300 kg by the end of May.

Source; Progress report on seed sale (mini-doses) at Gassi Research Station.

distribution of S 35 between 1987 and 1995.

Adoption of S 35 in Mayo-Kebbi was much lower than in Guera, and in Chari-Baguirmi, adoption only began in 1992. The lower adoption rates can be explained by a preference in these two regions for the local red sorghum (djigari) rather than white sorghum such as S 35. Also, the climate is more favorable to cultivation of other crops, and seed of S 35 is not as easily available.

During the past few years, however, significant rates of adoption have been noted in the Mayo-Kebbi and Chari-Baguirmi regions. The increasing importance of S 35 in regions previously considered secondary for this variety is perhaps an indication that dietary habits of the population are changing.

Reasons for adopting S 35

Farmers had a number of reasons for adopting S 35. The three most common were early maturity, high yield, and good taste (Table 9).

Early maturity. The fact that early maturity is more important to farmers in Guera than in the other two regions is a confirmation that drought is a more serious problem in that region. Early maturity is also important in Mayo-Kebbi (73%) and Chari-Baguirmi (75%), an indication that drought is also spreading to these regions. Contrary to common belief, however, early maturity is not always associated with drought resistance.

High yield. The percentage of farmers citing high yield as an important factor in all three study zones confirms the importance of this criterion independent of agroclimatic zones.

Good taste. This is an important criterion for adoption in Guera because dietary habits in this region tend toward white sorghum; in fact, there is a price difference between the two types of sorghum in Chad, especially in Guera. It is surprising that such a high percentage of farmers adopted S 35 for its taste in the other two regions (53% in Mayo-Kebbi and 38% in Chari-Baguirmi), especially in the latter where red sorghum is preferred. Perhaps dietary habits are adapting to the new environmental conditions in which farmers live.

Table 9. Frequency (%) of reasons cited by farmers for adopting S 35 sorghum.

Reason for adoption	Guera (62)[1]	Mayo-Kebbi (55)	Chari-Baguirmi (8)	Across 3 regions (125)
Grain whiteness	31	20	0	24
Short duration	81	73	75	77
High yield	52	62	50	66
Taste	63	53	38	58
Sweet stalk	11	26	13	17
Good threshability	5	0	0	2
Drought resistance	48	7	0	27
High sale price	42	0	1	22
Insect pest resistance	3	2	0	2
Good storability	8	4	0	6
Other uses	0	2	0	1
Dough consistency	6	0	0	3
Non-lodging	3	0	0	2
Large grain size	5	20	0	11
Germination	2	0	0	1
Good seed viability	2	0	0	1
Floury	2	2	0	2

1. Sample size.
Source: Formal on-farm survey, ICRISAT/DRTA, 1994/95.

Less important reasons for adoption cited by the farmers include drought resistance, a higher sales price, and the 'sweetness' of the sorghum stalk.

Constraints to adoption of S 35

Constraints mentioned by farmers included bird damage, land degradation, seed availability, and seed cost (Table 10).

Benefits

We evaluated the data to learn important lessons about setting research policies and priorities, and future extension activities. In order to evaluate the impact of S 35, the following information was collected:

- production level of sorghum in a base year (1989) for each of the three regions;
- production costs and input use of S 35 and the best local variety;
- adoption rates in the different study regions during the years of investigation;
- research and extension costs; and
- yield increase and additional costs for growing S 35.

Growing S 35 requires a higher initial investment by farmers. Soil preparation is more expensive because deep plowing followed by ridging is

Table 10. Frequency (%) of constraints cited by farmers as reasons for not adopting S 35.

Constraint	Guera (8)[1]	Mayo-Kebbi (17)	Chari-Baguirmi (2)	Across 3 regions (26)
Lack of seed	13	18	0	15
High cost of seed	13	12	0	11
Land degradation	13	24	0	19
Bird damage	62	24	100	41
Insect pest damage	13	6	0	8
Laborious work	13	0	0	4
Growth duration (too short)	13	0	0	4
Stem (too sweet)	13	0	0	4
Susceptibility to *Striga*	0	12	0	7
Short height	0	6	0	4
Sowing date (not controlled)	0	13	0	4
Lack of time	0	6	0	4
Susceptibility to smut	0	0	0	0

1.Sample size.
Source: Formal on-farm survey, ICRISAT/DRTA, 1994/95.

recommended. Harvesting is also more expensive because S 35 is so much more productive (51%) than the local variety, but there is an efficiency to the additional harvest — it only requires 9% more work. This efficiency is because S 35 is less than half the height of the local variety (200 cm vs. 440 cm), thus the panicle can be cut without having to first cut the stalk, and planting in rows facilitates moving through the fields during harvest. Farmers have the additional expense of protecting their fields because S 35 is susceptible to bird damage.

With a yield increase of 51 % in the three regions over three years compared to the best local variety, the production cost was reduced by about US$ 38 t^{-1}. This reduction (US$ t^{-1}) varied by region depending on the yield increase — 46 in Guera, 16 in Mayo-Kebbi, and 36 in Chari-Baguirmi. Soil preparation required less time in Guera than in the other two areas because there is less vegetation, hence the reduction in production costs is greatest. Planting S 35 has enabled farmers to reduce their unit cost of production and increased their efficiency.

The higher productivity of S 35 has thus improved family food security and even provided a surplus for marketing, especially in Guera, where farmers said that a high market price was one reason for adopting this variety. Furthermore, improved cultivation techniques introduced with the variety reduced the trade deficit caused by import of cereals.

The investment in S 35 for research and extension is justified because:

- growing this variety has improved food security,

- improved cultivation techniques introduced with the variety have increased efficiency and decreased production costs, and
- yielded a net economic surplus of US$ 15 million, and an internal rate of return of 95%.

Implications for agricultural research priorities

Primary information collected from farmers remains an important means to determine priorities for future research. The following research topics are based on problems farmers identified as they adopted S 35 technology.

Date of sowing

While citing "loss caused by bird menace" as a factor preventing the adoption of S 35, farmers said they are still confused about sowing dates. Bird damage is a consequence of early maturity, thus adaptive research to determine the optimal sowing date for S 35 in the three zones is a research priority.

Fertilizer and post-harvest

Farmers identified "degeneration of soil'' as a problem for adoption of S 35, and suggested that researchers study fertility management techniques.

Raising farmer income is a prerequisite to investing in fertility management. Considering the low income levels of farmers and their reluctance to invest in nutrient management, research on simple fertilization techniques using locally available raw materials is necessary. Composting, use of organic material such as crop residues, introduction of leguminous plants in a rotation, and application of mineral fertilizers are all research priorities.

Likewise, post-harvest technologies aimed at increasing demand for sorghum, development of new uses, and improved marketing networks are essential and should receive attention when planning future sorghum research activities in Chad.

Seed sector

Farmers said that "lack of seeds" and "high cost of seeds" were major constraints to adoption of S 35. Tackling this problem is a priority.

Research on seeds at the Gassi research station — the most important center for multiplication and distribution of improved varieties in the country — now simply involves packaging high-quality breeder's seed into mini-doses. This activity should be expanded on a large scale by farmers with the help of government and NGO extension workers. Farmers are advised to use new, improved varieties of seeds every three years, but when they grow and sow their own seeds, over time these seeds lose their purity and productivity is lower. Research on an integrated system to multiply and distribute high quality seeds is a priority.

Fundamental questions

The successful introduction of S 35 in Chad demonstrates that it is worthwhile for African NARS and regional research networks to cooperate, communicate research data, and exchange genetic materials. It is important that newly developed agricultural technologies be made available to farmers as quickly as possible. The consequences of the eventual refusal by farmers of an unsuccessful technology seem less serious than the costs that are incurred by a long delay between perfecting a technology and it's adoption.

When considering research and extension programs, the government needs to create a system that produces quality seeds in the required quantities and at the lowest cost.

Development of such a seed system should involve competition from the private sector, with the government creating an appropriate environment. While waiting for such a system to develop in Chad, it is important to reinforce the efficiency of the Gassi Seed Project, which is currently being funded by FAO (Food and Agriculture Organization). While continued funding by FAO is extremely important, it is also unrealistic to think it will continue indefinitely, and thus identifying other funding sources is essential.

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Impact of Sorghum S 35 in Extreme North Cameroon

C Ndjomaha[1], A Yapi[2], and A Adamou[1]

In extreme north Cameroon, agricultural researchers aim to create technologies that can:

- increase production,
- improve productivity,
- contribute to social well-being, and
- improve food security.

To attain this objective, researchers at IAR (Institute for Agronomic Research) obtain financial and technical support from the government of Cameroon, foreign donors such as USAID (U.S. Agency for International Development) and FAC (Fund for Aid and Cooperation), and from international agricultural research organizations such as the International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and Center for International Cooperation in Agronomic Research and Development (CIRAD). As part of the R&D process, it is essential that after a period of time, stakeholders understand the impact of their investments through an evaluation. Such an evaluation establishes the rate of adoption of a crop variety, documents the different factors affecting adoption, and provides feedback to refine future research efforts.

Because impact studies are of such importance to researchers, donors, and the government, ICRISAT initiated a collaborative study with the national program in Cameroon to evaluate the impact of the S 35 variety of sorghum in the extreme north of the country.

Extreme north Cameroon

Cameroon is a central African country with an area of 475 440 km^2 and an estimated population of 12 658 439 (Central Intelligence Agency 1992). Extreme north Cameroon covers about 7.4% of the country and its estimated population is 2 154 067 people (RGPH 1987) (Fig. 1). It is a Sudanian-Sahelien region with an annual rainfall of 500-900 mm and temperatures that vary from 24°C to 40°C. In the prov-

Ndjomaha, C., Yapi, A., and Adamou, A. 1998. Impact of sorghum S 35 in extreme North Cameroon. Pages 26-37 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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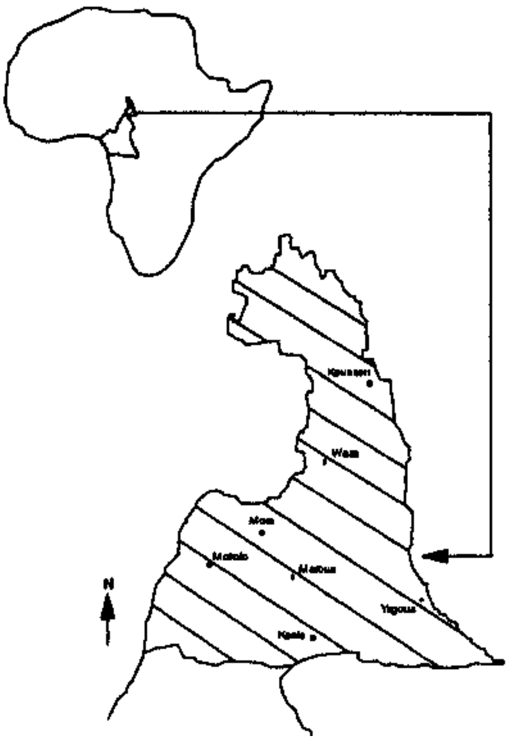

Figure 1. Extreme North region of Cameroon

inces, agriculture mainly involves cultivation of cotton, cereals, (sorghum, millet, rice, and maize), pulses (groundnuts and cowpea), maraichers (onions, lettuce, and carrots), and fruits. Pastoral activities include cattle, calves, poultry, and pig breeding.

Annual sorghum production is estimated at 400 519 t (284 785 t rainfed and 115 734 t grown in the off season (SNAR 1995) (Table 1).

According to a survey carried out by the Testing and Liaison Unit (TLU), Maroua in 1990/91, annual consumption of sorghum per rural family is 1 000-2 500 kg. Sorghum is consumed either as a porridge or as beer. The

Table 1. Area and production of sorghum in Cameroon.

Year	Area (ha)	Production (t)
1983	179 425	109 322
1984	273 629	163 926
1985	259 264	248 247
1986	319 560	396 997
1987	277 336	281 543
1988	302 890	366 150
1989	232 902	224 308
1990	283 553	194 981
1991	281 925	252 643
1992	296 569	316 927

Source: SNAR 1995.

residue from the local breweries is widely used in pig breeding. This survey also showed that consumption of sorghum is much higher than other foods such as millet, groundnut, cowpea, rice, and maize. In addition to its role in feeding humans and pigs, sorghum stalks are widely used in hut construction and fed to cattle during the dry season.

Considering the importance of sorghum in this region, agricultural research began in 1964 to develop technologies to increase and stabilize production. The estimated average production of sorghum and millet in north Cameroon is 700-780 kg ha^{-1}, but according to researchers, output of 2 500-4 000 kg ha^{-1} can be achieved in the zone with rainfall of 600-800 mm (IRAT 1971).

Attaining stable and high production is strongly limited by uncertain climatic conditions. For example, annual rainfall varies from 500-1 000 mm and is not temporally or geographically

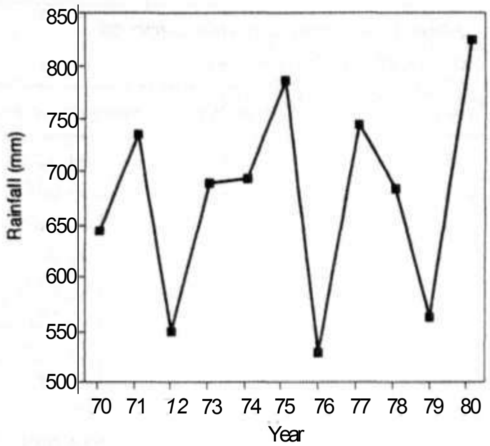

Figure 2 . Annual rainfall - Mora region (1970-80).

uniform. The cultivation period during which it rains is Jun-Oct, but since rains are irregular and not predictable, farmers often face a difficult sowing season in June and floods and erosion in August (Figs. 2 and 3). In 1982, the Agricultural Research Center in Maroua began work to select and improve sorghum varieties that were:

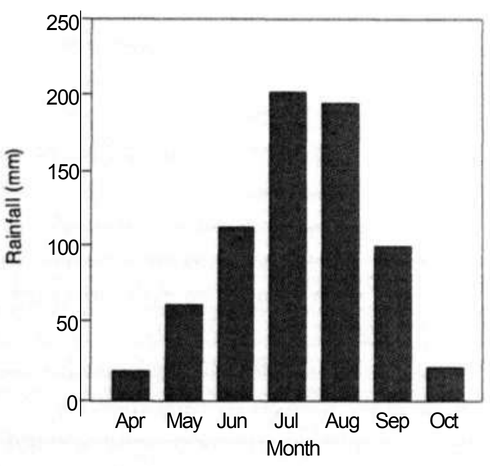

Figure 3. Monthly rainfall- The Mora region (1970-80).

- early maturing (80-95 days) in the semi-arid zone with 300-900 mm of

- stable and high yielding;
- tolerant to drought stress and *Striga;*
- resistant to diseases and insect pests; and
- compatible with farmer and consumer preferences (Dangi et al. 1990).

S 35 in Cameroon

The S 35 variety was selected by the Agricultural Research Center of Maroua in 1983 based on a collection obtained in 1981 from N G P Rao, the sorghum breeder at the Samaru research station in Nigeria. Favorable characteristics were identified at Maroua, and during 1983-85 multilocational trials were used to establish recommended areas for the new variety. Simultaneously, experiments in rural areas were carried out by the TLU in collaboration with SODECOTON (Organization for the Development of Cotton). In 1984, it was tested in 88 farmers' fields and the yield was practically double that of the local variety.

This spectacular performance of S 35 in a year when rainfall was less than 500 mm led the heads of research and development to propose its use in 1986. It was retested in 1985 with particular emphasis on cultivation techniques that could improve or stabilize yield. In the off-season of 1985, more than 20 t of S 35 was produced to launch the extension program in 1986. The zone where S 35 is recommended has an average rainfall of 300-800 mm. S 35 has a higher yield than the most widely grown local variety in the study area, Djigari, and is more resistant to drought and *Striga,* but Djigari seems to be more resistant to grain mold and appears to be hardier when grown on marginal soils.

Research on S 35 was mainly carried in north-central Cameroon (Fig. 4). Mountainous zones were not considered because the average rainfall exceeds 800 mm and humidity is quite high. The northern zone of the province was abandoned even though rainfall was adequate for S 35 (500-600 mm) because the area lacked the necessary infrastructure. Extension of this variety was done in north-central Cameroon with participation of the seed project and SODECOTON.

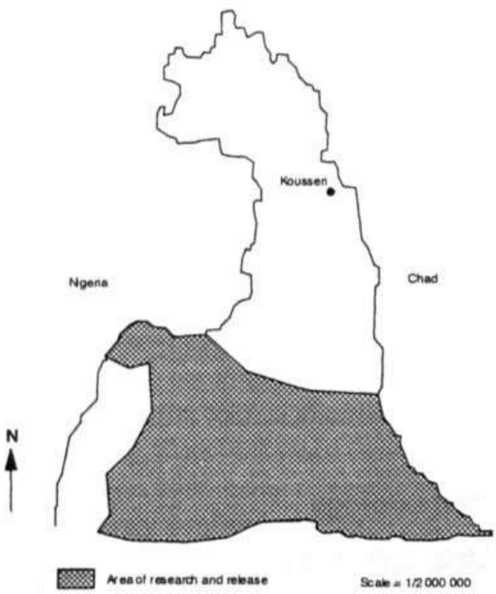

Figure 4. Area of research and release of S 35 in the Extreme-Nord (Far North) region of Cameroon.

Study area

The area where the impact of S 35 was studied, after introduction in 1986, is popularly called the cotton belt of north-central Cameroon (Fig. 4). It was divided into three zones: Mayo Sava, Mayo Danay, and Diamare (Table 2 and Fig 5). These zones have notable differences that could influence adoption of a variety:

Table 2. Estimated area of the three study zones in north-central Cameroon.

	Mayo Sava	Diamare	Mayo Danay
Total area (km^2)	3 408	7418	6 897
Potential area for rainfed sorghum	2215	4 822	3 829

Source: BEDI 1988.

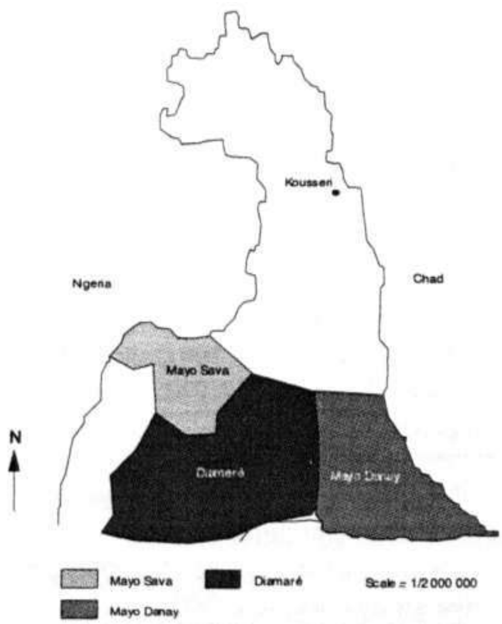

Figure 5. Areas of study of S 35 impact in the Extreme-Nord (Far North) region of Cameroon.

- Annual rainfall is relatively lower in Mayo Sava compared to the two other zones (Table 3).
- Farmers in Mayo Sava (which is closer to the Nigerian border) have the opportunity to buy fertilizer at relatively lower prices than in the zone itself.
- Activities under the agricultural extension program were first launched in the Mayo Sava zone in 1989. The Diamare and Mayo Danay zones began in 1991 and 1993.
- Cotton is not cultivated in a part of Mayo Danay and therefore cannot benefit from the services of SODECOTON.

Table 3. Annual rainfall in the three study regions of north-central Cameroon (mm).

Year	Mayo Sava	Diamar6	Mayo Danay
1986	582	876	860
1987	526	588	716
1988	783	846	902
1989	635	813	756
1990	604	736	650
1991	773	785	840
1992	709	797	782
1993	697	768	773
1994	884	1 046	928
1995	686	941	909
Average	688	820	812

Source: DPA 1986-95.

Many varieties of rainfed sorghum are cultivated in north-central Cameroon, which can be classified into three groups (Russell 1991):

- Varieties with an average growing period (100-130 days) are 3-4 m high with compact panicles. Grain color varies from red to white, including Djigari (red pericarp), Tchergue (yellow pericarp), Boulbassiri, Walagamari, and Gueling (white pericarp). Djigari is the most widely used in the zone and is often the local variety in pre-extension experiments.
- Varieties with a short growing period (85-100 days) such as Damougari and Makalari also have a red pericarp. These varieties are often considered by farmers as types of Djigari.
- Varieties with a long growing period (>130 days) are presently on the verge of disappearing in the north-central areas because annual rainfall is lower. These varieties are Yolobri and Mbairi. Rainfed sorghum can be cultivated as a sole crop, rotated with cotton, or as an intercrop with cowpea (Mayo Tsanga), groundnut (Mayo Tsanga), or pearl millet (Mayo Danay). Sorghum is grown as a sole crop on over 70% of the land (Kamuanga 1991).

The use of organic waste and fertilizers on rainfed sorghum is quite common in north-central Cameroon. According to a study carried out in 1991 by TLU/Maroua, only small quantities of fertilizers are used because farmers cannot afford more.

Methodology

Data collection

Data were collected from field studies and supplemented by secondary data obtained from village heads, officers of

SODECOTON, agricultural organizations, and NGOs.

Sampling. A team traveled through the three research zones in July 1995 to explain study objectives to district agricultural officers and solicit their support. Two villages were chosen at random from each district, and one officer from each village was selected and trained to conduct the study. Thirty-four villages were selected: 8 in Mayo Sava, 14 in Diamare, and 12 in Mayo Danay. In every village, a survey guided by the traditional chiefs was carried out to classify land used for cotton cultivation in 1995. From this survey, the team of researchers first sampled 20 farmers before moving to the larger survey of 571 farmers: 136 from Mayo Sava, 250 from Diamare, and 185 from Mayo Danay. Farmers were classified by cultivated area because SODECOTON recommends a yearly rotation of cotton-sorghum to farmers, hence a large producer of cotton is also considered a large producer of rainfed sorghum. In addition, cotton cultivation is an indicator of revenue because it is the most profitable cash crop in the study area. The village samples were supposed to include a range of sorghum growers and revenue levels.

Training. Data collectors were trained in August 1995 using a questionnaire previously prepared and pretested. Modules of the questionnaire were designed to gather data about farmer characteristics, production, area under rainfed sorghum, reasons for adoption and non-adoption, market price, etc. (Bantilan 1996). The research team kept in frequent contact with the study villages to ensure smooth data collection, which occurred Sep-Nov 1995.

Problems. Certain areas are not accessible from July-Sep because the roads are impassable, so they were not covered in the sample. In addition, the sample size in some villages was reduced because some farmers had moved, were traveling, or had died. Finally, one village in the Diamare zone was dropped from the sample due to difficulties faced by the surveyor in completing data collection. After meeting with local agriculture officials, it was thought that changes in the sample would not significantly influence results of the study.

Method to determine adoption and Impact

Adoption rate. The adoption rate for S 35 was calculated as a percentage of the total area on which rainfed sorghum is grown. For each of the three zones under study, a ratio of adoption was estimated from the sample and a calculation was made from 1986 (the first year of adoption) to 2015. Thirty years was selected as the period during which S 35 could generate benefits before becoming obsolete or before being replaced by an improved technology (Table 4).

Economic surplus approach. The main objective of this method is to estimate the additional benefit that S 35

Table 4. Observed and projected adoption of sorghum S 35 in the three study regions as a percentage of total area planted to sorghum.

Year	Mayo Sava (n=48)[1]	Diamare (n=137)	Mayo Danay (n=119)
1986	10.6	6.5	0.4
1987	15.4	7.5	0.4
1988	20.3	6.0	5.8
1989	30.1	4.2	1.6
1990	36.0	3.6	14.8
1991	35.9	4.5	9.3
1992	39.1	5.3	9.6
1993	47.1	6.6	15.9
1994	46.5	9.8	17.7
1995	49.4	13.6	12.1
1996	51.9	15.9	13.0
1997	54.0	18.0	13.8
1998	55.6	19.8	14.6
1999	56.8	21.2	15.3
2000	57.7	22.3	16.0
2001	58.3	23.1	16.5
2002	58.8	23.6	17.0
2003	59.1	24.1	17.5
2004	59.4	24.3	17.9
2005	59.6	24.6	18.2
2006	59.7	24.7	18.5
2007	59.8	24.8	18.7
2008	59.9	24.9	18.9
2009	60.0	25.0	19.1
2010	60.0	25.0	19.2
2011	60.0	25.0	19.4
2012	60.0	25.0	19.5
2013	60.0	25.0	19.6
2014	60.0	25.0	20.0
2015	60.0	25.0	20.0

1. n= Number of sample households.

provides to producers and consumers. This estimate is based on an analysis of the changes that S 35 will bring to supply and demand of rainfed sorghum in the area. The additional benefit thus determined represents the potential contribution of the technology to the economy (Fig. 6). The economic surplus is divided into two parts — consumer surplus and producer surplus.

The extent of the additional surplus generated by the new technology is a function of reduced per hectare production costs.

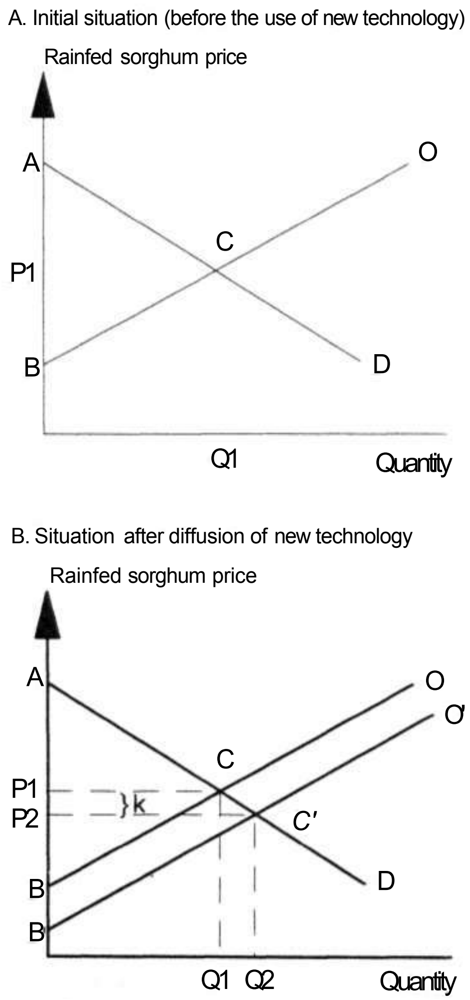

Figure 6. Schematic representation of economic surplus.

Extreme north Cameroon is a closed economy — sorghum sales outside the area are negligible, thus suggesting that in a state of market equilibrium, supply equals demand. Inelasticity of the supply occurs because rainfed sorghum is the staple diet for rural families in this area, and farmers cultivate it primarily to meet their nutritional needs, thus changes in the market price will not markedly affect quantities sold. Constraints such as limited agricultural credit and operating funds will not allow farmers to react favorably to a higher market price for sorghum. In addition, consumers rank rainfed sorghum lower when compared to *mouskwari* (dry season) sorghum, maize, or rice.

Research and extension costs. These costs include the sorghum selection program at Maroua, pre-extension work with Semi-Arid Food Grain Research and Development (SAFGRAD) and SODECOTON, seed multiplication, and delivering seed to farmers.

Results

Adoption of S 35

Ten years after introduction, S 35 was being grown on 50% of the rainfed sorghum area by 85% of the farmers in the Mayo Sava zone, but in the Diamare and Mayo Danay zones, the results were lower (Figs. 7 and 8). Over the 10-year-period 1986-95, the per hectare difference in productivity between S 35 and the local variety was

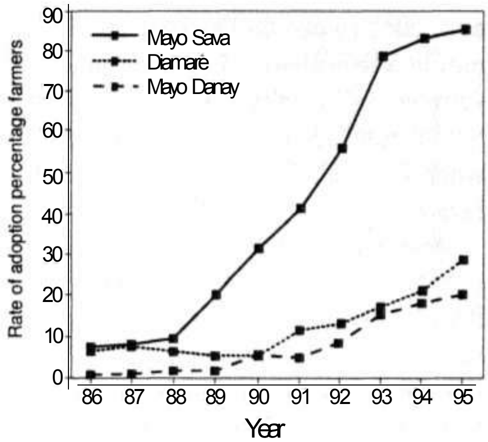

Figure 7. Rate of adoption of S 35 in the three study zones (percentage of farmers).

432 kg in Mayo Sava, 89 kg in Diamare, and 52 kg in Mayo Danay. These differences indicate a better genetic potential for S 35 in Mayo Sava than in the other two areas, probably because rainfall is more congruent with the 300-800 mm research recommendation. During this same period, average rainfall in Mayo Sava was 687

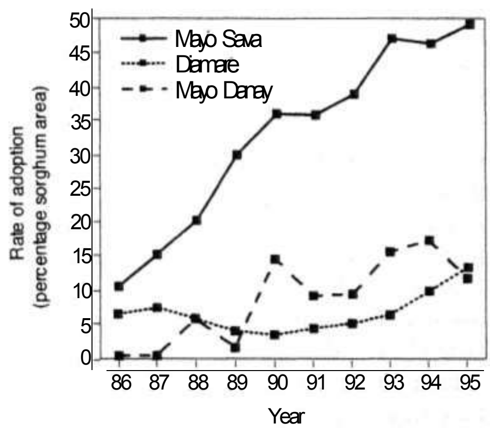

Figure 8. Rate of adoption of S 35 in the three study zones (percentage rainfed sorghum area).

mm, but 819 mm in Diamare and 811 mm in Mayo Danay. Local sorghum varieties are usually sown in June, but S 35 can be sown up to 15 July, thus when June rainfall is weak, S 35 fares better.

Another factor influencing S 35 adoption was extension services from PNVFA (Program national de vulgarisation et de formation agricoles). Mayo Sava had their services since 1989, but Diamare and Mayo Danay were covered only in 1992 and 1994. These extension efforts may have contributed to the higher adoption rate of S 35 in Mayo Sava.

Farmers cite several reasons for adopting S 35 — earliness, and food and feed quality. In addition, farmers in Mayo Sava and Diamare appreciate S 35 for its high productivity and grain color. In Mayo Sava, 27% of those interviewed adopted the variety for its high market price, which was 22-40% higher than the local variety. In Diamare, the stem of S 35 is consumed like sugarcane, a characteristic that was mentioned by nearly 20% of the farmers. Reasons for non-adoption were more numerous (Table 5).

Table 5. Reasons for not adopting S 35 in the three study regions in north-central Cameroon (percentage of farmers citing reason).

Reason	Mayo Sava (n=48)[1]	Diamare (n =137)	Mayo Danay (n=119)
Losses due to birds	37.5	35.1	7.6
Grain mold	37.5	17.5	5.0
High price of milling	27.1	13.1	
Light food	22.9	13.9	5.9
Regermination of seed	20.8		
Requirement of fertile soils	16.7	17.5	18.5
Poor quality of beer	12.5		
Small stalks for construction	10.4	5.1	
Stalks disliked by animals	10.4	4.4	
Lack of seed	8.3	24.1	
Requires weeding many times	6.2		
Requires quick harvest	6.2	1.4	
Problem with threshing area	6.2		
Inadequate labor	4.2	1.4	
Loss of stalk from fields	2.1	8.7	5.9
Susceptible to wind	2.1		
Date of sowing unknown		10.9	
Variety unknown		7.3	15.1
Low return		8.7	
Susceptible to insect attacks		6.6	4.2
High cost of seed		4.4	

1. n = Total number of sample households.

To mitigate bird damage and grain mold, researchers recommend late sowing (early July) of S 35 so that maturity will coincide with that of early local varieties and thus 'distribute' the bird damage. Late sowing aims for grain maturity at the end of the big rains, which should reduce the incidence of mold.

According to the systems research team, these general recommendations are not sufficient, and more research is necessary to determine appropriate sowing dates in each agroclimatic zone recommended for S 35. These experiments are of great importance to mitigate the two main constraints that hinder adoption of S 35 in north-central Cameroon. It is hoped that the problem of lack of seeds highlighted by farmers (52% in Mayo Danay and 25% in Diamare) will be gradually solved by joint seed production and multiplication by IAR and PNVFA that began in 1994. The officers in charge of the distribution program should be asked to work actively to inform farmers who do not yet know about the potential of S 35.

Adopters and non-adopters

The study determined that adopters of S 35 cultivate relatively large areas, and have more plows and draft animals than the non-adopters. They also have more contact with extension agents and seem to exploit new technologies more readily.

Factors such as education and age do not seem to affect adoption, but most of the adopters belong to the Mafa, Toupouri, and Guiziga groups. On the other hand, the Foulbe, Moundang, and Masa cultivate smaller amounts of S 35. This can be explained by the wide availability of Djagari, which is a good substitute for S 35, in the zones where the non-adopters live.

Impact of S 35

Internal rate of return (IRR) and net present worth (NPW) were used to assess the impact of S 35. IRR and NPW helped to judge investment opportunities and estimate productivity. Use of the economic surplus method allowed the potential gain generated by S 35 to be determined in each zone. By expressing the gain in reduced unit costs, the cost reduction 'k' is significant in Mayo Sava (k - 19.8) and quite weak in Diamare (k = 4.6) and Mayo Danay (k = 0.7). The higher productivity of S 35 relative to the local variety explains the lower unit cost.

The impact of S 35 is noticeable in Mayo Sava with an IRR of about 123% and a NPW of more than 2 billion CFA. In Diamare, the IRR is about 36% with NPW at 140 million CFA. The impact is lowest in Mayo Danay, with an IRR of 11%.

Comparison of results

Kamuanga and Fobasso (1994) conducted a similar study of S 35 adoption in north-central Cameroon in 1990. In that study 13% of farmers adopted S 35, with 8.7% of the area covered by rainfed sorghum. In extreme north

Cameroon, adoption rates were 12%, 14%, and 50% respectively in Mayo Danay, Diamare, and Mayo Sava. Reasons for adoption cited by farmers were similar in the two studies. In addition, S 35 improved food security in the region — in 1984 average rainfall was 480 mm, but productivity of S 35 was double that of the local variety. Food security was not measured in the present study, but it is hoped that future studies will consider it.

Conclusion

The data from this study indicate that Mayo Sava is the zone best suited for S 35 in extreme north Cameroon. An internal rate of return of 123% and a net present worth of more than 2 billion CFA were obtained. Rates of adoption in the other two zones were less than 20%, which reduces the IRR and NPW, but it should be noted that many farmers in these two zones did not have access to S 35 and were not well informed about its advantages compared to the local variety.

Further research is necessary to determine optimal sowing periods in the three zones, and joint seed production by IRA Maroua and PNVFA should be maintained to ensure an adequate seed supply. Finally, it is necessary to conduct research on S 35 in other parts of north Cameroon such as Logone and Chari.

Acknowledgements

We are most grateful to the individuals and organizations that have contributed to the different phases of our work. ICRISAT provided technical and financial support for data collection and analysis, the Garoua II Project helped with logistics for our field work, officers of local agricultural agencies and AVZ (agents de vulgarisation) were active in data collection, and traditional chiefs and officers of SODECOTON, particularly Mr. Asfom, shared their experience with distribution of S 35. At the Center for Agricultural Research, Maroua, Mr M M Samatana Marc, Kenga Richard, and Djonnewa Andre provided useful advice throughout the study. Finally, we thank Mr. Boumnso for his active participation in data collection.

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Dual-purpose Sorghum — A Case Study in India

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The bovine population in the Indian state of Andhra Pradesh declined from 21.9 million to 21.1 million (a 3.6% decrease) between 1983 and 1987 (Government of Andhra Pradesh 1996). Straw and stover are important feed for bovines, and higher fodder prices combined with a decline in the area under fodder crops forced farmers to reduce herd size (Kelley and Parthasarathy Rao 1994). Although the supply of rice straw has increased in irrigated areas while sorghum fodder production declined in rainfed areas, farmers in rainfed areas tend to prefer feeding sorghum straw to their livestock (Anders and Satyanarayana 1994).

Dual-purpose sorghum varieties were proposed by ICRISAT for this area to meet the demand for rainfed fodder at reasonable prices. Feed demand in rainfed areas has been increasing as the availability of traditional communal lands has declined, and fallow periods in crop rotations have become less frequent (Anders, Mulder, and Satyanarayana 1993). Despite a negative growth rate in animal population, the pressure on fodder has increased during the past two decades (Kelley and Parthasarathy Rao 1994).

Improved cultivars have been adopted at a high rate in some areas of India, but many other areas either had no exposure to improved cultivars or have rejected those that have been made available (Anders and Satyanarayana 1994). A method for farmers and researchers to identify fanners' needs, along with constraints to adoption of improved cultivars, was developed to better understand their reasons for not adopting improved genetic material (Anders and Satyanarayana 1994). ICRIS AT scientists were keen to become involved in a project that would focus on an area with potential for growing improved cultivars, but where they had not been adopted by farmers.

Asokan, M., Bantilan, M.C.S., Joshi, P.K., Anders, M.M., and Valasayya, S. 1998. Dual-purpose sorghum — a case study in India. Pages 38-51 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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

The Indo-Swiss Project Andhra Pradesh (ISPA) is a bilateral project that has been operating in the state since 1990. ISPA made efforts to increase and maintain the bovine population and conduct research to introduce appropriate fodder varieties to meet the growing demand. One of its major objectives is to improve feeding systems to optimize the existing fodder resource base and integrate fodder cultivation into the farming system. Because both ICRISAT scientists and ISPA wanted to develop a comprehensive profile of sorghum production in a mixed crop-livestock system, a collaborative project began in 1991. The objectives were to assess farmer preferences for dual-purpose sorghum varieties by introducing a wide range of genetic materials and to identify and quantify constraints to adoption of improved sorghum.

A methodology was jointly developed to bring together farmers, extension personnel, and researchers and to evaluate different cultivars in farmers' fields with the same management practices applied to all plots (Anders and Satyanarayana 1994). Researchers made available a wide range of genetic material from which farmers could select according to their needs. The methodology also included monitoring the adoption and impact of the project. Anders, Mulder, and Satyanarayana (1993) evaluated different sorghum genotypes in farmers' fields and found that the dual-purpose sorghum varieties ICSV 112 and ICSV 745 were much preferred by farmers in the Warangal district of Andhra Pradesh.

The initial reconnaissance survey in Bachannapet and its neighboring villages found farmers expressing the need for good quality seed, but it was not available nearby. If the seed of a new cultivar is an important component of a technology, steps should be taken to multiply it quickly to meet the demands of interested farmers (Nene 1993). This was followed by distribution of about 1.2 t of seed of ICSV 745 and ICSV 112 and 240 kg of pigeonpea (ICRISAT plant materials) during the 1993 rainy season. Therefore, a study was planned in 1993 to document the performance of ICSV 112 and ICSV 745. This paper reports:

- yield and fodder advantages of ICSV 745 and ICSV 112 sorghum varieties over the local sorghum under the same management practices,
- farmer perceptions about different traits, and
- early adoption and spread through seed tracking and monitoring (ICSV 745 and ICSV 112 are not yet officially released in this area).

Results of a follow-up survey to confirm adoption in the following rainy season (1994) using a subsample of farmers from two villages are also presented.

Study Area

The study was conducted in Bachannapet and the surrounding villages of Warangal district in Andhra Pradesh during 1993/94 (Fig. 1). District-level secondary data from the 1970s indicate that sorghum was a major crop in this region, occupying about 35% of the gross cropped area (GCA). Warangal district is endowed with assured annual rainfall of 1041 mm. A large proportion of the cultivated area in this region is characterized as rainfed where sorghum is the main staple food grain as well as a fodder crop. The crop has traditionally been an important food grain and a good source of dry fodder. However, sorghum area has drastically declined

Figure 1. Location of Warangal district in the state of Andhra Pradesh

in the last two decades. The total area under sorghum in the district significantly declined from 191 000 ha in the early 1970s to 32 000 ha in the early 1990s (Government of Andhra Pradesh 1994), and now occupies only 7% of GCA (Table 1). Long-term trends initially indicated increasing production during 1966-74, but fluctuations were high during the subsequent 10 years, which could be due to high variation in the annual rainfall during that period. After 1980, the area under sorghum started declining remarkably in both the rainy and postrainy seasons. Rainy season sorghum declined from 66 000 ha in 1971-73 to 6 000 ha in 1991-93, while postrainy season dropped from 125 000 ha in 1971-73 to 26 000 ha in 1991-93. While the rainy season sorghum yield has fluctuated widely but increased marginally, the postrainy season yield increased from 500 to 620 kg ha^{-1} during the 1971-73 and 1991-93 periods.

Adoption of high yielding varieties (HYV) of sorghum in Warangal District is presented in Figure 2. Until the late 1970s, adoption of these varieties was minimal. The area under HYV expanded from 20% in 1980 to 42% in 1984, but during 1985 suddenly dropped to 5%. However, since 1986, the area under HYV increased to about 21% in 1992 (Fertilizer Association of India 1994). In the study villages, however, no modern varieties of sorghum were found during our reconnaissance survey in 1992.

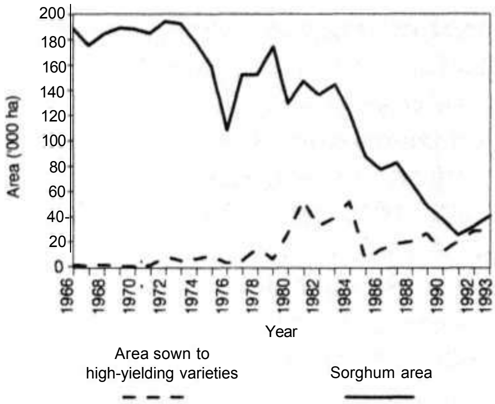

Figure 2. Area sown to sorghum and adoption of high-yielding sorghum varieties in Warangal district.

Analysis of cropping patterns in the study villages showed that sorghum maintained its importance in terms of cultivation and consumption. Survey data collected during Nov 1993

Table 1. Trends in sorghum area, production, and productivity, Warangal district, Andhra Pradesh.

	Rainy season			Postrainy season			Total		
Time period	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})
1971-73	66	40	610	125	62	500	191	102	530
1981-83	61	29	470	82	44	540	143	73	510
1991-93	6	4	670	26	16	620	32	20	630

indicated that rice is the most important crop, occupying about 23% of total cropped area (TCA), and among the rainfed crops, sorghum occupied 23% of TCA, sesamum about 20%, castor 10%, and sunflower 8% (Table 2% Adoption of HYV rice was high (about 97%), while adoption of ICSV 745 and ICSV 112 was also high (45%), primarily due to the seed distribution that occurred in 1993. Adoption of improved cotton (74%) and sunflower (87%) cultivars was also high.

Methodology

Bachannapet and its cluster of villages are located about 100 km from Hyderabad. ISPA is actively working in this area to improve and maintain the livestock population through improved technology for the farming systems in villages that were previously selected.

Table 2. Cropping patterns of sample farmers in eight selected villages, Warangal district, 1993/94.

	Rainy season		Postrainy season		Total	
Crop	Area (percentage of total crop area)	Percent of crop sown to HYV[1]	Area (percentage of total crop area)	Percent of crop sown to HYV[1]	Area (percentage of total crop area)	Percent of crop sown to HYV[1]
Rice	23.2	97.1	22.5	96.9	23.0	97.0
Sorghum[2]	22.0	61.6	25.6	2.2	22.9	44.5
Maize	3.6	62.6	4.3	48.5	3.8	58.5
Pearl millet	0.1	0	0	0	0.1	0
Wheat	0	0	0.1	0	0.1	0
Pigeonpea	0.4	19.9	0	0	0.2	19.9
Chickpea	0	0	1.7	0	0.4	0
Green gram	2.3	0	0.2	0	1.8	0
Horsegram	1.9	0	12.8	0	4.7	0
Cowpea	0.2	0	0.1	0	0.1	0
Sesamum[2]	26.4	0	1.7	0	20.1	0
Castor	12.8	55.4	2.9	53.9	10.2	55.3
Groundnut[2]	2.5	10.3	1.9	11.7	2.3	10.6
Sunflower	2.7	95.7	22.3	84.2	7.7	87.2
Safflower	0.1	0	1.5	0	0.4	0
Mustard	0.1	0	0	0	0.1	0
Cotton	0.6	74.1	0	0	0.4	74.1
Vegetables	0.6	0	0.8	0	0.7	0
Fodder sorghum	0.2	0	1.3	0	0.5	0
Grass	0.2	0	0.2	0	0.2	0
Total	100.0	48.8	100.0	45.1	100.0	47.8

1. High-yielding varieties. 2. Includes intercrops.

One approach was to introduce suitable fodder varieties. On-farm trials to test several ICRISAT sorghum varieties were conducted in the villages during 1991-93 in collaboration with ISPA (Anders 1994).

After 2 years of on-farm work, Anders, Mulder, and Satyanarayana (1993) found that two sorghum varieties, ICSV 112 and ICSV 745, were suitable for this location and favored by farmers for higher grain and fodder yields, improved seed and fodder quality, and higher profits than four other varieties, N 1, M 35-1, ICSV 422, and SP 260. Grain and fodder yields of ICSV 745 and ICSV 112 were much higher than other varieties tested (Table 3). Fodder yield, however, was lower than or equal to fodder variety N 1, but higher than the other varieties. The performance of the dual-purpose sorghum varieties ICSV 112 and ICSV 745 was relatively better than the other four varieties, hence ISPA decided to collaborate with ICRISAT and introduce these two varieties to their program.

Table 3. Yield comparisons of local and improved sorghum genotypes, Bachannapet, 1992.

Genotype	Grain yield (t ha^{-1})	Fodder yield (tha^{1})	Failed plots
ICSV 745	1.2	10.9	0
M 35-1	1.5	8.1	3
N 1	0	10.9	1
ICSV 112	1.3	9.1	0
SP 260	0.8	6.3	1
ICSV 442	0	6.4	2
Mean	0.8	8.5	1

Source : Anders, Mulder and Satyanarayana (1993).

ICSV 112 was identified by ICRISAT after 8 years of research (Reddy and Stenhouse 1994). It was recommended by the National Seed Release Committee as CSV 13 in India in 1987. It is of medium height, matures in 110-120 days, is suitable for intercropping, and is recommended for its high and stable yield at low and intermediate altitudes. It can be cultivated as a rainfed crop during the rainy season and as an irrigated crop during the postrainy season.

ICSV 745 sorghum was developed by NARS using materials from ICRISAT. Research began in 1983 and the product was identified after seven years of research (Reddy and Stenhouse 1994). It was released in India in 1993 for midge-prone areas. ICSV 745 matures in 100-110 days, is highly resistant to sorghum midge, and has high yield potential. It is also less susceptible to leaf diseases such as ergot and downy mildew.

Because availability of quality seeds was a major constraint in the region, ISPA and ICRISAT decided to produce sufficient quantities of ICSV 745 and ICSV 112, and make them available to farmers for the rainy season of 1993. Initially, 1.2 t of seed was sold to 240 farmers in these villages through ISPA. Each farmer paid Rs. 14 for 5 kg of ICSV 745 or ICSV 112, along with 1 kg of pigeonpea seed (an ICRISAT variety) because most farmers were growing pigeonpea as an intercrop with sorghum. (At the time of this study, 1 US$ was worth about 30 Indian rupees [Rs.].)

Farmers were interviewed to determine how much land they cultivated, cropping patterns, adoption and assessment of the technology, and cost of cultivation. Although ISPA reported that 240 farmers bought seeds in this program, we could identify only 159 farmers as adopters of ICSV 112 and ICSV 745. It was planned to trace the 240 seed kits distributed to farmers, but we found that about 159 farmers bought 164 kits for themselves, 22 reported that someone might have taken seed in their name, 6 were from distant villages, and 31 reported that they did not sow the seed during this season.We also took a sample of 57 farmers who did not sow ICSV 112 and ICSV 745, but instead grew local sorghum varieties. Thus data were collected from 216 farmers in 8 villages. About half the seed was sold in the two villages closest to the seed distribution center.

Scientific experts visited at different stages, monitored crop growth during the 1993 rainy season, and were impressed with the crop's performance. During Nov 1993, farmers who sowed ICRISAT varieties and those who sowed local varieties were interviewed. An additional survey in February of the next year gathered data on the pigeonpea crop, and a third survey in Sep 1994 confirmed second-year adoption of these varieties by fanners.

District-level data on area, yield, and production were used to assess sorghum performance in the study region. Tabular analysis looked at technology dissemination and farmer perceptions of varietal traits. Desirable characteristics listed by farmers were ranked in order of importance. A partial budget approach was used to evaluate performance. The value of family labor, bullock labor, and major equipment were imputed on the basis of market prices. Adoption rates were also estimated from the available data.

Survey results

Technology dissemination

The two dual-purpose sorghum varieties were distributed to farmers only during the rainy season of 1993. About 50% of the adopter respondents learned about the improved varieties through ISPA, 18% from other farmers, and 32% from other sources (a friend, veterinary hospital staff, etc.). Heads of households usually decide which variety to sow, and only 6% of respondents reported that other farmers induced them to adopt these varieties.

Farmer perceptions

Among 159 adopters, 93% were convinced about the superiority of these varieties in terms of their performance and the crop stand before harvest. Eleven farmers were not convinced about the superiority of these varieties in any of the traits featured. Among 57 non-adopters, only three were unaware of these varieties, and 89% of the non-adopters rated these varieties superior when compared to local materials. The responses were based on their observations of neighboring fields. Two non-adopter farmers rated these varieties equal to local ones, while four rated them as inferior to the local.

Table 4 presents the most preferred grain and fodder traits of ICSV 112 and ICSV 745. All responding farmers liked the easy threshability, an important characteristic in view of the declining labor supply during peak periods, especially immediately after harvest.

Table 4. Desirable characteristics of ICSV 112 and ICSV 745 as perceived by farmers.

Characteristic	Response (%)
Grain	
Easy threshability	100.0
Higher yield	58.5
Big ear head	48.4
White color	40.2
Drought resistant	24.5
Sweetness	17.0
Bold grain	16.3
Small grain	9.4
Uniformity	6.9
Good seed	3.8
Other	8.2
Fodder	
More yield	59.7
Broad leaves	32.1
Shorter than local	29.6
Good stem quality	20.7
More palatable	16.3
Sweetness	3.8
Equal with local	3.8
Others	4.4

Table 5. Characteristics of ICSV 112 and ICSV 745 disliked by farmers.

Product	Problem
Grain	Grain mold Small grain size
Fodder	Shorter than local Breaks easily Thick stem

Farmers were concerned about grain mold, which was brought on by rain just before harvest. Farmers also complained about the smaller grain size (Table 5). In terms of fodder, farmers disliked the short plant height, easy stem breakage while tying bundles for fodder, and the thick stem that is not easily chewed by animals. Farmers were positive about their initial experience with these two varieties, and were expecting higher income than with the local varieties, as well as more fodder for their livestock.

Economic evaluation

Adoption of improved varieties is largely determined by their profitability compared to existing varieties. Cost and returns data were examined to determine the profitability of ICSV 112 and ICSV 745. The analysis looked at sorghum grown as sole crop and as an intercrop with pigeonpea (Table 6).

Local varieties tended to be sown using a higher seed rate than improved varieties, and the seed price of the local variety was higher (3 vs 2 Rs. kg^{-1}) due to the subsidy offered by the project. More farmyard manure was

Table 6. Cost analysis of the research impacts of ICSV 112 and ICSV 745.

	Local varieties		ICSV 745		ICSV 112	
	Quantity	Cost (Rs.)	Quantity	Cost(Rs.)	Quantity	Cost (Rs.)
Sole crop						
Number of farmers	25		13		18	
Total variable costs[1]		2 104		2 067		2 051
Total fixed costs[2]		1 020		1 020		1 020
Total costs		3 124		3 087		3071
Output						
Sorghum grain (kg)	546	1 606	733	1 980	851	2 255
Grain price (Rs. kg^{-1})		2.94		2.7		2.65
Sorghum fodder (t)	2.7	1 202	2.2	888	2.3	871
Fodder price (Rs. t^{-1})		445		404		379
Gross returns		2 808		2 868		3 126
Unit cost assessment						
Variable costs (Rs. t^{-1})		3 850		2819		2 410
Fixed costs (Rs. t^{-1})		1 867		1 391		1 199
Total cost (Rs. t^{-1})		5717		4210		3 609
Unit cost reduction						
Variable costs (Rs. t^{-1})				1 031		1 440
Fixed costs (Rs. t^{-1})				476		668
Total cost (Rs. t^{-1})				1 507		2 108
Intercrop with pigeonpea						
Number of farmers	49		47		86	
Total variable costs[1]		2 253		2 370		2 131
Total fixed costs[2]		1 020		1 020		1 020
Total costs		3 273		3 390		3 151
Output						
Sorghum grain (kg.)	421	1 237	542	1 464	571	1 514
Grain price (Rs. kg^{-1})		2.94		2.7		2.65
Sorghum fodder (t)	2.2	977	1.7	685	1.7	642
Fodder price (Rs. t^{-1})		444		403		378
Pigeonpea grain (kg)	35.7	165	38.4	182	45.8	266
Grain price (Rs. kg^{-1})		4.62		4.74		5.81
Pigeonpea stalk (t)	0.01	3	0.09	23	0.10	26
Fodder price (Rs. t^{-1})		300		256		260
Gross returns		2 382		2 355	2	448
Unit cost assessment						
Variable costs (Rs. t^{-1})		5 356		4 371		3 730
Fixed costs (Rs. t^{-1})		2 425		1 881		1 785
Total cost (Rs. t^{-1})		7 780		6 252		5515
Unit cost reduction						
Variable costs (Rs. t^{-1})				984		1 626
Fixed costs (Rs. t^{-1})				544		640
Total cost (Rs. t^{-1})				1 528		2 266

1. Variable costs include male labor, female labor, bullock labor, seed, farmyard manure, fertilizer, pesticides, and cost of using equipment.
2. Fixed costs include land taxes, land rent, and depreciation and interest on capital.

used for the local varieties, while the improved varieties received more inorganic fertilizer. Total labor used in both cropping systems did not vary significantly (about 60 days). Overall, however, variable input costs did not significantly differ among the different varieties, i.e., no extraordinary expenses were involved in the cultivation of ICRISAT varieties. Total variable costs for growing ICSV 112 were lowest in both the sole and intercrop with pigeonpea.

Compared to local varieties, the yield of ICSV 112 as a sole crop was 56% higher and the intercrop was 36% higher. Although the yield of ICSV 745 was lower than that of ICSV 112, it was still higher than the local varieties —34% for the sole crop and 29% for the intercrop. The price of ICSV 112 and ICSV 745 was lower than the local varieties, but for the sole crops, the total value of grain harvested from ICSV 112 was 40% higher than the local varieties while ICSV 745 was 23% higher.

Results were similar for the intercrop with pigeonpea. The gross returns from sorghum for ICSV 112 were 22% higher than the local varieties, and ICSV 745 was 18% higher. Grain mold disease due to rains before harvest of ICSV 112 and ICSV 745 caused severe damage to the crop, and the pigeonpea crop suffered an insect infestation due to cloudy weather. In addition, there were no rains for the pigeonpea crop and its yield was poor. The pigeonpea crop grown with ICSV 112 and ICSV 745 was an ICRISAT material, and its yield was much higher than the local pigeonpea grown with the local sorghum.

The fodder yield of the local varieties was much higher than the dual-purpose varieties in both sole and intercrops, an expected result since the local varieties are more of a fodder type.

The gross returns from ICSV 745 were only slightly better than the local varieties for the sole crop, but slightly lower for the intercrop. Gross returns from ICSV 112 were 11 % higher than the local variety in the sole crop, and 3% higher in the intercrop.

For the sole crop, net farm income was higher by 13% for ICSV 745 and 52% for ICSV 112. For the intercrop with pigeonpea, net farm income from the local varieties and ICSV 745 was negative, but ICSV 112 yielded about Rs. 700 ha^{-1} net income. In terms of unit cost reduction, ICSV 112 gave higher returns when compared to local varieties and ICSV 745. When compared to the local varieties, unit cost reduction (Rs t^{-1}) for ICSV 112 was Rs. 2 108 for the sole crop and Rs. 2 266 for the intercrop, with ICSV 745 at about 1 507.

The two dual-purpose sorghum varieties showed significant economic advantages, and hence they have a high potential for adoption in this region.

Adoption

Sample farmers in the eight villages around Bachannapet sowed 44.7 ha of

ICSV 112, 26.9 ha of ICSV 745, and 45.6 ha of local varieties of sorghum during the rainy season of 1993. The distribution of areas sown to ICSV 112 and ICSV 745 is shown in Table 7. The area expected to be sown to ICSV 112 and ICSV 745 was much higher in Bachannapet and Pochannapet, the two main villages where ISPA operated.

Information on planned use of these varieties for the next rainy season was also gathered from farmers. In interviews conducted before the 1993 rainy season harvest, farmers said they expected to sow about 101 ha of the two dual-purpose sorghum varieties during the rainy season of 1994. Farmers in Alimpur, Itekalampally, Thammadapally, and Yeddugudam said they expected to sow about 70% of their 1994 rainy season sorghum area to the two ICRISAT varieties, while in other villages expected adoption was about 95%.

During the rainy season of 1994, a follow-up survey determined that the actual area sown to the two varieties was much less than had been earlier predicted (Table 7). The follow-up survey indicated that farmer perceptions of ICSV 112 and ICSV 745 had changed substantially (Table 8). More than one-third of the farmers interviewed said they had switched to a commercial crop such as sesamum. Grain mold is a major constraint to the adoption of ICSV 112 and ICSV 745, which contributed to low market prices.

Lessons learned and future research

The methodology used by Anders, Mulder and Satyanarayana (1993) in selecting and introducing appropriate varieties to new areas provided important lessons for researchers who are involved in on-farm research. Involving an established project staff such as ISPA was an ideal way to introduce new technologies. This participatory method of technology generation, evaluation, and transfer is an efficient way to introduce new technologies.

Some farmers benefited by selling sorghum as seed to ISPA under the seed buying policy of the project. Other farmers were unable to sell their seed to the program because of the grain mold problem, and others mixed the two varieties after harvest. There is, therefore, a need to closely monitor the harvest if a seed procurement program is built into the project plan.

Most farmers did not know how to maintain seed purity. Farmers can harvest the crop for food and feed, but are not sure how to harvest for seed. Training in seed production is an obvious need.

Prior to the rainy season of 1994, ISPA made available a sufficient quantity of ICSV 112 and ICSV 745 seed to farmers, but they thought it was too expensive. Farmers were ready to buy seed at Rs. 2.50- 5.00 kg^{-1} but during the follow-up survey, many farmers said that they did not know seed was available at the project center.

Table 7. Area sown to sorghum during 1993 rainy season and expected and actual adoption of ICSV 112 and ICSV 745 during 1994 rainy season.

	Area planted, 1993 rainy season					Area planted, 1994 rainy season			
	ICSV 112 (ha)	ICSV 745 (ha)	Other (ha)	ICSV112 and ICSV 745 area as percentage of total	Area expected to be sown to ICSV 112 and ICSV 745 during1994	ICSV 112 (ha)	ICSV 745 (ha)	Other (ha)	ICSV 112 and ICSV 745 area as percentage of total
Alimpur	2.2	1.5	5.7	39.7	6.5				
Bachannapet	10.7	5.8	10.7	60.6	25.9	2.2	8.5	10.3	51.1
Chinna Ram Cherla	4.3	3.0	3.9	65.0		10.9			
Itekalampally	4.9	3.5	4.5	65.5		8.9			
Nakkavanigudem	1.7	0.6	0.6	79.7		2.8			
Pochannapet	12.6	9.8	11.6	65.9	32.4	6.8	6.1	15.6	45.3
Thammadapally	2.7	1.3	5.1	44.4		6.2			
Yeddugudem	5.5	1.4	3.6	65.6		7.7			
Total	44.7	26.9	45.6	61.1		101.3			
Bachannapet and Pochannapet	23.3	15.6	22.3	63.5	58.3	9.1	14.6	25.8	47.8

Table 8. Reasons for decline in the area sown to ICSV 112 and ICSV 745 from 1993 rainy season to 1994 rainy season.

Reason	Responses (%) (n - 115)
Shift to commercial crops	35
Low grain price	32
Poor fodder quality	16
Lost interest due to crop failure	14
Not shown interest	13
Seed not available	12
Not satisfied with performance	9
Susceptible to grain mold	8
No drought tolerance	4
Not preferable for consumption	3
Varieties not suitable for double cropping	2

One year is not long enough for conclusive results in such an attempt to introduce new crop varieties. Monitoring should continue at this location to document the adoption behavior of farmers.

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Research on High Yielding Pearl Millet — Background for an Impact Study in India

M C S Bantilan, K V Subba Rao, K N Rai, and S D Singh[1]

Pearl millet is an important coarse grain that is generally grown as a rainfed crop on marginal lands with few inputs and little management. It provides food for millions of people living in the arid and semi-arid regions of the Indian subcontinent and Africa. This grain has a high feed value for poultry and is a good source of energy and nitrogen in ruminant diets. Pearl millet is a diploid-tillering, protogynous, cross-pollinated cereal that easily produces hybrid and selfed seed (Andrews and Rajewski 1995). This grain is grown as a food crop in tropical Africa and India, with most production concentrated in Sahelian western Africa and northwestern India. High temperatures and a short growing season characterize these regions that are prone to frequent droughts caused by low and erratic rainfall. Soils are sandy and infertile.

Millets are grown on 36 million ha, producing 27 million t of grain. More than 90% of millet area and production are in developing countries with a food deficit — 47% of the area is in Asia, producing about 55% of the world crop. Of the Asian contribution to world millet production, India alone covers 83% of the area, producing 71 % of the crop (about 40% of world millet area and production) (FAO 1995). The pearl millet area in India declined from more than 13 million ha in 1973 to less than 11 million ha during 1993.

As high yielding varieties (HYV) began to be adopted in the mid 1980s, productivity steadily increased, and now they occupy 55% of the pearl millet area in India (Fertiliser Association of India 1993). The states of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh, and Haryana account for around 90% of the total area and production of pearl millet in India. Rajasthan alone accounts for 46% of India's total pearl millet area, but only 30% of its total production because rain is erratic and suitable HYV seed is often unavailable (Figs. 1 and 2).

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

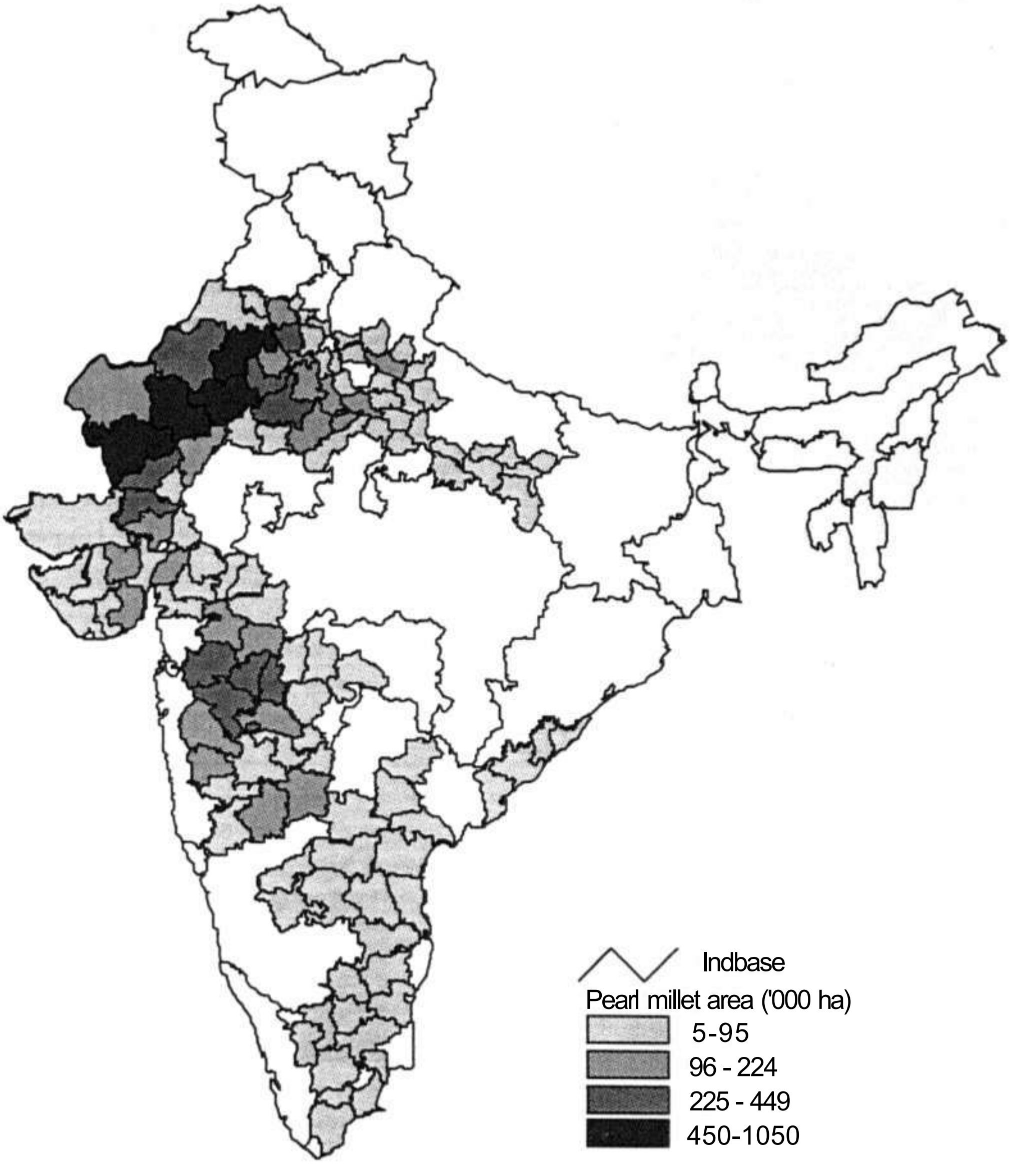

Figure 1. Distribution of pearl millet area in India, 1988-90.

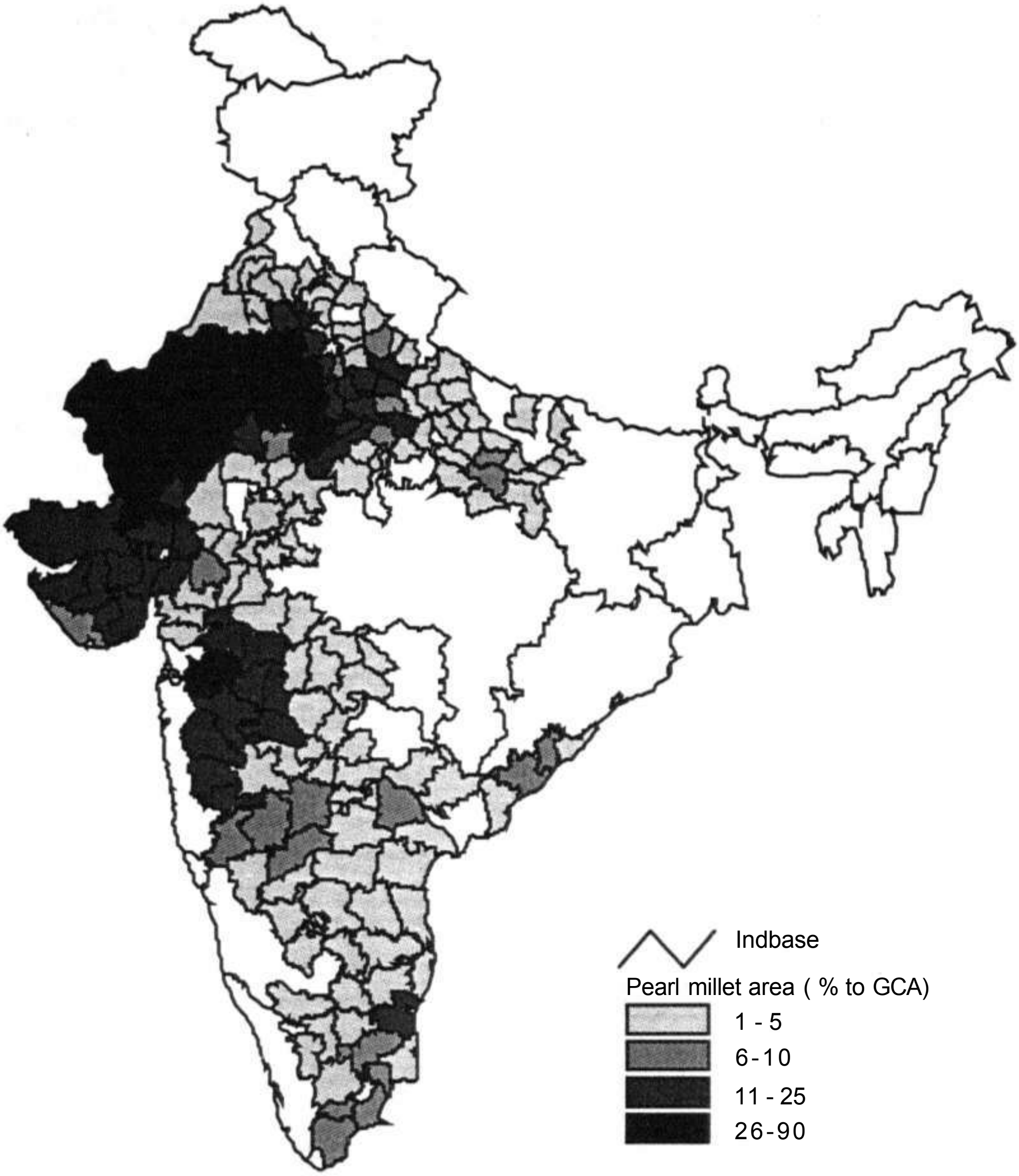

Figure 2. Pearl millet area as a percentage of gross cropped area in India, 1988-90.

In collaboration with researchers of the national agricultural research system (NARS), ICRISAT and its partners developed several open-pollinated varieties, hybrids, and parental materials that have been released to farmers in India by government authorities since 1982. These research products were developed to increase yields by alleviating primary biotic and abiotic constraints. NARS, including the private seed sector, heavily depend on ICRISAT parental materials for their breeding programs. The significant improvements in the relative research strength of NARS through the years had led ICRISAT to focus increasingly on strategic aspects to improve grain yield and downy mildew resistance, and develop intermediate products.

Among biological constraints to pearl millet production in Asia, downy mildew is the single most important. Research on both intermediate and final products was pursued. Among intermediate products, for example, development of more effective screening procedures to evaluate a wide array of germplasm and breeding materials from around the world has contributed substantially to research efficiency in NARS breeding programs in India and Africa.

ICRISAT, in partnership with NARS scientists, worked on breeding open-pollinated varieties and hybrids resistant to downy mildew. This effort has been productive. In 1982, an ICRISAT-bred, open-pollinated variety (WC-C75) that was resistant to downy mildew and produced grain and stover yields equal to the best available hybrid at that time (BJ 104) was released in India. Release of this variety provided a timely alternative to the susceptible BJ 104, and to low-yielding local landraces. The rapid multiplication of WC-C75 and its adoption by farmers helped to prevent a decline in pearl millet production. In 1986, an ICRISAT downy mildew resistant hybrid, ICMH 451 (also known as MH 179) was released. It out-yielded all other varieties and hybrids released earlier, and its seed production was relatively easy and profitable.

The range of final products from the pearl millet R&D program in India is given in Table 1. The pearl millet breeding program at ICRISAT developed varieties, hybrids, and hybrid parents, and supplied materials to its public and private sector partners. The availability of ICRISAT-bred parental materials and their use by private and public sector pearl millet breeders in India substantially reduced the research time lag in developing new hybrids. Many hybrid cultivars bred by the Indian NARS and now under cultivation are based on parental materials from ICRISAT.

The objective of this paper is to provide an overview of research evaluation undertaken to assess the impact of pearl millet research and development. It highlights surveys conducted to determine adoption and impact of pearl millet breeding research in India. To date, the surveys have covered regions in western Maharashtra, where 90% of pearl millet in the state is grown. Surveys have also been completed for the rainy

Table 1. Pearl millet hybrids and varieties released in India, 1965-98.				
Type[1]	Cultivar	Bred at	Released in	Pedigree
H	HB 1	Ludhiana	1965	Tift 23A x Bil 3B
H	HB2	Jamnagar	1966	Tift 23A x J-88
H	HB 3	Jamnagar	1968	Tift 23A x J -104
H	HB 4	Kanpur (IARI)	1968	Tift 23A x K560
H	HB5	Kanpur (IARI)	1969	Tift 23A x K559
H	PHB 10(HB 6)	Ludhiana	1975	Pb 111A x PIB 155
H	PHB 14(HB 7)	Ludhiana	1975	Pb 111A x PIB 228
H	GHB 1399	Jamnagar	1975	MS 126 D_2A x J -1399
H	NHB 3	Delhi (IARI)	1975	5071A x J104
H	NHB 4	Delhi (IARI)	1975	5071A x K560 -230
H	NHB 5	Delhi (IARI)	1975	5071A x K559
H	CJ 104	Delhi (IARI)	1977	5054A x J104
H	BD 111	Delhi (IARI)	1977	5141AxDIII
H	BJ 104 (KM 1)	Delhi (IARI)	1977	5141AxJ104
H	BK 560 (KM 2)	Delhi (IARI)	1977	5141A x K560-230
H	X4 (COH 2)	Coimbatore	1984	5141A x PT 1921
H	GHB 27	Jamnagar	1981	MS5141A x J2002
H	MBH 110	Mahyco Seeds	1981	MS 2A x PL 2
H	CM 46	Delhi (IARI)	1981	5054A x M46
H	BD 763	Delhi (IARI)	1982	5141A x D763
V	WC-C75	ICRISAT	1982	7 full sibs of World Composite cycle 1975
H	GHB 32	Jamnagar	1984	MS5141AxJ1188
H	PHB 47	Ludhiana	1983	Pb 111A x PIB 1234
H	MBH 118	Mahyco Seeds	1984	MS 2A x PL 3
H	X5	Coimbatore	1984	Pb 111A x PT 1921
H	HHB 45	Hisar	1984	5141A x H 90/4-5
V	ICMS 7703 (MP 15)	ICRISAT	1985	Synthetic variety bred by crossing inbred lines derived from seven crosses.
V	HC 4	Hisar	1985	
H	ICMH 451 (MH 179)	ICRISAT	1986	81A x ICMP 451
H	MH 182	Pune	1986	PT 732A x PNBM 83009
H	ICMH 501 (MH 180)	ICRISAT	1986	834A x ICMP 501
H	GHB 30	Jamnagar	1986	MS 5054A x J2002
H	MHB 130	Mahyco Seeds	1987	MS 2A x PL 4
H	Pusa 23 (MH 169)	Delhi (IARI)	1987	841A x D23
H	HHB 50	Hisar	1988	81A x H 90/4-5

Continued

Table 1. *Continued*

Type[1]	Cultivar	Bred at	Released in	Pedigree
V	ICTP 8203 (MP 124) (PCB 138)	ICRISAT	1988	5 S_2 progenies from a sample of the early-maturing Iniadi land race from northern Togo.
H	ICMH 423 (MH 143)	ICRISAT	1988	841A x ICMP 423
H	HHB 60	Hisar	1988	81A x H 77/833-2
H	MBH 136	Mahyco Seeds	1989	MS 2A x PL 6
H	GHB 181	Jamnagar	1989	MS 81A x J2002
H	RHB 58 (MH 320)	Jaipur	1990	81A x RIB 20-K-86
II	VBH 4	Vijay Seeds	1990	VBMS IA x VBR 19
H	HHB 67 (MH 338)	Hisar	1990	843A x H 77/833-2
V	ICMV 155 (ICMV 84400, MP 155)	ICRISAT	1991	59 mass-selected S_1 plants from New Elite Composite Cycle 4 bulk
H	RHB 30	Jaipur	1991	843A x RIB 335/74
H	Eknath 301	Nath Seeds	1991	NBMS 13A x NB 37
H	MLBH 104 (MH-351)	Mahendra Seeds, Jalna	1991	MS 3A x I 3
V	Raj 171 (RCB-IC 9)	ICRISAT/Jaipur	1992	8 S_2 progenies of ICRISAT Intervarietal Composite cycle 5.
H	MH 419 (GHB 229)	Jamnagar	1992	Pb 111A x J2290
H	MH 402 (RHRBH 8802)	Rahuri	1992	RHRB 3A x RHRB 138
H	MH 439 (RHRBH 8803)	Rahuri	1992	RHRB 3A x RHRBL 458
H	MLBH 27 (MH 425)	Mahendra Seeds	1992	MS 3A x I 53
II	ICMH 312 (Pooja)	ICRISAT	1993[2]	81A x ICMR 312
H	GHB 235	Jamnagar	1993	MS 81A x J2296
V	ICMV 221 (ICMV 88904, MP 221)	ICRISAT	1993	124 S_1 progenies from C3 of ICRISAT Bold-Seeded Early Composite.

Continued

Table 1. *Continued*

Type[1]	Cultivar	Bred at	Released in	Pedigree
V	PCB 141	Ludhiana	1993	Based on plants selected from ICRISAT composites.
H	HHB 68 (MH 306)	Hisar	1993	842A x H 77/833-2
H	Pusa 322 (MH 322)	Delhi (IARI)	1993	841A x PPMI 301
H	ICMH 356 (ICMH 88735, MH356)	ICRISAT	1993	ICMA 88004 x ICMR 356
H	Pusa 444 (MH444)	Delhi (IARI)	1994	189A x PPMI 301
H	Pusa 325	Delhi (IARI)	1995	490A x PPMI 303
H	GHB 183 [3]	Jamnagar	1993	MS 81A x J-998
H	GHB 316	Jamnagar	1997	MS 405A x J-2290
H	GHB 229[4]	Jamnagar	1998	MS L_{111}A x J-2290
Other cultivars included in national program trials of 'released' materials				
V	Pusa 266	Delhi (IARI)		
H	X6(UCH 11)	Coimbatore		PT 732A x PT 3095
V	CZ-IC 923	ICRISAT/Jaipur	1996+	
H	RHRBH 8609 (Shraddha)	Rahuri		RHRB 1A x RHRBI 138
H	MLBH 285 (MH-518)	Mahendra Seeds, Jalna	1997	MS 11A x MI 51
H	GHB 15 (MH 404)	Jamnagar	1992	MS 5054 A x J -108
H	AHB 251	Aurangabad		81 A x AIB 16
H	X7	Coimbatore		Pb 111A x PT 1890
Other cultivars that were included in national trials of released cultivars				
V	Mukta	Palem		
V	Pusa Safed Bajra	Delhi (IARI)		
V	Mallikarjuna	Palem		
V	PCB 15	Ludhiana		
H	PHB 47	Ludhiana		Pb 111A x PIB 1234
V	RCB 2	Jaipur		
	RHR 1	Rahuri		
Commercially marketed and under tests in project trials				
H	MLBH 287	Mahendra	1995	MS 7A x MI-62
H	MLBH 305	Mahendra	1997	MS 36A x MI-67
H	MLBH 308	Mahendra	1998	MS 38A x MI-71

1. H = hybrid; V = variety.
2. Not officially released, but marketed privately.
3. Only for summer season cultivation.
4. Yet to be notified.

Note: Authors gratefully acknowledge C T Hash, K V Pethani and K R Chopra for their substantial contribution to factual content of table 1.

and postrainy crops of adjoining Gujarat. The other regions covered by the study are Tamil Nadu in southern India and the states of Haryana and Rajasthan in northern India.

The survey sites are primarily selected based on secondary district-level data and reconnaissance surveys of pearl millet growing districts. Field observations and interviews with regional research and extension staff and the private seed sector are used to provide directions on specific pearl millet target areas. This information is augmented by data on pearl millet seed sales by public and private sector agencies to confirm whether or not adoption of improved cultivars is widespread in the region.

A stratified multi-stage sampling procedure was used to select a sample of farmer respondents. Once the pearl millet growing districts in the study area were identified, blocks were classified into two strata according to the intensity of pearl millet cultivation. Block-level data on pearl millet areas were obtained from the Department of Agriculture in each identified pearl millet growing district. One block was then randomly selected from each strata, providing a representative sample of two blocks from each distinct. Sample villages were randomly selected from each block, and a random sample of farmers was taken from each selected village.

A survey questionnaire with modules on important aspects was developed to obtain structured information on basic farm characteristics, land use, cropping system, adoption of pearl millet cultivars, farm cost structure, post-harvest practices, and seed use.

This paper features results from the Maharashtra survey. Based on the survey, it was observed that 21 HYVs and hybrids had been sown in Maharashtra. Data for 1990-94 (Table 2) show that substantial changes in adoption of pearl millet cultivars have occurred. Demand for varieties and hybrids that dominated in the 1980s (for example, WC-C75, BK 560, and MBH 110) had dropped substantially, or these cultivars had been replaced. Decline in adoption of BK 560 from 23% of the pearl millet area in 1990 to 5% in 1994 is notable. Both WC-C75 and MBH 110 were replaced by improved cultivars — from 8% in 1990 (when use of both had declined substantially from earlier peak levels) to 1% in 1994 (Fig. 3).

The expansion of India's seed industry in the late 1980s and early 1990s was accompanied by a significant rise in R&D investment, and spawned a

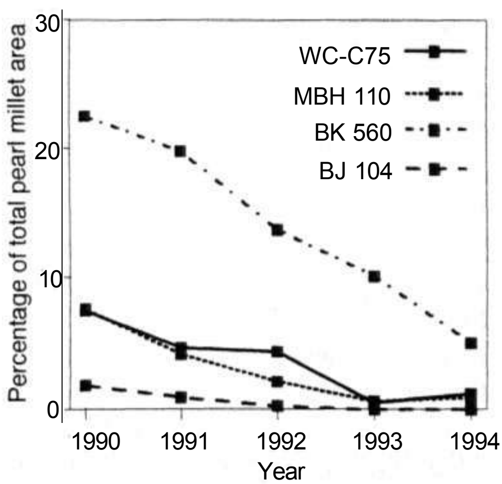

Figure 3. Decreasing use of older pearl millet cultivars in Maharashtra, 1990-94.

Table 2. Adoption of improved pearl millet cultivars in Maharashtra state (percentage of total pearl millet area).

Cultivar	1990	1991	1992	1993	1994
ICRISAT cultivars	35.5	44.4	46.8	37.2	36.4
WC-C75	7.6	4.7	4.4	0.5	1.2
ICTP 8203	26.4	37.1	40.3	35.5	33.5
ICMH 451	1.5	2.7	2.0	1.2	1.6
NARS public	24.5	21.0	16.8	18.7	14.1
RHRBH series			2.8	8.5	7.9
BK 560	22.6	19.9	13.8	10.2	5.1
NARS private	18.2	20.9	28.0	38.2	41.5
MLBH 104	5.1	8.5	13.9	23.0	22.8
MLBH 27	1.2	1.9	2.8	4.8	7.8
PA 7701	1.1	1.9	1.5	2.0	2.4
PA 7501	0.2	0.9	0.2	0.7	0.8
PO 7602	0.2	0.4	0.9	2.6	0.9
PO 7604			0.6	0.3	
PO 7701					0.1
PO 7709			0.2	0.1	0.4
PO 7702			0.2		0.2
Paras 20					1.1
Paras 13			0.4	0.4	0.2
Nath 301	1.3	1.7	3.5	1.7	1.6
KPRATAP			0.1	0.4	0.4
Nav Bharat	0.2	0.2	0.4	0.4	0.1
Vijay 4	1.2	1.1	1.2	1.4	1.9
MBH 110	7.7	4.2	2.1	0.6	0.9
Total HYV	78.1	86.2	91.6	94.1	92.0

Source: Survey in Maharashtra in 1995 by staff from ICRISAT's Research Evaluation and Impact Assessment project.

flourishing seed market and availability of improved seeds to farmers in Maharashtra and other pearl millet growing states. The three cultivars that dominated during the 1980s (WC-C75, MBH 110, and BJ 104) were practically replaced by new varieties and hybrids from ICRISAT, NARS, and the private sector. The increase in demand for ICTP 8203, MLBH 104, MLBH 27, RHRBH 8609, and a series of hybrids from ProAgro and Pioneer seed companies from 1990-94 was significant (Fig. 4).

The trends clearly show the dominance of an early-maturing, large-grained, downy mildew resistant, open-pollinated variety, ICTP 8203, which was developed at ICRISAT, and the increasing importance of early-maturing private sector hybrids — MLBH 104 and MLBH 27 (Mahendra Hybrid Co.), PA 7701 and PA 7501 (ProAgro Seed Co. Ltd.) and PO 7602 (Pioneer Overseas International), among others.

Figure 4 reflects the resurgence of public materials in Maharashtra when

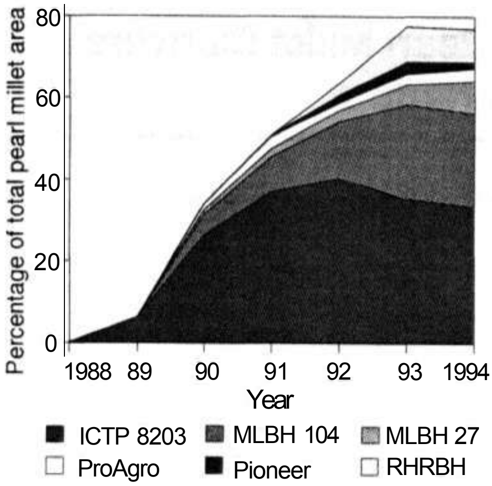

Figure 4. Increasing adoption of improved pearl millet cultivars in Maharashtra, 1988-94.

MBH 110's downy mildew resistance was overcome. Until 1991, ICRISAT and the public sector shares dominated the market, while the private sector was in its early expansion phase. Analysis of data through this period highlights the role that ICRISAT has played in providing final products to farmers in collaboration with its NARS and private sector partners, as well as supplying parental materials to its clientele — the public and private seed sectors, which in turn produce final products for farmers.

Acknowledgments

We are grateful to C T Hash for providing information on pedigrees and release of pearl millet hybrids and varieties in India; Y Mohan Rao, who collected the primary farm survey data on adoption and impact modules from districts of western Maharashtra; K V Anupama, who processed and analyzed adoption and other survey modules, and B Gnaneshwar, who patiently entered and proofread the data.

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Adoption of Improved Pearl Millet Cultivars in Tamil Nadu

C Ramasamy[1], S Elangovan[1], M C S Bantilan[2], and M Asokan[2]

Pearl millet is the third most important cereal in the Indian state of Tamil Nadu after rice and sorghum. It is grown in 236 000 ha, and its production was estimated at 338 000 t in 1993 (FAO 1994). It is grown in 12 of the 22 districts in the state, and its outstanding adaptation to a range of environments is well reported in the literature (Bidinger et al. 1982, ICRISAT 1996). The rainfall where it is grown in Tamil Nadu ranges from 662 mm in V O Chidambaranar district to 1 100 mm in South Arcot Vallalar district. Although leading pearl millet growing states in India irrigate a negligible 5% of the crop, about 15% is irrigated in Tamil Nadu.

The area sown to pearl millet has declined dramatically, from 451 000 ha in 1972 to 236 000 ha in 1993 (Fig. 1). Subsidized rice and wheat under the public distribution system have lowered the demand for pearl millet, but in addition, more profitable crops such as groundnut, pulses, sunflower, and maize have also affected the crop. Despite the drop in area, productivity has almost doubled (Fig. 2), hence the production of pearl millet is at about the same level as in the early 1970s. Given the competition from other crops and the limited scope for an increase in net cropped area in Tamil Nadu, it is

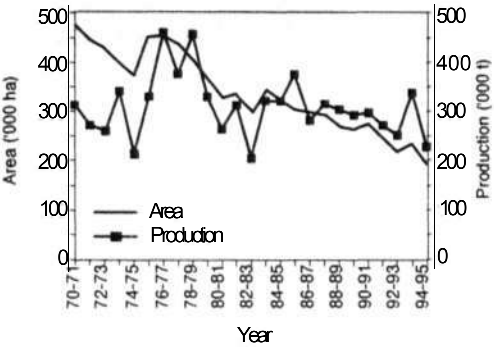

Figure 1. Trends in area and production of pearl millet in Tamil Nadu, 1970-94.

Ramasamy, C., Elangovan, S., Bantilan, M.C.S., and Asokan, M. 1998. Adoption of improved pearl millet cultivars in Tamil Nadu. Pages 62-75 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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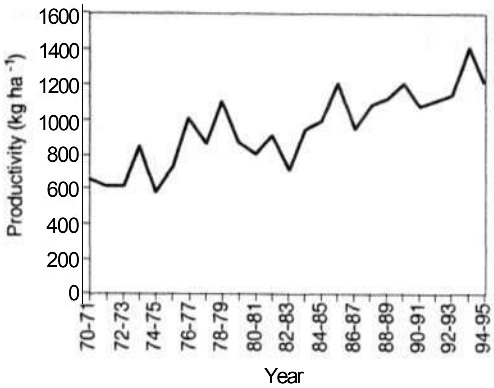

Figure* 2. *Trend in productivity of pearl millet in Tamil Nadu, 1970-94.

likely that pearl millet area will either remain at its present level or shrink further.

While the demand for pearl millet as a food grain has diminished sharply, its use in poultry and other animal feeds is growing, and it appears that this crop will remain important in Tamil Nadu as an industrial raw material. The situation sends clear messages to agricultural planners and pearl millet researchers to rethink their strategies.

A significant bright spot in pearl millet production is that over the last 15 years, new cultivars have enabled production to remain at the same level as crop area has decreased. Productivity enhancements have also helped pearl millet to be more financially competitive with other crops.

Pearl millet breeding research in Tamil Nadu dates back to the late 1930s. The first variety, CO 1 was released in 1939 (Table 1). Since then, 13 cultivars have been released by the Tamil Nadu Agricultural University (TNAU) and the Agricultural College and Research Institute, Coimbatore. The Department of Agriculture in the state has released three cultivars, KM 1 (BJ 104), KM 2 (BK 560) and KM 3. Other new cultivars, both public and private, released from other Indian states have also made a solid impact on pearl millet production in Tamil Nadu.

Early plant breeding research focused on open-pollinated cultivars, including mass selection from locally adapted landraces. Some hybridization between landraces or between inbred lines and landraces followed by progeny selection also occured (Krishnaswamy 1962). These cultivars, however, did not make much of a contribution to increasing yields (Bidinger and Parthasarathy Rao 1990). The next phase of the pearl millet breeding research employed male sterile line 23 A to produce F_1 hybrids (Anand Kumar and Andrews 1980). Grain yields of the hybrids were substantially higher than the prevailing varieties, which led to their rapid adoption by farmers on up to 20% of the pearl millet area in India. Downy mildew epidemics, however, occurred all over India, and collapsed the life of many hybrids, including HB 1, HB 2 and HB 4 (Walker 1989). Consequently, the trend to adopt hybrids rapidly slowed down.

After the downy mildew epidemics, pearl millet breeding programs were reorganized to incorporate resistance in hybrid parents and reexamine open-pollinated cultivars (Bidinger and Parthasarathy Rao 1988). Breeding research on pearl millet was signifi-

Table 1. Pearl millet cultivars grown in Tamil Nadu.

Cultivar	Parents	Year of release	Research lag (years)
NARS			
CO 1		1939	7
CO 2		1940	7
CO 3		1942	7
CO 4		1953	7
CO 5		1954	7
CO 6		1976	
CO 7		1986	7
X1	PT 348 x PT 350	1950	9
X2	PT 411 x PT 422	1951	9
X3	PT 926/7 x PT 829/8	1953	9
X4	5141A x PT 1921	1980	9
X 5	Pb 111A x PT1921	1983	7
X 6	732A x PT3095	1983	7
KM 1			
KM 2		1979	
KM 3		1977	
HB 1	Tift 23A x Bil 3B	1965	
HB 3	Tift 23A x J104	1968	
Private sector			
Eknath 101		1988	
Eknath 301,302, 303		1992	
Pioneer		1987	
Pioneer 7602		1995	
Plantgene		1988	
Mahyco 151		1995	
Pioneer 7686		1996	
PBH 13,19,37,38		1996	
ICRISAT			
WC-C75	7 full-sibs of World Composite	1985	12
ICMS 7703	7 inbreds: Ind x Afr. Crosses	1986	11
ICMV 155	59 S_1 progenies of NELC	1993	6
ICTP 8203	5 S_2 progenies of a Togo landrace	1993	5
ICMV 221	124 S_1 progenies of BSEC	1995	5

Note: Empty cells indicate that data are not available.

cantly strengthened by the establishment of ICRISAT in 1972, activities of the Indian Council on Agricultural Research (ICAR) under the All India Coordinated Pearl Millet Improvement Program (AICPMIP), and state agricultural universities (SAUs) in the late 1970s and 1980s. Of particular importance was the introduction by ICRISAT of new materials from Africa with resistance to downy mildew, development of several male sterile lines, diversification of hybrid parents, and new methods of breeding (using molecular markers).

These new pearl millet cultivars were sown by farmers in significant quantities, and by the late 1980s and early 1990s, the private sector began to market new hybrids to challenge the materials that originated from the public sector. And most recently, biotechnology has opened new vistas to plant breeders — hybrids with enough heterogeneity for resistance and enough uniformity for good agronomic performance will be soon in the field. The first field evaluations of these new hybrids began during the 1996 rainy season (ICRISAT 1996).

Research Issues and Objectives

Tamil Nadu is an agriculturally progressive state and in the forefront of adopting improved technologies for crop production. Over the years, the state has built a good agricultural extension system that has helped farmers to consistently grow improved cultivars. Hybrids such as HB 1, HB 2, and HB 3 were grown in the early 1970s, but were later discontinued due to downy mildew. Table 1 lists other improved cultivars grown in the state. Improved cultivars have been grown on a large scale over the entire state during the last decade, but there are issues that need detailed scrutiny:

- Despite widespread growth, no scientifically based study has measured the adoption rate of improved cultivars.
- Adoption rates and varietal composition vary considerably across production environments, which may affect income distribution.
- Reasons for decline in the area under pearl millet in Tamil Nadu.
- Research products from the private sector appear to be taking over products from public sector research, both national agricultural research systems (NARS) and international agricultural research centers (IARCs). This has implications for agricultural research investment and prioritization.
- The traits of improved cultivars do not seem to have totally met the requirements of pearl millet growers.

This paper attempts to provide an accurate perspective on the current state of pearl millet production in Tamil Nadu in order to foster appropriate policies to promote its production. The objectives of this study of improved pearl millet cultivars are to:

- measure the scale of adoption and varietal composition;
- identify the determinants of adoption and quantify their influence;
- study the magnitude of time lags to adoption;
- determine farmer perceptions on the constraints that inhibit increased adoption; and
- assess the impact of ICRIS AT pearl millet cultivars in Tamil Nadu.

Methodology

Data

This study uses data drawn from a survey of pearl millet producers in 28 villages spanning 7 districts of Tamil Nadu (Fig. 3). The purpose is to measure the extent of adoption and to explain, at farm level, the reasons for adoption of improved cultivars. The sample districts, blocks, and villages were selected based on total pearl millet acreage data from 1991-93 averages. The surveyed sample included 336 cultivator households, 84 agricultural labor households, and 28 non-agricultural households. The sample distribution is uniform across all the villages — farmers represent all production environments covering different rainfall regimes and soil types under which pearl millet is cultivated in Tamil Nadu. Information about household characteristics, cropping pattern, adoption pattern, seed source, reasons for adoption, and cost of cultivation were collected using a structured questionnaire

Figure 3. Location of sample villages in Tamil Nadu.

(Tables 2, 3, and 4). This was supported by a detailed discussion with leading farmers, agricultural extension personnel, researchers, seed producers, and agricultural policymakers in the sample area. In addition, secondary data about area, production, productivity, seed distribution, rainfall, cropping patterns, and soil characteristics were obtained from the offices of the Joint Director of Agriculture in each district.

Table 2. Size of land holding and tenurial status of sample farms (ha).

Tenurial status	Adopters	Non-adopters
Owned land	3.93	2.55
Leased/mortgaged-in land	0.14	0.02
Sharecropped-in	0.02	0
Leased/mortgaged-out land	0.02	0.02
Sharecropped-out	0	0.07
Current fallow land	0.23	0.03
Permanent fallow land	0.04	0
Total	3.80	2.45

Table 3. Educational level in sample households (%).

Educational status	Adopters (235)[1]	Non-Adopters (101)[1]
Illiterate	15.3	22.8
Up to primary school	26.4	27.7
Up to middle school	25.5	29.7
Up to high school	20.4	12.9
Intermediate/diploma course	8.5	4
Graduation	3	3
Post-graduate and above	0.9	0

1. Figures in parentheses represent number of household heads.

Table 4. Percentage of income in sample households derived from different sources.

Source	Adopters	Non-Adopters
Crops	74.3	68.6
Livestock	2	0.84
Trade	7.9	15.7
Labor	9.8	10.7
Other	6	4.2

Analytical framework

Disaggregation. Research attempts to quantify the adoption of improved cultivars often employ a single variable by aggregating all cultivars. Realizing the importance of disaggregating the data, cultivars were grouped as those developed by NARS (including ICAR and SAUs), the private sector, and IARCs such as ICRISAT.

Time period. The analysis looked at the adoption patterns for groups of cultivars for the period 1989/90 to 1994/95. Adoption patterns for individual cultivars were also determined.

Replacement of seed. Adoption of a cultivar is a dynamic process. Seed technology is an important element to maximize yield that necessitates a knowledgeable farmer or guidance by others to know:

- when to replace the seed,
- where to buy seed,
- where to get information about new seed, and
- when to replace an adopted cultivar.

The present analysis embraces these issues.

Determinants of adoption. Farmers are economic decisionmakers. Unless they are convinced of the benefits of a cultivar or technology, they might not adopt it. A combination of factors and their interrelationships influence adoption decisions by farmers. Our analytical framework attempts to understand farmers' perceptions of factors that convinced them to sow new cultivars.

Econometric model. It is critical to precisely measure the degree of influence of variables that determine adoption. Literature on adoption lists a set of variables that influence adoption — farm size, number of family labor, proximity to market, human capital, capital availability, input prices, agricultural information, production uncertainty, and risk (Adesina and Zinnah 1993, Shakya and Flinn 1985, Rauniyar and Goode 1996). Our study was designed to measure the extent of adoption of improved pearl millet cultivars by farmers in Tamil Nadu and to identify and quantify effects of variables on adoption. Econometric analysis provides ample scope to study the adoption behavior of new technologies. Feder et al. (1985) provide an excellent review of adoption models. Limited dependent variable models provide a good framework to study the adoption behavior in agriculture. Some of the most appropriate models are Probit, Logit, and Tobit. The Tobit model (Tobin 1958) is considered most appropriate because it measures not only the probability that a pearl millet farmer will adopt a new variety, but also the intensity of use of the technology once adopted and hence was preferred for this study. The functional form of the model is:

$$Y_i = X_i ß \quad \text{if } i^* = X_i ß + \mu_i > T$$

(or)

$$- 0 \quad \text{if } i^* = X_i ß + \mu_i < T$$

where:

Y_i is the probability of adopting and the intensity of use of improved cultivars,

i^* is a non-observable latent variable,

T is a non-observed threshold level,

X. is the vector of independent variables determining adoption of the i^{th} farmer,

ß is the estimated coefficient, and

μ_i is an independently normally distributed error term with zero mean and constant variance a^2.

This equation is a simultaneous and stochastic decision model. If the non-observed latent variable i* is greater than T, the observed qualitative variable Y. that indexes adoption becomes a continuous function of the explanatory variables and zero otherwise. In the present case, there are farmers who have not adopted the technology and many farmers who have completely adopted the technology. Hence a 2-Limit Tobit proposed by Rosset and Nelson (1975) is followed. The Tobit model uses a maximum likelihood method to estimate the coefficients of the equation. The regression coefficients are asymptotically efficient, unbiased, and normally distributed.

Variables, The empirical model assumes that the dependent variable, the area sown to improved pearl millet cultivars as a proportion of the total pearl millet area, depends on these variables — education, non-farm income, farm size, irrigation, market distance, existence of private companies, and regional characteristics.

The adoption behavioral model (Leagans 1979) suggests that the personal variable of education, the socioeconomic variable of farm size, and biophysical variable of irrigation, all in the primary farmer's environment, would affect adoption of a technology. Non-farm income was also hypothesized to be negatively related to adoption because the farmer's concentration would be distracted from agriculture. Similarly, distance to market was assumed to negatively affect adoption. Because the data showed that NARS and the private sector are increasing their share of the seed market over time, it was hypothesized that the sales networks of private companies could raise adoption and thus these were included in the model. District dummies were included to capture whether spatial changes in adoption could be attributed to such region-specific agroclimatic characteristics as soil, temperature, rainfall, etc.

The total effect of these explanatory variables can be decomposed using the framework suggested by McDonald and Moffitt (1980). The two effects of a given change in a variable are the effects on adoption probability and intensity of adoption. To derive elasticities, see Adesina and Zinnah (1993).

Results

Farm size. Table 2 shows the land use pattern of the sample farmers. Among farmers growing pearl millet, land leasing was almost absent and almost all cropped land was owned. The average adopter farmed 3.8 ha and the average non-adopter farmed 2.5 ha. Farm size may exert a positive influence on adoption of improved cultivars because farmers with larger holdings may have a better capital base and risk-bearing capacity. However, when tested through the Tobit model, farm size was positively related to adoption, but its influence was not significant. Pearl millet is grown mostly as a rainfed crop. Rainfed farms of adopters are an average 1.3 ha larger than non-adopters, but the size of irrigated farms was almost the same among adopters and non-adopters.

Education. Education has universally proved to be a fundamental factor for economic and social change (Myrdal 1968). Is formal education always a prerequisite for technology adoption? An analysis of education defined in terms of different levels of schooling as related to adoption of improved cultivars of pearl millet appears in Table 3. Average level of education between adopters and non-adopters differs only negligibly. Illiterates are higher by one-third among non-adopters, but this group has a larger share of primary and middle school. With the present level of modernization in communications and infrastructure, even less-educated farmers do not lag behind in adoption of improved cultivars. An earlier study reported a similar conclusion (Shakya and Flinn 1985). The Tobit analysis, however, reveals that when measured in number of school years, education is positively and significantly related to farmers' adoption behavior.

Income. Crop production offers the largest slice of household income in all the households covered in the survey (Table 4). While income from crop production alone accounts for about 75% of total income among adopters, non-adopters had a 70% share. Availability of non-farm income through trade may influence a lower level of adoption. Livestock as a source of income influencing adoption is also empirically testable. Share of labor earnings is similar across the two groups. As expected, non-farm income was negatively related to adoption in the model, and its effect was significant. This implied that farmers who earn more non-farm income paid little attention to pearl millet HYVs.

Varietal composition. Improved cultivars are developed and released by both public and private research systems. Cultivars were categorized into those from ICRISAT, NARS, and the private sector to facilitate analysis. The number of farmers who adopted improved cultivars and the area under different cultivars during 1994/95 are shown in Table 5. About 25% of the adopters grew ICRISAT cultivars on about 23% of the pearl millet area, while 28% of the adopters grew private-sector cultivars on 43% of the land. NARS cultivars were found among 20% of adopters on 12% of the pearl millet area. Of three ICRISAT cultivars, WC - C75 accounts for about 50% of the area sown to these cultivars, and ICMS 7703 is the second most important variety. Pioneer dominated with 70% of the total area sown to private-sector cultivars. Pioneer followed by with Eknath (6.6%) and

Table 5. Pearl millet cultivars grown on sample farms, 1994/95.

Cultivar	Number of farmers	Cultivated area (ha)	Cultivars as percentage of total area
ICRISAT			
ICMS 7703	33	24.7	6.2
ICMV 221	13	18.2	4.6
WC-C 75	41	46.8	11.8
Subtotal	87	89.7	22.6
Private sector			
Eknath	6	26.1	6.6
HLL	1	1.6	0.4
Mahyco	12	13	3.3
MBH 110	4	5.8	1.5
PBH 3	1	0.6	0.2
PG 5822	3	2.2	0.6
PG 5877	2	0.8	0.2
Pioneer	68	116	29.2
Plantgene	2	4.9	1.2
Subtotal	99	171.1	43.1
NARS			
CO 3	1	0.6	0.15
CO 7	32	19.9	5.0
KM 2	33	19.8	5
KM3	3	0.8	0.2
X5	2	4.9	1.2
Subtotal	71	45.9	11.6
Local	97	90.2	22.7
Grand total	354	397	100

Mahyco (3.3%). The leading cultivars among NARS-released cultivars are CO 7 and KM 2.

Adoption of cultivars. Efforts were made to understand the pattern of adoption from 1989/90 to 1994/95. The proportion of area under private-sector cultivars increased from 5% in 1989 to 40% in 1994, while that sown to ICRISAT cultivars declined from 38% in 1989 to 23% in 1994 (Fig. 4). The total

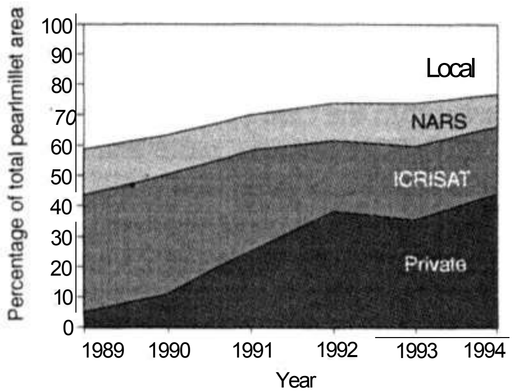

Figure 4. Temporal adoption pattern of pearl millet growers in Tamil Nadu, 1989-94.

pearl millet area remained almost constant. During this period, however, WC-C75 dominated, while ICMV 221 has become more popular in recent years, mainly in southern districts where drought occurs more frequently. The area sown to NARS cultivars also increased, but its proportion among other groups has declined from 15% to 11% over the last 3 years. Of NARS cultivars, CO 7 and KM 2 are significant.

ICRISAT cultivars. WC-C75 was released in 1982 for cultivation in all millet-growing areas in India. It was first sown in the sample area in 1985 by six farmers, but was then adopted by more farmers because of its high resistance to downy mildew that had been devastating the cultivar KM 2 (Table 6). ICMS 7703, also highly resistant to downy mildew, was introduced in 1985, and the drought resistant ICMV 221 made its entry during 1994 within a year of release from ICRISAT The survey revealed that ICRISAT cultivars were superior to local cultivars in terms of yield and were more responsive to nutrient applications in drought situations. A rapid rural appraisal confirmed that ICRISAT cultivars occupy half of the pearl millet areas of Tamil Nadu. The tough competition to ICRISAT

Table 6. Year sample households first adopted ICRISAT cultivars.

Cultivar	Year of adoption	Number of farmers adopting	Area (ha)
WC-C75	1985	6	12.6
	1986	2	0.9
	1987	14	12.2
	1988	5	7.5
	1989	21	51.6
	1990	13	22.3
	1991	14	16.6
	1992	21	22.3
	1993	15	10.5
	1994	6	4.7
ICMS 7703	1990	4	1.4
	1991	9	16.4
	1992	18	13.8
	1993	9	7.4
	1994	5	2
ICMV 221	1994	5	5.9
	1995	7	14.9

cultivars grown in irrigated and good rainfall regions has come from private-sector cultivars that are higher yielding.

Sources of seed and information. Information dissemination and good sources of seed are critical elements for the adoption of improved cultivars (Table 7). The state Department of Agriculture was a major source of both seed and information, and while other farmers and relatives also played significant roles in the adoption of improved cultivars, all sources of both seed and information have important complementary roles.

Preference for improved cultivars. Eighteen different factors were identified that influenced farmers to adopt improved cultivars, with about 60% citing expected high productivity (Table 8). Resistance to drought was the second most important factor.

Adoption by women. Adoption of a new agricultural technology may involve some risks that could affect household welfare. The survey indicated that women are consulted about technology adoption where they perform the larger share of field work in crop production.

Seed replacement. Pure seed is critical to realize the full benefits of a crop. In the case of non-hybrids (ICRISAT cultivars), more than 70% of farmers sow pure seed every year, and about 6% replace seed once in two years. Only for WC-C75 does use of pure seed extend to 7 years.

Table 7. Sources of seed and information (percentage of sample households).

	ICRISAT cultivars			Private-sector cultivars				
Source	WC-C75	ICMS 7703	ICMV 221	MAHYCO	MBH 110	PBH 13	PG 5877	PIONEER
Seed source								
Other farmers	0.9							
Seed shop	7.7	17.8	8.3	100	100	100	80	98.7
Department of Agriculture	85.5	82.2	75				20	1.3
Other	1.7		8.3					
Relatives	1.7		8.3					
Coop society	4.3							
Information source								
Other farmers	14.5	6.7	16.7	33.3	75	50		29
Relatives	7.7	2.2	16.7	26.7				27.6
Department of Agriculture	73.5	80	58.3		25		20	10.5
Research institute	0.9							
Other		6.7		6.7				14.5
Seed shop	3.4	4.4	8.3	33.3		50	60	18.4

Table 8. Reasons cited for adoption of improved cultivars.

Reason	Percentage of households citing reason
High yield	59.3
Drought resistant	10.3
Availability of seed	8.8
Influence of private traders/ family members	4.8
Good grain size	4.0
Good market price	3.3
Short duration	1.8
Seed production	1.5
No insect pests or diseases	1.1
Fewer bird problem	1.1
Fewer input requirements	1.1
Requires less water	0.7
Compact earhead	0.4
Short height	0.4
Uniform maturity	0.4
Good taste	0.4
Higher fodder yield	0.4
Easy threshing	0.4

On average, 17% of farmers never bought pure seed. Only a small group of farmers did not sow pure hybrid seed every year.

Longevity of cultivars. Several factors influence the number of years that farmers may grow a cultivar — desirable and undesirable traits, seed supply, entry of new cultivars, supply of extension services, among others. Among the non-hybrids, KM 2 and WC-C75 had a longer life than other cultivars (Table 9). Hybrids had a relatively shorter life because they are replaced by newer ones as private companies regularly offer better and improved products.

Table 9. Life of selected cultivars.

Cultivar	Range (years)
KM 2	2-8
WC-C75	3-7
ICMS 7703	3-4
CO 7	3-5
HB 3	1-3
Pioneer	2
PBH 13	1
MBH 110	3
Mahyco	3

Impact of ICRISAT cultivars.

After the debacle of HB 1, HB 2, and HB 3 hybrids in the early 1970s, farmers in Tamil Nadu were skeptical about improved varieties. The confidence was regained with the entry of WC-C75 in 1985. Subsequently, ICMS 7703 and ICMV 221 were adopted without hesitation by farmers. The impact that ICRISAT cultivars made on yield levels of pearl millet in Tamil Nadu encouraged farmers to sow more area to improved cultivars. Their downy mildew resistance and larger grains accelerated the adoption of improved cultivars, and the grain size brightened the prospect for using pearl millet as a raw material in poultry and cattle feeds, thus strengthening the link between agriculture and industry. The drought tolerance and shorter duration of ICMV 221 fit very nicely into the dryland environment of the southern districts. Another impact indicator was the exchange of breeding techniques between TNAU and ICRISAT Exchange of germplasm is another significant activity that deserves mention in the impact analysis.

The indirect impact of ICRISAT germplasm is mirrored through the rapid spread of private-sector hybrids that has more than doubled pearl millet yields in Tamil Nadu. It must be emphasized that most private-sector hybrids might have used ICRISAT germplasm. With 75% of the pearl millet area sown to private-sector hybrids in Tamil Nadu and 90% of hybrid production flowing to the industrial sector, ICRISAT has made a notable contribution to pearl millet-based economic activities in Tamil Nadu.

Conclusions

The adoption of improved cultivars of pearl millet in Tamil Nadu is impressive, with 75% of the area sown to new cultivars. Both public and private research have played a significant role in releasing improved cultivars. Earlier contributions in breeding pearl millet were made by ICRISAT and NARS. Using the parent material from ICRISAT and NARS, the private sector has produced a number of hybrids that are increasingly adopted by more and more farmers, mainly due to their grain characteristics and yield gains. The state extension system is the major source of information and seed for private-sector varieties, and private seed dealers play a critical role. On average, in one-third of pearl millet growing households, women were consulted in adoption decisions.

The econometric model suggested that education, irrigation, distance to market center, presence of private-sector seed distribution, and regional characteristics have significantly determined the probability of adoption and degree of adoption. Hence these variables condition adoption decisions.

Farmers reported that the desirable features of a pearl millet variety are high yield, drought resistance, good grain size, insect pest and disease resistance, and short duration, all of which breeders try to incorporate into new cultivars. Availability of seed, presence of private dealers, and quality seed are equally important factors for farmers. Policymakers, extension workers, and agricultural development agencies must note these points when devising policies and implementation strategies.

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Impact of Sorghum and Millet Research in Mali

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Competition for funding has led research sponsors to ask hard questions about the impact of research they have funded. This study is a joint effort of ICRISAT, the Institute of Rural Economy in Mali (IER), and the National Program of Agricultural Extension (PNVA). Researchers associated with the study intended to:

- determine adoption rates of millet and sorghum varieties currently grown by farmers that were produced from local research;
- document fanner opinions about these varieties;
- determine factors associated with extension and adoption of these varieties;
- estimate the return to investments in agricultural research; and
- estimate the benefits to producers and consumers from improved varieties of these cereals.

Millet and sorghum in Mali

Millet and sorghum are important foods in Mali. An estimated 135 kg of these two cereals is consumed annually by each person (FAO 1994) as flour, boiled seeds, cream, and drinks. Together, millet and sorghum provide approximately 1 088 calories, 49% of the total daily need per person.

The area covered by millet and sorghum is about 2.25 million ha, around 80% of the total cereal area in the country (FAO 1994). Total production is about 2.5 million t, with average yields estimated at 659 kg ha^{-1}. Production increases at an annual rate of about 2.4% as new areas are brought under cultivation, primarily in the Kayes, Koulikoro, Mopti, Segou, and Sikasso regions, which provide close to 92% of the national production.

Yapi, A., Kergna, A.O., Debrah, S.K., Sidibe, A., and Sanogo, O. 1998. Impact of sorghum and millet research in Mali. Pages 76-93 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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Study regions

The three regions selected for the study are at elevations between 400 and 900 m, but each occupies a different ecological niche (Fig. 1).

Koulikoro. Average annual rainfall of 877 mm makes this the most humid of the three regions. Soils are generally ferruginous tropical soils. In addition to sorghum and millet, maize, groundnut, cotton, and a significant number of marshland and fruit crops are grown.

Segou. Rainfall in this area ranges between 456 and 962 mm, with an average of 877 mm. The area is less humid than Kouiikoro but more humid than Mopti. Ferruginous hardpan tropical soils are present, and hydromorphic mineral soils are prevalent in the alluvial deposits of Bani. Sorghum and millet are important crops in the

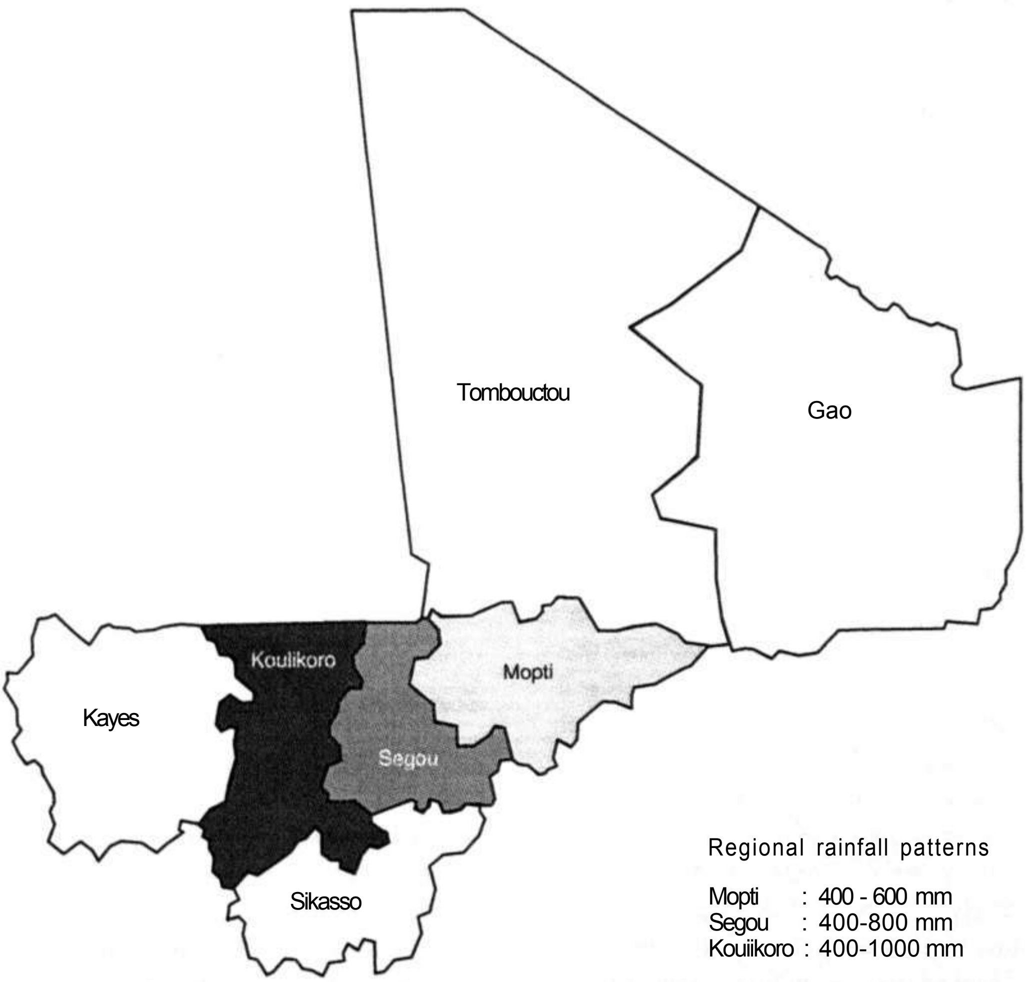

Figure 1. Map of Mali, showing the three study regions

region. Other crops include maize, rice, groundnut, cowpea, cotton, and marshland varieties.

Mopti. With an average rainfall of 533 mm, Mopti is the driest of the three regions, with three distinct geomorphologies — the central Nigerian delta, the Dogon plateau, and the Seno plain. The delta is a flood plain, the plateau is a large gravelly horizon, and the Seno plain is a strip of land with sandy eroded formations, flat, and often with slightly leached soil with low clay content. Rice, millet, and sorghum are the principal crops.

Agricultural research and extension in Mali

Agronomic research has been conducted in Mali for more than half a century. It began in 1925 with the establishment of a cotton research station at M'pessoba by the colonial administration. Before independence, agricultural policy called for cash crops such as sugarcane, rice, cotton, sisal, and groundnut on state farms in Samanko, Same and M'pessoba, The government took over administration of agricultural research in 1962 with the establishment of the Institute of Rural Economy (IER). Agricultural research was thus redefined, with emphasis moved to food crops, livestock, and forestry. Until 1977, research was conducted on a contract basis exclusively by a number of French research institutes, of which the Institute of Tropical Agronomic Research (IRAT) was the most important.

In 1970, the Division of Agronomic Research (DRA) was created in IER, and there has been active collaboration with ILCA (International Livestock Centre for Africa, now part of ILRI, the International Livestock Research Institute), ICRISAT (International Crops Research Institute of the Semi-Arid Tropics), SAFGRAD (Semi-Arid Food Grain Research and Development), and WARDA (West Africa Rice Development Association). Bilateral donors, including USAID, Canada, and the Netherlands, are important funders of agricultural research. The annual agricultural research budget is estimated at US$ 11 million, of which US$ 4 million was generated internally.

Principal research stations for food crops are Sotuba (sorghum and maize), Kogoni (rice), Cinzana (millet), Same (cereals and groundnut), and Dire (wheat). Varietal improvement, new crop techniques, and management of natural resources remain the main objectives of agricultural research. It is in this capacity that a number of millet and sorghum varieties were tested with the combined effort of IER and collaborating bodies, notably ICRISAT.

Sorghum selection

The objective of the sorghum improvement program is to select cultivars for a higher and more stable yield by:

- collecting and improving local varieties,
- introducing exotic materials,
- selecting and breeding from populations,

- researching the use of mutations, and
- selecting F_1 hybrids.

It was necessary to establish research priorities in each agroclimatic zone in the country based on rainfall:

- In low rainfall areas, selection is made for higher yield, earliness, drought resistance, germination at high temperatures, and resistance to borers.
- In average rainfall areas, high yield, average growing period, grain quality, germination at high temperatures, and resistance to diseases and drought were the selection criteria.
- In high rainfall areas, selection criteria included high yield, maturity after the rainy season ends, grain quality, and resistance to foliar diseases.

Table 1 summarizes the history of sorghum improvement under the Mali-ICRISAT program.

Table 1. Chronology of sorghum improvement by the ICRISAT-Mali program.

Year	Activity
1979-82	Collection of local varieties Develop populations (local x exotic) Develop screening method Test introductions
1982-86	Mass selection in landraces Population improvement/line derivation
1986	Naming of Malisor 1 to Malisor 7
1986	Pedigree breeding (Malisor x exotic) Population improvement Evaluate new introductions Develop head bug screening On-farm variety tests Improve seed stocks

Source: Shetty et al. (1991).

Millet selection

Compared to sorghum, millet is cultivated in areas of lower rainfall because it is more resistant to water-stress. Two primary objectives of millet improvement are to increase productivity of local varieties, and select for stable yield by improved tolerance to pests and abiotic stresses. Methods to satisfy these objectives include creation of synthetic varieties using both local and exotic material, selection of synthetic dwarf varieties, selection for larger grains, and much later, F_1 hybrids.

It was necessary to establish research priorities in each agroclimatic zone in the country based on rainfall:

- In the Sahelian zone (low rainfall), resistance to drought, *Striga,* and insect pests are the main selection criteria, with resistance to diseases as a secondary criterion.
- In the Sudanian-Sahelian zone, cultivars are selected first for resistance to *Striga,* then to drought, insect pests, and diseases, and finally for response to fertilizers.
- In the Sudanian-Guinean zone (high rainfall), resistance to *Striga* and response to fertilizer are the main selection criteria, with resistance to downy mildew a secondary criterion.

Table 2. Chronology of pearl millet improvement by the ICRISAT-Mali Program.

Year	Breeder	Activity
1979-82	J Scheuring	Collection and evaluation of local genetic resources Introductions from ICRISAT in India Selection for improved harvest index
1983/84	J Scheuring 0 Niangado	Recurring selection of local varieties Intervarietal hybridization Development of downy mildew screening nursery
1984-90	O Niangado	Improvement of composites Formation of synthetic varieties Evaluation of introductions to the ICRISAT Sahelian Center Evaluation of F_1 hybrids and topcross hybrids

Source: Shetty et al. (1991).

Table 2 summarizes the history of pearl millet improvement under the Mali-ICRISAT program.

Extension in Mali

Prior to independence, extension was primarily for farmers of cash crops, with demonstrations on selected private farms or state-run farms. Beginning in the 1980s, the benefits of education and farming organizations began to have an effect.

The evaluation of the extension system by the Program of Structural Adjustment of the Agricultural Sector (PASA) during 1986-88 identified insufficient organization and structure (no calendar or personnel rules) with a need for:

- regular training,
- formal technical education,
- elimination of duplication,
- reinforcement of research-extension links and links with credit agencies and forest rangers,
- harmony within existing projects and programs,
- improved participation by women, and
- better links with farming organizations.

National Seed Service

The National Seed Service (SSN) is officially in charge of multiplying and distributing seed in Mali. The demand for improved cultivars is first determined so that a significant quantity of breeder seed can be produced for multiplication in two succeeding generations before distribution to farmers through state-controlled training centers, non-governmental organizations (NGOs), and seed growers.

From 1989 to 1990,569 t of improved sorghum seed and 295 t of improved millet seed were produced and distributed by SSN. The primary sorghum varieties that were multiplied were CSM 388 (42%), CSM 63-E (32%), and Tiemarifing (20%). Multiplication of sorghum seed reached its highest level in 1991 with 284 t, but there was a considerable reduction of both sorghum and millet seed production in 1992 as SSN was reorganized. The primary millet varieties that were multiplied were IBV 8001 (28%), NKK (25%), HKP (25%), and Toronio (21%). As with sorghum, mutiplication of millet reached its highest production in 1991 at 155 t.

Informal seed distribution

The most important informal system of seed distribution is farmer-to-farmer, but the quantities distributed this way are unclear. Other sources of improved seed varieties are collection of small quantities by farmers during demonstrations, saving a portion of the harvest for the next season, and NGOs.

Methodology

In order to measure the impact of research on sorghum and millet production and productivity, it is first necessary to estimate the adoption rate for improved varieties, a ratio of the area occupied by improved varieties to total crop area.

It is difficult to estimate the area cultivated with improved varieties of sorghum and millet in Mali for at least three reasons:

- SSN data are limited to a few varieties,
- seed distribution is often informal and therefore not recorded, and
- improved varieties sometimes lose their identity at the farm level.

Improved varieties may acquire several names depending on the source, or may be mixed with local varieties and lose their purity. To overcome these obstacles to data collection, it was necessary to work closely with extension departments.

Sampling method

A three-stage sampling procedure was established to determine the study area, sample villages, and sample farmers (Table 3).

Stage one was a review of secondary data on production, area, and consumption of sorghum and millet in the different regions of Mali. Primary areas of production and consumption were identified, along with the high rainfall regions targeted for research on improved varieties — Koulikoro, Mopti, and Segou.

Stage two included reconnaissance visits to the three regions to identify representative areas, along with training and research facilities. In this manner, the Banamba and the Ouelessebougou sectors were chosen for the Koulikoro region; Bankass, Djenne, and Koro for the Mopti region; and Braoeli, Macina, and Segou for the Segou region.

Stage three included choosing representative villages, followed by randomly choosing units of agricultural production (UAP). Farmer selection was based on UAP lists supplied by village agricultural organizers or village chiefs.

Table 3. Multistage sampling procedure adopted for the study of improved varieties of sorghum and millet in Mali.

Level of analysis	Unit of analysis	Type and source of data	Results	Sample
National	Region	Journal of collected data, FAO and National Statistics (DNSI)	Regions producing millet and sorghum in Mali identified	Regions of Segou, Koulikoro, and Mopti were selected
Regional	District	Reconnaissance visits to selected regions DRA database and discussions with development and extension personnel	Identification of districts representing the regions	Districts chosen: two in Segou, three in Koulikoro,, and three in and Mopti
District	Village	Reconnaissance visits to selected districts and discussions with development and extension personnel	Complete list of villages in the selected districts	Villages randomly selected in Segou, Koulikoro, and Mopti: Sorghum: 18, 13, and 12 Millet: 8, 19, and 16
Village	Production unit	Reconnaissance visits to selected villages and meetings with village associations	Complete list of units of production in the chosen village associations	300 and 345 UAPs chosen at random in which to collect primary data on sorghum and millet
Production unit	Field	General features of the UAP and their fields	Collection of socioeconomic data on UAP	

Data collection

Data collection covered 300 UAP for sorghum and 345 UAP for millet. These production units are distributed over 43 villages. Questionnaires were given to the UAP chief or his representative. The survey was carried out by 10 surveyors and 4 supervisors during 20 days. The difficulties encountered were mostly related to the languages of the different regions, particularly in Mopti, Koro, and Bankass where the main language is Dogon. On more than one occasion it was necessary to use an interpreter between the Bambara surveyor and the Dogon farmer.

Economic surplus approach

The economic surplus approach permits an objective evaluation of impact based on return to capital investments.

The essence of this concept is that the adoption of an improved technology leads to lower production costs and a vertical shift in the supply curve. The total yearly profit (or social gain) from this shift is measured by the total changes in the producer and the consumer surpluses.

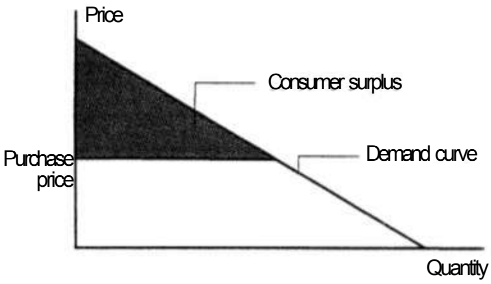

Figure 2. Illustration of consumer surplus

Consumer surplus is a measure of welfare represented by the difference between what consumers pay and what they would be required to pay for every marginal unit of goods up to the amount of purchased quantities. This measure of welfare is the area between the equilibrium price line and the demand curve (Fig. 2).

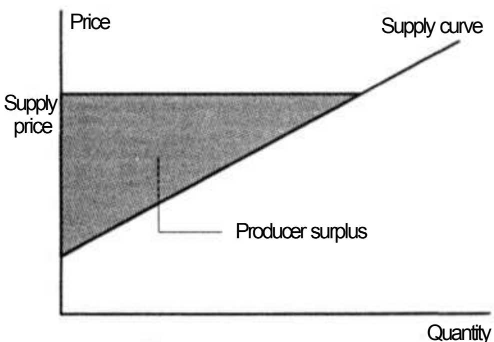

Figure 3. Illustration of producer surplus

Producer surplus is the difference between the producer price on the market and what they expect to receive (on the basis of unit cost of production) for the sale of every marginal unit of their products up to the total quantity sold. The total welfare of the producers is the area defined by the equilibrium price line and the supply curve (Fig. 3).

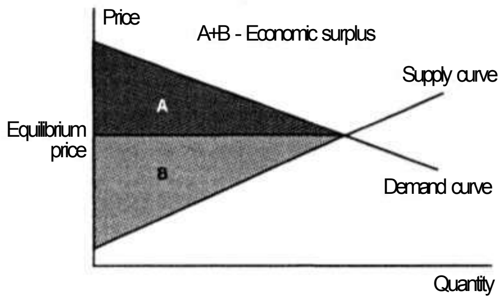

Figure 4. Illustration of the economic surplus concept

The consumer and producer surpluses (Fig. 4) are supposed to change following a shift in the supply curve due to the adoption of a new technology. For consumers, the shift in the supply curve increases the availability of consumer goods on the market at a lower price, while for producers, an increase in their productivity reduces production costs.

In order to measure the gains from research by the economic surplus method, it is necessary to compare the production and consumption situations with and without research. The simplest model to use in this context is the static unidimensional model that supposes a parallel shift in the supply curve.

Certain conditions should be fulfilled for the benefits of research to be realized. First, the research project should effectively produce the expected technology, and second, the technology generated should be effectively transferred to farms. The range of annual welfare gains depends on how intensely the technology is used.

The net gains from research therefore include all benefits in the time period during which technology is used, minus research and extension costs and other costs associated with use of the technology.

Research and release costs

In order to estimate the net benefits of research, it is necessary to establish gross benefits as well as research costs. The research costs for improved varieties of millet and sorghum in Mali are estimated based on the annual budgets of the intervening institutions (IER, ICRISAT, and PNVA). The costs allotted by this study were estimated by considering the share of the budget allotted for research, improvement, release and extension.

Results and discussion

Adoption study

Characteristics of UAPs. Characteristics are common for both crops (Table 4). The UAPs are large (average

Table 4. Socioeconomic characteristics of the units of agricultural production.

Characteristic	Mopti	Segou	Koulikoro	Mali
Average number of people	22.4	21.4	22.6	22
Average number of active people	10.8	8.6	6.7	8.7
Average experience (years)	17.2	17.5	20.9	18.6
Member of village association (%)	81	73	77	76
Use of chemical fertilisers (%)	24	21	25	23
Use of organic fertilisers (%)	97	96	83	94
Possession of agricultural equipment (%)	94	98	93	96
Land (ha)				
Collective drained land	9.3	9.8	6.6	8.6
Collective lowland	1.1	1.44	0.2	0.9
Individual drained land	2.5	2.1	2.0	2.2
Individual lowland	0.2	0.1	0.2	0.2
Fallow land	3.7	3.8	3.7	3.7
Education (percentage of sample)				
Do not write or read either French or local language	74	65	56	67
Read and write French	2	1	4	2
Read and write the local language	13	21	31	20
Speak French	2	1	4	2
Read and write French and local language	2	1	4	2
Read, write and speak French	3	3	3	3
Read, write and speak French and local language	5	8	5	6

Source: Formal ICRISAT/IER survey, 1995/96.

of 22 people, with 9 employed) and usually include several households. Unemployed people are probably children. Average duration of a UAP chief is 18 years, an indication of a broad knowledge of agricultural activities. The chief is responsible for decisions about all activities on common land. An average 77% of the UAP chiefs belong to an agricultural organization, and most are illiterate. Only 6% know French, but 21% know to read and write their native language.

About 96% of the farmers have some agricultural equipment. Only 23% use mineral fertilizer because of its high cost, but 94% use manure. Mineral fertilizer is used in the Mopti and Koulikoro areas on crops other than millet and sorghum.

In Mopti, the decision to adopt an improved variety of millet or sorghum seems to correlate with the chief's educational level, size of the UAP, and membership in a farming organization. In other words, 'educated' farmers with a responsibility for many people who belong to a village-level organization are more likely to adopt a new variety. Land availability, possession of agricultural equipment, experience with cultivation of sorghum and millet, and the number of employed people in the UAP do not seem to influence the adoption decision.

In Segou, four characteristics con-elate with the decision to adopt improved varieties:

- educational level of the UAP chief,
- contact with extension officers,
- tendency of the farmer to use mineral fertiliser, and
- land availability.

Size of the UAP, number of employed people, experience, membership in a village-level organization, and possession of agricultural equipment do not seem to affect the farmer decisions to adopt new varieties.

In Koulikoro, seven characteristics seem to influence adoption decisions:

- educational level of the chief,
- size of the UAP,
- membership in farming organization,
- contact with extension officers,
- possession of agricultural equipment,
- number of active people in the UAP, and
- land availability.

Only experience and the tendency of a farmer to use organic fertilizer do not seem to influence the adoption of new varieties in Koulikoro.

Two trends seem to be independent of location — younger and more educated chiefs are more likely to adopt new varieties than older and less educated ones. These two factors may be linked because young chiefs are likely to be more educated.

Varieties. The formal survey carried out in 645 UAP (300 for sorghum and 345 for millet) spread over 43 villages in Mopti, Segou, and Koulikoro revealed a significant number of improved varieties — 28 millet and 47 sorghum.

Some of the names are quite revealing. For example, the variety Monperegnon is certainly a sorghum introduced by a priest (Monpere =

father/priest), whereas Diakitegnon seems to be a variety introduced in the village by Diakite, a farmer or an officer of the training service. It would be tempting to conclude that Monperegnon is an improved variety, since it is unlikely that a 'white father' would introduce a traditional variety (which is less productive) in a community that frequently suffers from a food deficit. It is also improbable that a farmer would introduce another traditional variety in his community when the local varieties are no longer responding to environmental changes. Diakitegnon could also be an improved variety. Farmers consider these improved varieties even though their vernacular names have nothing to do with scientific names of varieties developed by researchers and introduced to the farming environment. Only varieties correctly identified by the researchers and/or the -releasing agents as having been improved were considered for calculations in this study.

With the help of PNVA officers and rural organizers, the sorghum variety known as FAO-nion was identified as CSM 388, the multiplication and seed distribution of which was entirely financed by FAO. It was also possible to associate Monperegnon with the inventoried sorghum varieties ICSV 1079 BF or ICSV 1063 BF according to locality. However, most of the inventoried varieties could not be clearly identified.

Adoption rates — millet. There were 220 adopters in 345 UAPs, with an adoption rate in cultivated area ranging from 12% in 1990 to 23% in 1995 for all three regions. By region during the same period, the rates were 13-20% in Koulikoro, 13-29% in Segou, and 10-17% in Mopti (Table 5). The higher adoption rates in Segou are explained by the presence of SSN, several development organizations, and the Cinzana research station (the country's principle millet research station).

The lower rates in Mopti could be partially explained by scarce technical services and farmers' apparent mistrust of the improved varieties. In Koulikoro, reduced interest in millet cultivation by OHVN (the Niger Upper Valley Operation, the zone's main development service) partially explains the lower adoption rates.

Table 5. Adoption rate (%) and area sown to improved millet varieties, 1990-1995.

Year	Mopti	Segou	Koulikoro	3 regions	Area sown to improved millet varieties (ha)
1990	10	13	13	12	1 45 440
1991	12	14	15	13	1 62 760
1992	13	15	15	14	1 43 780
1993	15	18	16	16	1 44 000
1994	15	24	18	19	2 66 760
1995	17	29	20	23	3 22 920

Table 6. Adoption rate (%) and area sown to improved sorghum varieties, 1990-1995.

Year	Mopti	Segou	Koulikoro	3 regions	Area sown to improved sorghum varieties (ha)
1990	14	14	20	17	1 37 530
1991	16	15	23	19	1 40 790
1992	19	15	23	20	1 64 000
1993	19	18	24	22	1 71 600
1994	20	21	26	24	2 34 480
1995	23	29	30	29	2 83 330

Adoption rates — sorghum. There were 213 adopters from 300 UAPs, with an adoption rate in cultivated area ranging from 17 to 29% between 1990 and 1995 for all three regions. During this same period, adoption rates rose from 20 to 30% in Koulikoro, from 14 to 29% in Segou, and from 14 to 23% in Mopti (Table 6).

The higher rate in Koulikoro can be explained by the importance of sorghum in the local diet and favorable conditions for sorghum cultivation. Adoption rates in the other two regions are relatively important considering that sorghum is a secondary crop in the local diets.

Adoption rates after the survey period (1990-95) were projected to ceilings of 35% for millet and 40% for sorghum for all three regions based on adoption constraints noted by farmers. These constraints were not predicted to improve significantly by the year 2000 without significant policy changes in research and extension (Figs. 5 and 6).

Adopting new varieties. For all the three regions, the main reasons for adoption of new millet varieties are earliness (91%), productivity (72%), and food quality (33%). Reasons for adopting new sorghum varieties are the same, but the percentages differ — earliness (85%), productivity (67%), and food quality (34%). These reasons vary in order and in importance in the three regions, perhaps due to rainfall differences (Tables 7 and 8).

Constraints to adoption. The most significant constraints to adoption cited by farmers for sorghum are lack of information about the existence and use of new varieties (58%); lack of seed

Table 7. Reasons (% of respondents) for adopting improved sorghum varieties.

Reason	Mopti	Segou	Koulikoro	3 regions
Number of respondents	70	104	46	220
Earliness	97	87	89	91
Productivity	53	89	74	72
Food quality	31	31	36	33
Yield stability	4	2	0	2
Striga resistance	0	2	24	9
Storage facilities	3	2	4	3
Fodder quality	4	3	0	2

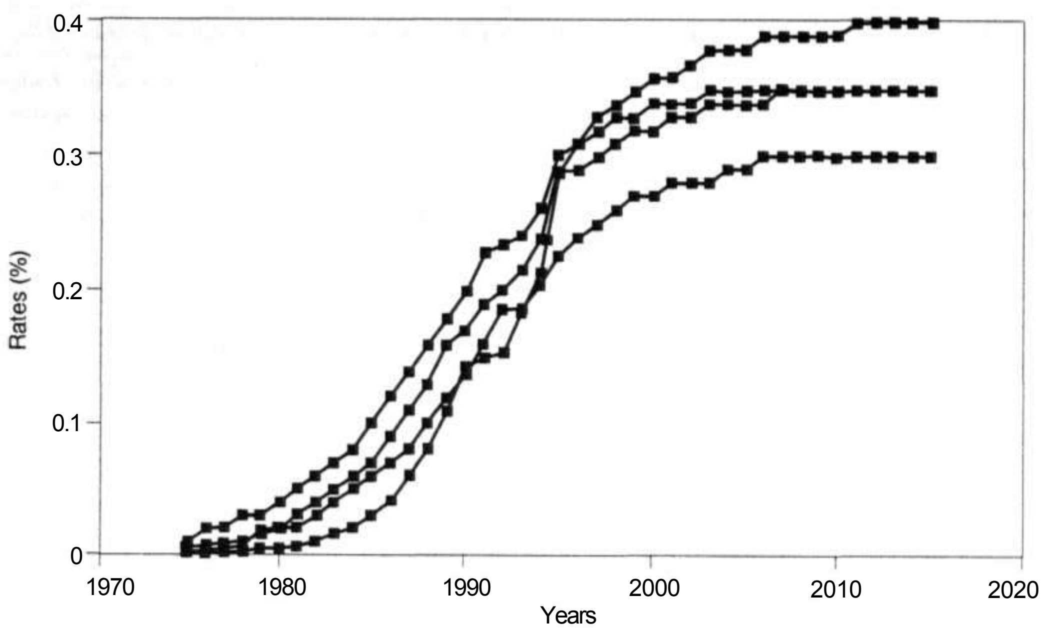

Figure 5. Illustration of the logistic adoption curve for improved varieties of sorghum in Mali

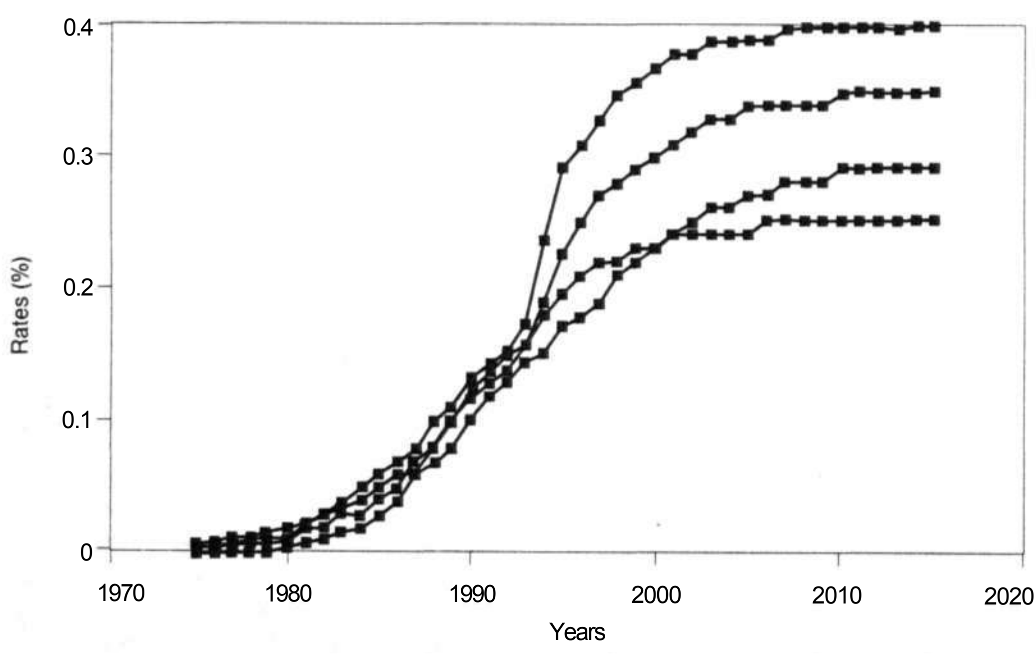

Figure 6. Illustration of the logistic adoption curve for improved varieties of millet in Mali

Table 8. Reasons (%) for adopting improved millet varieties.

Reason	Mopti	Segou	Kouli-koro	3 regions
Number of respondants	32	25	156	213
Earliness	94	84	76	85
Productivity	50	72	79	67
Food quality	34	40	29	34
Yield stability	3	0	1	1
Striga resistance	0	4	13	6
Storage facilities	0	0	2	1
Fodder quality	3	0	2	2
Insect resistance	0	0	2	2
Commercial	0	0	1	0.33

(50%), and poor soil (13%). The same reasons are cited for millet — lack of information (49%), lack of seed (33%), and poor soil (26%). Lack of information and seed are the most important constraints in all three regions, and poor soil is only a problem in Mopti. In Segou, there is a strong preference for local varieties. For sorghum in Koulikoro, the need to use fertilizer on improved varieties, bird damage, labor shortages, and storage are constraints. The need for fertilizer is the most important constraint to growing improved pearl millet in Koulikoro.

Impact Indicators

Indicators of food security, production efficiency, and economic surplus derived from use of improved varieties of millet and sorghum were used to analyze impact.

Food security. Data from the survey showed that yields after adopting new varieties rose substantially — 63% for millet and 51% for sorghum. Millet yields rose from 570 kg ha^{1} with the best local variety to 930 kg ha^{1} for improved varieties. Sorghum yield increases were similar — 620 kg ha^{-1} for the best local variety, and 940 kg ha^{-1} for improved varieties.

These yields are consistent with those found in previous studies. Shetty et al. (1991) noted that in Mali sorghum yields are about 600 kg ha^{-1}; compared to 2 000-3 000 kg ha^{-1} on research stations, and those of millet vary from 300 kg ha^{-1} in the Sahelian zone to 700 kg ha^{-1} in the zone with most rainfall in the south, compared to on-station yields of 1 500-2 000 kg ha^{-1}. Our on-farm yield estimates seem congruent with these data.

With production at these leyels, farmers not only feed their families, but also have surplus grain to market. Growing improved varieties assures food security and reduces production risks linked to drought at the end of the growing season. Farmers are interested in these varieties because they produce a consumable and marketable crop earlier in the season.

Production efficiency. Using improved varieties of millet reduced production costs as much as 38% (US$ 38 t^{-1}), while the saving for sorghum was 25% (US$ 34 t^{-1}), both compared to local varieties. The absolute production cost per hectare was higher for improved varieties because of additional inputs, but the higher productivity still provided these economies. With this higher productivity, farmers have the opportunity to reduce the area sown to sorghum and millet and diversify their farming to grow other crops for either the market or home consumption.

Economic surplus. Considering research and extension costs, the net present value of benefits from research on improved varieties is US$ 25 million for millet and US$ 16 million for sorghum. These figures represent an internal rate of return of 69% for sorghum and 50% for millet. The sensitivity analysis showed that these estimates are robust, and do not change significantly with marginal variation in elasticities and yield levels.

Conclusions

Investments in varietal research on millet and sorghum in Mali are beneficial because yields increased significantly, thus lowering unit production costs and consumer prices. Both of these factors are important indicators of impact.

Despite the low use of agricultural inputs, the benefits are significant. In Mali and throughout the Sahel, production risks are high, usually from highly variable rainfall and pests, thus farmers are reluctant to invest in inputs beyond what is absolutely necessary. Highly variable producer prices also discourage investment in inputs.

In all three regions, farmers reported that the major constraints to adoption of improved varieties were lack of information, lack of pure seed, and poor soil. Lack of information is related to the limited number of extension agents and the weakness of the research-extension link. Lack of pure seed reflects the limited capacity of SSN, inadequate coordination of the production-distribution network, and farmers' reluctance to invest in pure seed when production risks are so high. Expansion of cropping into marginal land as population increases, as well as limited investment in inputs and techniques to improve soil fertility, all contribute to 'poor soil'.

Farmers have indicated that selection criteria adopted by researchers correspond to their needs — earliness, high yield, and good food quality. Adoption rates have increased since 1985 (Matlon 1990), and quantitative impact indicators calculated on the basis of these adoption rates are encouraging.

Farmers continue to sow a major portion of their fields to traditional varieties, so it is necessary continue promoting improved varieties with new and creative approaches so that unit costs decrease and production, productivity, and food security increase.

Implications for research

The quantitative economic impact indicators produced by this study are significant, indicating that past investments have been beneficial and profitable compared to all other alternatives of investment in the public sector during this period. High net profits and internal rates of return, however, do not necessarily justify continued investments in the same area.

Of great importance is the ability to use primary data from the study to set priorities for future research (Bantilan 1996). The important primary data include levels and rates of adoption; feedback from farmers on factors affecting adoption, adoption constraints, and desirable characteristics for improved varieties; and profit gains due to use of new technologies. These data provide important insights for researchers to consider on-farm situations and problems.

On the basis of information collected on farms, this section proposes to establish priority areas of agronomy, breeding and socioeconomics. Recommendations in the domains of extension and the seed sector will be made subsequently.

Agronomy—Improved soil fertility

The formal survey found that poor soil is one of the principal constraints in adopting improved varieties on a large scale in Mali. This was strongly reported in all three regions, thus suggesting that future research must consider restoration and maintenance of soil fertility.

Considering the relatively high costs of inputs, low non-farm income, and farmer reluctance to invest in sorghum and millet production, research must focus on simple fertilization techniques that use organic raw materials that are available on farm. Research topics should include composting, use of organic materials, crop and fertilizer residue, soil cultivation, bench management using level curves, strip cropping, integration of crop-livestock systems, conservation of water and nutrients, rotation, use of legumes in crop systems, and judicious applications of mineral fertilizers.

Plant breeding

Enormous progress has been made in sorghum and millet breeding in Mali. Several high-yielding early maturing varieties have good resistance to diseases and insect pests and have acceptable taste. By citing earliness, productivity, and food quality of new varieties as reasons for adoption, farmers expressed their satisfaction with the achievements of Malian researchers. Consequently, it would seem to be more profitable to direct future research to removing adoption constraints and more intensive use of improved varieties that are already available rather than breeding new varieties with the same favorable characteristics.

Recent studies on food crops have indicated that at this stage of agricultural research, crop management (and not crop genetics) is the principal factor limiting cereal production in Mali (Shetty et al. 1991). Moreover, studies on production systems in the south of Mali have shown that the fight against pests — especially *Striga* — is much more difficult when soil fertility limits plant growth.

Socioeconomic research

Further improvement of sorghum and millet production in Mali depends largely on the capacity of farmers to manage soil fertility and pests. Socio-economic research must therefore focus on how to improve farmer income to enable investing of inputs for technology adoption. Future research should consider strategies to increase demand for sorghum and millet, new uses for these cereals, improved commercial channels, and reform of pricing policies for inputs and agricultural funds.

Seed sector and extension

Lack of pure seed of improved varieties limits adoption. One priority should be collaborative research to create an integrated and efficient seed multiplication and distribution system. Creation of such a system must not be the sole responsibility of SSN, but should also include researchers, extension officers, and the Ministry of Agriculture. Roles and responsibilities should be clearly defined.

The National Seed Service should be an essential link in the seed system, but not the entire system. It should keep accurate records of seed origin, as well as report all multiplication and distribution. Detailed annual reporting should record all multiplication and growing conditions, quantities of seed produced and distributed, distribution locations, and the related activities of extension officers. Such detailed data will enable researchers to follow adoption of improved cultivars and new technologies.

Extension officers should create technology packets (including improved seed), and clearly document their activities so that any weak or non-functioning links in the technology transfer chain can be identified. And the Ministry of Agriculture should respond to research and extension needs, including timely payment of salaries.

Farmers often cited 'lack of information' as a constraint to adopting improved cultivars, an indication of the current weakness in the collaboration among research, extension, and farmers. For example, there is no well-defined procedure to name and distribute new varieties, so names often change from village to village without the knowledge of researchers or extension officers. They are even returned to research stations for identification, draining manpower and other resources, and adding confusion for all concerned.

It is important to establish a committee responsible for naming varieties in the local languages of the areas where they are intended for distribution. A system of continuous follow-up should be established to evaluate the level of adoption success, as well as preferences and perceptions of farmers, rather than halting research when extension begins. Such practices would better integrate research and extension in the partnership of rural development. This partnership is essential for the permanent follow-up of varieties introduced on farms so that they do not lose productivity through seed deterioration.

To summarize, the appropriate individuals and organizations should work to improve multiplication and distribution of high-quality seed; follow improved varieties where they have been adopted as a means to improve adoption rates, production, and productivity; and conduct research to restore and maintain soil fertility.

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Chickpea in the Hot and Dry Climate of India — Adoption and Impact of Improved Varieties

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Introduction

During the past few years, chickpea has become more important as a winter crop in peninsular and central India. Although not traditionally a prominent pulse crop in this region, during the last decade improved cultivars have enabled a production shift from the traditional growing areas in the northwest and northeast of the country. A large portion of peninsular and central India suffers a hot and dry climate, along with the production-limiting constraints of wilt (*Fusarium oxysporum)* and root rots *(Rhizoctonia bataticola),* stunt virus[Bean *(pea) leaf roll virus],* and pod borer *(Helicoverpa armigera).* Development of short-duration cultivars adapted to these conditions, however, has led to expansion of chickpea area, and peninsular and central India now contributes more than 70% of the national production, and has enormous potential for further expansion.

Chickpea improvement research at the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) aimed to alleviate major abiotic and biotic production constraints under rainfed, low-input farming systems. Researchers began to develop short- and medium-duration *desi* and *kabuli* chickpea varieties adapted to peninsular and central Indian conditions with stable and high yields and good consumer acceptance.

A direct result of this research investment was the development of nine extra-short and short-duration improved chickpea varieties — ICCV 1, ICCV 2, ICCV 3, ICCV 5, ICCV 6, ICCV 10, ICCC 37, ICCC 42, and ICCV 88202. Among these, ICCV 1, ICCV 2, ICCV 10, ICCC 37, and

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ICCV 88202 were released for general cultivation in different parts of India. Their performance in on-farm trials was quite impressive and generated great interest among farmers, as well as the public and private seed sectors.

In the past, adoption assessment of improved chickpea varieties did not attract the attention of plant breeders, economists, and policymakers. Information that was available on seed sales through public and private seed companies was an indicator of the popularity of improved varieties among farmers. But information based on these statistics is incomplete because it does not include the most vital informal channel — farmer-to-farmer transfer of seed.

Objectives

The objectives of this study in a hot and dry climate were to:

- assess adoption patterns of improved chickpea varieties, and
- measure returns to investment on chickpea research.

The study provides farmers' responses to adoption of these varieties at the district, state, and regional levels. This information will be useful to help adjust research, production, and marketing strategies. The analysis will also justify returns to investment on chickpea research efforts at ICRISAT.

Methodology

Chickpea area in peninsular and central India covers about 4 million ha, more than half of the Indian total (Table 1). Important states are Andhra Pradesh, Gujarat, Karnataka, southern part of Madhya Pradesh, Maharashtra, and Tamil Nadu. This study was confined to these states, with the exceptions of Karnataka and Tamil Nadu. Chickpea yield in these states, except Madhya Pradesh, is below the national average of 855 kg ha^{-1}, but is on the increase.

A systematic sampling scheme was designed to choose the representative chickpea growing areas and growers in the selected states (Table 2). A three-stage random sampling method was

Table 1. Chickpea area, production, and yield in peninsular and central India, 1994.

State	Area ('000 ha)	Production 0000 t)	Yield (kg ha^{-1})
Andhra Pradesh	168	136	808
Gujarat	153	122	799
Karnataka	441	222	529
Madhya Pradesh	2 741	2 487	908
Maharashtra	763	469	614
Tamil Nadu	7	5	684
Total	4 273	3 441	805
India	7 260	5 020	855

Table 2. Sample size of the adoption impact study (number of villages and farmers).

State	Villages	Farmers
Andhra Pradesh	21	210
Gujarat	24	240
Madhya Pradesh	16	160
Maharashtra	54	540
Total	115	1 150

employed to choose the sample unit. In all, 1 150 chickpea farmers from 115 villages in 41 blocks of 20 districts in 4 states formed the study sample.

Primary data were collected from sample farmers through a formal survey using a questionnaire that covered general information on farm holdings, adoption of improved chickpea varieties, sources of seed, and farmer preferences on variety traits. The survey was conducted in 1995/96, and asked farmers to recall information for the period 1992-1995.

The study estimates the pattern and spread of adoption of improved chickpea cultivars, their rate of adoption, and ceiling levels. It also measures the returns to research investment on chickpea improvement at ICRISAT.

Results and discussion

Research lag

Among several varieties developed at ICRISAT, ICCV 1, ICCV 2, ICCV 10, and ICCC 37 were released for general cultivation and became popular in the selected states. ICCV 1 (also known as ICCC 4) was released by the state varietal committee in Gujarat for cultivation in 1983. ICCV 2 and ICCC 37 were released in Andhra Pradesh, and ICCV 10 was released for peninsular and central India, including Maharashtra. The time to develop these varieties varied from 10 to 17 years (Table 3).

Variety characteristics

The four most popular HYVs in the study area have distinct characteristics:

- ICCV 1 is of medium duration (110 - 140 days) with medium to large, yellow to light brown seeds, and is moderately resistant to the pod borer *(Helicoverpa armigera).*
- ICCV 2 is an extra-short duration (85 - 90 days) *kabuli* type and is resistant to fusarium wilt *(Fusarium oxysporum).* It was released as Shwetha in Andhra Pradesh and Maharashtra, is adapted to normal and late sowing, and can escape drought.
- ICCC 37 is a medium- to large-seeded high-yielding variety, matures in 90 - 100 days and is resistant to wilt and tolerant to dry root rot *{Rhizoctonia bataticola).* It was released as Kranti for general cultivation in Andhra Pradesh.
- ICCV 10 was released as Bharati for cultivation in the central and peninsular zones of India. It is a wilt

Table 3. Research process and time lag for important new varieties of chickpea.

Parameter	ICCV 1	ICCV 2	ICCV 10	ICCC 37
Research process started	1973	1975	1975	1974
Research product identified for release	1982	1984	1984	1983
Research product released	1983	1989	1992	1989
Total research lag (years)	10	14	17	15

and root rot resistant variety with wide adaptability. ICCV 10 is a medium-duration, high-yielding variety, reported to be drought tolerant.

Adoption of Improved varieties

Farmers who have full information about improved varieties and their potential benefits have sown them (Table 4).

Traditional chickpea varieties still dominate in all the selected states, but they are being replaced by improved varieties. In Maharashtra, Chaffa is the most popular traditional variety, and covers about 40% of total chickpea area, while in Andhra Pradesh, Annigeri occupies about 60% of the area. In Gujarat, Dahod Yellow is the most common among chickpea growers. In Madhya Pradesh, local varieties cover less than 20% of the chickpea area, but an improved but unreleased variety, Russian, covers about half of the chickpea area.

In Andhra Pradesh, ICCV 2 and ICCC 37 are replacing the ruling Annigeri variety, with about 30% of chickpea farmers growing these two improved varieties. The area under

Table 4. Adoption of improved chickpea varieties in hot and dry areas of India 1992-95 (percentage of total chickpea area).

State	Variety	1992	1993	1994	1995
Andhra Pradesh	ICCV 2	4	7	7	17
	ICCC 37	4	6	6	9
	Other improved	0.5	5	0.8	1.5
	Annigeri	74	66	70	58
	Local	17	16	15	15
Gujarat	ICCV 1	21	21	25	25
(only Jamnagar district)	Dahod Yellow	79	79	75	75
Madhya Pradesh	ICCV 2	n.a.[1]	n.a.	n.a.	13
	Ujjain	n.a.	n.a.	n.a.	21
	Russian	n.a.	n.a.	n.a.	48
	Local	n.a.	n.a.	n.a.	18
Maharashtra	ICCV 2	2.5	3	6	9
	ICCC 37	12	14	18	18
	Other ICRISAT varieties	0	0.6	1	1
	Other improved varieties	24	26	26	24
	Chaffa	49	44	38	39
	Other local	12	12	11	9

1. n.a. = not available

ICCV 2 and ICCC 37 increased from less than 10% in 1992 to about 26% in 1995, with ICCV 2 being adopted much faster than ICCC 37.

In Maharashtra, there is a wide choice of chickpea varieties. Although as many as 28 chickpea varieties are cultivated in the state, ICCV 2 and ICCC 37 occupy about 27% of the chickpea area, and are rapidly replacing the dominant variety, Chaffa. Other improved varieties were grown on 24% of the area. Among non-ICRISAT improved varieties, the area under G 12 was increasing, while that of G 5 declined. Both were developed at Punjabrao Krishi Vidyapeeth (PKV), Akola.

In Gujarat, the majority of farmers are still growing local varieties. ICCV 1 is found only in Jamnagar district. Its area among the sample farmers in the district increased from 20% in 1992 to 25% in 1995. This variety was first adopted in Gujarat in 1986, three years after its release, and has a niche in irrigated areas in groundnut-chickpea-based cropping systems.

In Madhya Pradesh, improved varieties cover about 34% of the chickpea area. Two improved varieties, Ujjain and ICCV 2, are popular with the sample farmers. Both are adopted in areas with a more favorable moisture regime.

In looking at adoption patterns, it appears that when progressive farmers have easy access to research institutes, they tend to adopt HYVs. Examples include Medak district in Andhra Pradesh (location of ICRISAT), Akola (location of PKV), and Parbhani (location of Marathawada Krishi Vidyapeeth).

Drought and wilt are the major constraints to chickpea production in most parts of peninsular India, thus varieties that escape drought and are wilt resistant are becoming popular among farmers. ICCV 2 escapes drought and is an early maturing variety with a premium price over other varieties because it is *kabuli.* The added advantage of this variety is that its performance is relatively better than other varieties in both rainfed and irrigated environments. It is gaining wide acceptance. ICCC 37 is wilt-resistant, of medium duration, and high-yielding. This variety is preferred where chickpea yields are suboptimal due to wilt. ICCV 2 and ICCC 37 are favored over other improved varieties in the study areas. ICCV 10 is still in the early adoption stage, but is expected to replace local varieties, and to some extent ICCC 37 if an adequate quantity of seed is available.

On-farm benefits

Table 5 presents the on-farm benefits of improved chickpea varieties over traditional varieties in selected states of India. An attempt was also made to examine the relationship between adoption of improved varieties and average productivity in Maharashtra at the district level. Using the on-farm survey adoption estimates of 1992-94 and district level yields during same period, as HYVs were increasingly adopted, yields rose, and vice-versa

Table 5. On-farm benefits of improved chickpea varieties compared to the popular variety (percentage change).

Indicator[1]	Andhra Pradesh	Andhra Pradesh	Gujarat	Madhya Pradesh
Variety	ICCV 2	ICCC 37	ICCV1	ICCV 2
Yield	108	29	67	123
Net income	440	116	143	624
Unit cost	-29	-5	-32	-33
Employment	-20	8	10	25
Gender	11	8	-35	65
Price premium	58	42	1	103

1. Unit cost is the cost of producing one unit of chickpea; employment is the male and female labor employment for chickpea cultivation; gender is share of female labor in total employment for chickpea cultivation.

(Table 6). It is interesting to note that average yields of chickpea in most of the districts during the early 1980s (when no improved varieties were adopted), ranged between 300 and 450 kg ha^{-1}. An impressive increase in chickpea yields was observed in districts where adoption of improved varieties was quite high during the early 1990s. Similar results were obtained for Jamnagar district in Gujarat where ICCV 1 was sown on about 25% of the chickpea area. The increase in the average yield of chickpea in Jamnagar was substantially higher and faster than other districts.

A large share of the chickpea area in Andhra Pradesh and Maharashtra is formerly fallow land, which is an important benefit of improved varieties. Use of this land intensifies and diversifies crop production and reduces soil erosion. This nitrogen-fixing leguminous crop fixes atmospheric nitrogen at a rate of 80-120 kg N ha^{-1} which is available to the subsequent crop.

Table 6. Effect of improved varieties on chickpea yield in Maharashtra.

District	Adoptionof improved varieties in 1994(%)	Average yield in early 1980 (kg ha^{-1})	Average yield in 1994 (kg ha^{-1})	Change in yield (%)
Osmanabad	24	430	489	14
Amravati	27	295	756	156
Nagpur	31	233	493	111
Yavatmal	43	455	765	68
Aurangabad	49	367	586	60
Wardha	62	178	585	238
Buldhana	72	265	850	223
Parbhani	77	319	505	58
Akola	83	243	838	245

The direct and indirect benefits of improved chickpea varieties are attractive enough to farmers in hot and dry climates that the area sown to chickpea increased from less than 3 million ha in the early 1980s to more than 4 million ha in 1994. It is expected that if improved varieties continue to be available, the area under chickpea will expand further.

Economic benefits of chickpea research

There are several methods available to estimate the economic benefits of research investment. In this study, the partial equilibrium model of supply and demand in a commodity market was used. Economic benefits from chickpea improvement research were estimated under a perfect market for ICCV 2 and ICCC 37. To estimate the economic benefits of ICCV 2, a *kabuli* chickpea variety, a shift in demand curve was assumed because there was a price premium on this variety due to its quality. On the other hand, to assess economic benefits of ICCC 37, a shift in supply function was assumed because its adoption resulted in reduced unit costs of production.

To estimate net economic benefits, information is required in three areas:

- research costs of developing the improved variety,
- adoption rates and ceiling levels, and
- savings in unit costs of production, or price premium in case of quality changes.

Research costs to develop ICCV 2 and ICCC 37 were not recorded, so they were estimated by considering the salary of researchers, operational expenses, and overhead costs for developing these varieties. Information on adoption rate, spread of adoption, ceiling levels, unit cost savings, and price premium were derived from the survey data (Table 7).

Assuming a perfect market, the internal rate of return (IRR) and net present value for research on ICCV 2 and ICCC 37 were computed. The internal rate of return was 21 % to develop the extra-short duration, drought-escaping *kabuli* type (ICCV 2), while the IRR was 25% for the high-yielding, wilt-resistant variety (ICCC 37). The present value of net benefits from research on ICCV 2 was US$ 1.44 million and on ICCC 37 was US$ 2.87 million (Table 8). The

Table 7. Parameters used to estimate economic benefits of chickpea research.

Parameter	Andhra Pradesh	Gujarat	Madhya Pradesh	Maharashtra
Base production ('000 t)	27	48	1483	324
Price of *desi* type (Rs kg^{-1})	12	10	8.75	11
Price of *kabuli* type (Rs kg^{-1})	19	12	18	16
Supply elasticity (%)	0.5	0.5	0.5	0.5
Demand elasticity (%)	-1.3	-1.3	-1.3	-1.3

Table 8. Economic benefits of the research investment in developing improved chickpea varieties.

Criteria	ICCV 2	ICCC 37
Internal rate of return (%)	21.21	25.43
Net present value ('000 US$)	1440	2875
Benefit cost ratio	11.82	12.63

aggregate net present benefits of research to develop these two varieties for a hot and dry climate is estimated to be about US$ 4.3 million — more than 10 times the entire chickpea research budget at ICRISAT in 1997.

These computed benefits are underestimated because our analysis was based on substitution of improved varieties for local landrace, however, there was a large gain from area expansion to fallow land that is not accounted for in the analysis.

Conclusions

Based on the preceding analysis, several areas merit attention.

Time lag

The time lag to develop improved chickpea varieties suited to a hot and dry climate was long because this environment is not favorable to traditional chickpea cultivation. To alleviate the formidable abiotic and biotic constraints, the long research lag was justified. Research and adoption lags assumed for research on drought and wilt in chickpea were underestimated in the ICRISAT's Medium Term Plan (ICRISAT 1992). In the absence of actual estimates, the research lag for drought-escaping, short-duration varieties was assumed to be 10 years, but in reality was 14 years. Similarly, the research lag for the wilt-resistant variety was estimated at 7 years, but it took 15 years to develop ICCC 37. These figures will now be used for future research planning.

Area and production expansion

The analysis showed that research efforts significantly expanded the chickpea area and production in a hot and dry climate because the new varieties were adapted to the environment. There is still further expansion potential. Chickpea is gaining importance in former winter fallow areas because the improved varieties mature early and can escape drought. Seed companies should plan production according to needs in the target regions.

On-farm benefits

Several on-farm benefits were derived by farmers as a result of adopting improved chickpea varieties. These were related to increases in average yields and net income, decline in unit cost of production, enhanced employment opportunities and labor productivity, positive implications on gender-related issues, and a price premium due to quality. Among these benefits, increased income was more prominent.

Yield increase

A significant increase in chickpea yield was noted in regions where improved varieties were adopted. A positive relationship between chickpea yields and adoption of improved varieties was observed in Andhra Pradesh, Maharashtra, and Gujarat.

Major expansion

A silent but significant contribution of improved chickpea varieties has occurred in the hot and dry climate. It was not visible like the green revolution in cereals in northwestern India because chickpea area is less than 10% of the gross cropped area in the country. But it should be noted that during the early 1980s, the hot and dry areas of India were contributing about 40% of chickpea production; in 1995, the figure approached 70%, despite the fact that yields are still lower than the national average.

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Reference

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Adoption of Improved Chickpea Varieties in Panchmahals District of Gujarat

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Introduction

In the Indian state of Gujarat, Panchmahals district ranks first in chickpea area (29%) and production (29%). Although chickpea area and production increased dramatically during the last decade, yield was stalled at about 800 kg ha^{-1} (Table 1). Expansion of chickpea area to marginal lands and slow adoption of improved varieties were the major factors responsible for low yields, hence it was necessary to introduce improved varieties and management techniques in the chickpea growing areas of Panchmahals district.

Krishak Bharti Cooperative Limited (KRIBHCO) decided to introduce improved technology to enhance agricultural productivity and improve food security. KRIBHCO is a farmer cooperative actively associated with the tormer British Overseas Development Administration (ODA), now Department for International Development (DFID). It promotes participatory natural resource development in the predominantly poor tribal districts of western India under the Indo-British Rainfed Farming Project.

Table 1. Area, production, and yield of chickpea, Panchmahals district and Gujarat state, 1970-1995.

Parameter	1970	1980	1990	1995
Panchmahals				
Area ('000 ha)	29.6	20.2	44.5	43.7
Production ('000 t)	22.8	16.3	36.0	35.6
Yield (kg ha^{-1})	770	807	809	815
Gujarat				
Area ('000 ha)	52.9	70.3	170.2	152.9
Production ('000 t)	43.9	53.8	115.8	122.2
Yield (kg ha^{-1})	530	765	680	799

Source: Directorate of Agriculture (1996).

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The project began in 1993, and covers 15 clusters, 3 in Gujarat and 6 each in Rajasthan and Madhya Pradesh. Various welfare activities are undertaken in each cluster of five to seven tribal villages.

Using a participatory rural appraisal, KRIBHCO assessed village problems and decided that the most effective approach to improving the livelihood of tribal people would be to identify improved chickpea varieties with traits preferred by farmers, and ensure that adequate quantities of seed were available. KRIBHCO partnered with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to identify improved varieties adapted to the environment. Five diverse chickpea varieties thought likely to be adapted to the project area were identified and introduced in six tribal villages of the KRIBHCO project area — ICCV 1 (ICCC 4), ICCV 2, ICCV 10, ICCC 37, and ICCV 88202.

In on-farm trials, the performance of these varieties was compared to local varieties. Three varieties, ICCV 2, ICCV 10, and ICCV 88202, were found to be promising in the villages located in Panchmahals district. Results of a survey conducted in two villages of Panchmahals district confirmed that the majority of sample farmers who had first sown these varieties in 1993/94 had resown them (Joshi and Witcombe 1996).

The purpose of this study was to evaluate the role of the KRIBHCO project. The specific objectives are to:

- assess the role of the KRIBHCO project in disseminating improved chickpea varieties,
- study the direct and indirect on-farm benefits of improved chickpea varieties, and
- identify the factors that influence adoption of improved chickpea varieties.

Sampling framework

The results of the study are based on four villages randomly selected from purposively chosen two clusters in Limkheda block of Panchmahals district where KRIBHCO activities were introduced (Table 2). The villages are Jaliapada and Sarjumi in the northern cluster, and Mahunala and Bor in the southern cluster. A complete list of all chickpea growers in the selected villages was obtained, and 12 farmers growing improved chickpea varieties (adopters) were randomly selected from each village. An equal number of farmers growing local chickpea varieties (non-adopters) was also randomly selected from the same villages, thus the total sample included 96 farmers who grow chickpea — 48 who had adopted improved varieties, and 48 who cultivated local varieties. The relevant data were collected by interviewing farmers using a pretested questionnaire during October 1996. Information on important aspects of the villages was also collected from secondary and official sources.

Table 2. Profiles of four villages.

Parameter	Jaliapada	Sarjumi	Mahunala	Bor
Total area (ha)	502	723	309	165
Size of holding (ha)	0.81	0.97	1.02	0.95
Forest land (%)	76.5	69.2	40.8	18.9
Soils	Black, red, stony	Bhuri, sandy, black stony	Red, sandy, stony	Bhuri, stony, black
Rainfall (mm)	800	900	900	800
Crops	Maize, rice, chickpea, pigeonpea	Maize, rice, chickpea	Maize, rice, chickpea	Maize, rice, chickpea, pigeonpea
Population (No.)	1 236	1 045	626	834
Electrification (%)	4.7	4.7	9.7	12.7
Literacy (%)				
Female	42	5	9	26
Male	44	14	42	37

Analytical framework

Temporal changes in adoption of different chickpea varieties were estimated. More particularly, the extent of adoption and on-farm benefits were estimated to ascertain the role of KRIBHCO in disseminating improved technologies. The study also attempted to identify and quantify the influence of independent variables on varietal adoption. The Tobit model (Tobin 1958) was used because it measures not only the probability that a farmer will adopt the new technology, but also the intensity of use of the technology once adopted (Adesina and Zinnah 1993). The functional form of the model is:

$$\text{if } i^* = X_i\beta + \mu > T$$

or

$$Y_i = 0 \qquad \text{if } i^* = X_i\beta + \mu < T$$

where:

Y. is the probability of adopting and the intensity of use of improved chickpea varieties,

i^* is a non-observable latent variable,

T is non-observed threshold level,

X is the n x k matrix of the explanatory variables,

ß is a k x 1 vector of parameters to be estimated, and

μ_i is an independently normally distributed error term with zero mean and constant variance a^2.

The equation is a simultaneous and stochastic decision model. If the non-observed latent variable i* is greater than T, the observed qualitative variable Y_i that indexes adoption which becomes a continuous function of the explanatory variables, and zero otherwise (i.e., no adoption). The maximum likelihood method was used to estimate the coefficients. The regression coefficients are asymptotically efficient, unbiased, and normally distributed.

Table 3. Variables considered in Tobit analysis.

Variables	Hypothesized sign
Education (score)	+
Size of holding (ha)	+/-
Chickpea duration (days)	-
Farmer's experience of growing chickpea (years)	+
Market distance (km)	-
Parcels of land (no.)	-
Village dummies (binary)	+/-
Yield risk (CV%)	+

Variables in the empirical model

The estimated empirical model derived from the equation was developed using the farm and farmer-specific attributes, together with farmer perceptions about technology-specific characteristics of the improved chickpea varieties. The model assumes that the dependent variable (proportion of area under improved chickpea varieties in the total chickpea area), depends on these independent variables — education, size of land holding, chickpea duration (maturity), experience of growing chickpea, market distance, number of parcels of land, village representation, and yield risk. The list of independent variables along with their units and hypothesized nature of responses are given in Table 3.

The level of education of the farmer is measured as zero for illiterate, 1 for primary education, 2 for high school education, 3 for secondary education, 4 for graduate, and 5 for post-graduate education. It is hypothesized that education is positively related to adoption because education helps an individual to acquire knowledge about improved varieties.

There are two schools of thought on the relationship between farm size and the adoption of improved technologies. One argues that the variable has a positive influence on adoption because large farms generate more income and therefore provide a better capital base and enhance the ability to take risks (Sarop and Vashist 1994). Another argument advocates that small fanners use their limited resources more efficiently and adopt new technology at a faster rate (Allauddin and Tisdell 1988).

Farmers in this study area perceived that early-maturing varieties would escape drought caused by receding soil moisture (Joshi and Witcombe 1996). It was hypothesized, therefore, that the duration of chickpea is negatively related to adoption of improved varieties.

Years of experience in chickpea farming is expected to be related to the ability of the farmer to obtain, process, and use information relevant to its cultivation. Therefore, a positive relationship between this variable and the probability of adoption of improved varieties is hypothesized. Adesina and Seidi (1995) and Adesina and Forson (1995) also confirmed that experience was positively related to adoption of new technologies.

Distance to product markets, measured in kilometers, is one of the most important variables, particularly in this study area where tribal farmers do not have easy access to markets. The market distance is, therefore, hypothesized to be negatively related to adoption.

Fragmentation of land holdings adversely affects adoption rate because it demands more time and resources per unit of production. The number of parcels, therefore, has also been included as one of the independent variables in the empirical model and is expected to be negatively related to adoption of improved varieties.

Study villages differ in many respects such as soil type and rainfall patterns. Village dummies have therefore been introduced in the model. These are measured as binary variables to capture the influence of soil type and rainfall pattern on adoption decisions.

Yield risk is measured as a coefficient of variation of the chickpea yield in bad, normal, and good years. Higher risk-bearing ability of farmers is an indication of a faster rate of adoption. A positive relationship is hypothesized between yield risk and the probability of adoption of improved chickpea varieties.

Farmer characteristics

Table 4 presents characteristics of farmers in the sample. Chickpea is grown on more than 40% of the total cropped area during the winter (postrainy) season by adopters of improved varieties. The corresponding figure for non-adopters is 50%. No significant difference was noticed in

Table 4. Characteristics of farmers in the sample, Panchmahals district, Gujarat.

Characteristic	ICCV 2	ICCV 10	Adopters	Non-adopters
Size of holding (ha)	1.3	1.2	1.2	1.3
Total operated land (ha)	1.1	1.2	1.1	1.2
Chickpea area to total area (%)	42	40	42	50
Number of parcels	1.3	1.4	1.4	1.3
Chickpea growing experience (years)	28	36	31	28
Chickpea rotation in same plot (percentage of sample farmers)	3.5	0	2	19
Crop rotations (percentage of sample farmers)				
Maize-chickpea	93	95	94	96
Rice-chickpea	0	6	2	4

the number of land parcels between adopters and non-adopters. A majority of farmers who adopted improved varieties (98%) do not grow chickpea continuously on the same plot. There is a general tendency to rotate chickpea to different plots to enhance soil fertility and increase productivity of the subsequent rainy-season crop. On the other hand, about 19% of non-adopters have grown chickpea continuously on the same plot. Tribal farmers generally grow chickpea after maize, which is one of the major rainy season cereal crops in the study area, widely used as food. The majority of sample farmers followed a maize-chickpea rotation, but a few used a rice-chickpea rotation.

Adoption of improved varieties

Of the adopters of improved chickpea varieties, 60% are growing ICCV 2 and 40% are growing ICCV 10 (Table 5). Adoption of ICCV 2 and ICCV 10 was almost the same (20%) during 1994, but in subsequent years adoption increased significantly by replacing the most popular local variety (Dahod Yellow). The increased adoption rate indicates that the improved chickpea varieties were preferred by the tribal farmers when compared to the local variety.

Table 5. Extent of adoption of improved chickpea varieties, 1994-1996, Panchmahals district, Gujarat (percentage of chickpea area).

Year	ICCV 2	ICCV 10	Adopters
1994	20	20	20
1995	31	45	42
1996	71	79	74

Rapid adoption of improved varieties by the tribal farmers is testimony to the role of KRIBHCO in disseminating the new technology. The participatory approach of understanding farmer needs about different varietal traits and identifying specific varieties was indeed responsible for wide acceptance and adoption of new varieties in the project area. The new varieties are also becoming popular outside the project area through KRIBHCO's contact farmers. It was reported that KRIBHCO is now producing commercial seed to develop a mechanism to ensure availability of quality seed of improved varieties in adequate quantities at the right time. With such a mechanism institutionalized, it is expected that the adoption rate of improved varieties will be much faster, which in turn produces several direct and indirect on-farm benefits to the tribal community.

It is interesting to note that over the 3-year period 1994-96, fanners increased their adoption levels. During 1994, about 60% of farmers adopted ICCV 2 and ICCV 10 on about 20% of their total chickpea area, but two years later, these varieties covered an area of more than 80% (Table 6). About 50% of the farmers sowed ICCV 2 and ICCV 10 in the range of 60-80% of their chickpea area. Such an impressive adoption rate can be attributed to the involvement of KRIBHCO.

The rate of change in the adoption of improved chickpea varieties during

Table 6. Percentage of sample farmers who have adopted improved chickpea varieties, 1994-1996, Panchmahals district, Gujarat.

Adoption range (percentage of chickpea area)	ICCV 2			ICCV 10			Total		
	1994	1995	1996	1994	1995	1996	1994	1995	1996
<20	59	17		63	5		60	13	
20-40	34	34	7	32	32	5	33	33	6
40-60	7	38	31	5	53	5	6	44	21
60-80		10	52		11	42		11	48
>80			10			47			25

last 3 years was also assessed separately for ICCV 2 and ICCV 10 (Table 7). Chickpea growers adopted ICCV 2 at a faster rate than ICCV 10. Examining the increase in adoption in the 50-100% range in 1996 over 1995, the proportion of chickpea growers was maximum for both the varieties (45% for ICCV 2 and 47% for ICCV 10). A higher proportion of chickpea growers was in the upper range of increase in 1996 over 1994 for both the improved varieties, however this proportion was significantly higher for ICCV 10. This could be attributed to the higher yield of ICCV 10 and its suitability to rainfed conditions because there is no irrigation in the study area. Farmers reported that ICCV 10 is a better replacement for the predominant local variety (Dahod Yellow).

Benefits of improved varieties

Although both ICCV 2 and ICCV 10 provided considerable yield gains over the local chickpea variety, yield of ICCV 10 (55%) was higher than ICCV 2 (34%). The higher yields reduced per unit production costs and increased profitability (Table 8)

The net returns for ICCV 10 were 84% higher than local varieties, while ICCV 2 was 68% higher. Higher

Table 7. Increase in rate of adoption of improved chickpea varieties (percentage of sample farmers), 1994-1996, Panchmahals district, Gujarat.

Increase in rate of adoption (percentage)	ICCV 2			ICCV 10		
	1995 over 1994	1996 over 1995	1996 over 1994	1995 over 1994	1996 over 1995	1996 over 1994
<50	34	24	3	26	21	
50-100	31	45	28	47	47	11
100-150	24	24	14	S	16	5
150-200	7	7	3		5	11
>200	3		52	21	11	74

Table 8. On-farm benefits of improved chickpea varieties, Panchmahals district, Gujarat.

Varieties	Yield (kg ha^{-1})	Price (Rs kg^{-1})	Gross returns (Rs ha^{-1})	Cost (Rs ha^{-1})	Net income (Rs ha^{-1})	Unit cost (Rs t^{-1})	Labor productivity (kg day^{-1})
ICCV 2	1 470	12	17 875	3 362	14513	2 290	76
ICCV 10	1 696	11	18 961	3 120	15 841	1 840	88
Dahod Yellow	1 096	10	11 245	2 626	8 619	2 400	43

profitability seems to be the most important reason for rapid adoption rate of ICCV 10. Unit cost for ICCV 10 was lower than the local variety (Rs. 560 t^{-1}). The corresponding figure for ICCV 2 was about 5% (Rs.110 t^{-1}). Another benefit was higher labor productivity, with ICCV 10 at 88 kg day^{-1}, ICCV 2 at 76 kg day^{-1}, and the local variety at 43 kg day^{-1}.

Generating additional marketable surplus was another significant benefit. The marketable surplus of those who adopted ICCV 2 was highest (61%), followed by ICCV 10 (21%), with the local varieties at a miserable 3% (Table 9). The marketable surplus of ICCV 2 was expected because this *kabuli* type sells at a higher price and is not preferred for consumption, thus farmers sell the maximum quantity of this variety in the market for a profit, and purchase the local variety for home consumption at a lower price.

Table 9. Disposition of chickpea by sample households, Panchmahals district, Gujarat (percentage of total production)

Use	ICCV 2	ICCV 10	Local
Home consumption	39	79	97
Marketable surplus	61	21	3

The yield risk was measured by computing coefficient of variation (CV) in chickpea yield during bad, normal, and good years (Table 10).

Table 10. Distribution of chickpea yield risk (percentage of sample farmers), Panchmahals district, Gujarat.

CV of yield (%)	Adopters	Cumulative	Non-adopters	Cumulative
<10	4	4	0	0
10-20	13	17	0	0
20-30	15	32	4	4
30-40	12	44	6	10
40-50	19	63	42	52
50-60	29	92	40	92
60-70	8	100	8	100

About 44% of adopters have a CV less than 40%, whereas only 10% of the non-adopters have this CV in yields. It is evident from the table that the farmers cultivating local varieties have high risk under a range of climatic changes.

Factors influencing adoption

There are several factors that determine adoption of the new technology. The adoption process begins as farmers experiment with the technology and then compare its results to existing technologies. While technology-specific traits are important, a farmer's own characteristics, resources, and market access also influence adoption.

As discussed earlier, the Tobit model was estimated using a maximum likelihood approach to identify important factors and their specific role in influencing the adoption of improved chickpea varieties in the tribal areas (Table 11). The number of parcels of land had no influence on the probability of adoption because most of the sample farmers have only one or two parcels. This variable was dropped and the estimated equation without it was selected to explain the results. Variables included in the model explained about 88% variation in the adoption of improved chickpea varieties (Table 12).

All but one of the variables had their expected signs, with five significant at 5% and 1 % levels, and one each at 10% and 15% levels. The size of holding was negatively related to the adoption. There are different schools of thought on adoption and farm size. In a study in Bangladesh, Allauddin and Tisdell (1988) observed that while

Table 11. Maximum likelihood of Tobit model estimates on factors affecting adoption of improved chickpea varieties.

		Asymptotic	
Variable	Coefficients	Standard error	t-ratio
Constant	412.900	33.030	12.50**
Education	2.665	3.187	0.84
Size of holding	-4.729	1.636	-2.89**
Chickpea duration	-3.821	0.304	12.54**
Experience of growing chickpea	0.421	0.276	1.52+
Market distance	0.543	1.073	0.51
Village 1 (Jaliapada)	-45.821	10.470	-4.38**
Village 2 (Sarjumi)	-26.415	7.488	-3.53**
Village 3 (Mahunala)	-14.564	5.687	-2.56*
Yield Risk	0.313	0.181	1.73++
F	14.802	1.557	9.51**
Adjusted R^2	87.76		

** Significant at 1% level; * Significant at 5% level; ++ Significant at 10% level; + Significant at 15% level

Table 12. Variables used in the empirical model.

Variable	Mean values	Standard deviation
Proportion of adoption (%)	36.9	36.3
Education (score)	0.71	0.65
Size of holding (ha)	7.7	3.6
Chickpea duration (days)	104	14.8
Experience of growing chickpea (years)	29	10
Market distance (km)	12.8	3.7
Parcels of land (no.)	1.3	0.6
Yield risk (%)	45	14

large farms were the early adopters of modern varieties, small farmers adjusted quickly and adopted as fast as large farms. Adesina and Seidi (1995) reported that the effect of farm size on adoption is unclear in the adoption literature. In the present study, it is interesting to note that small farmers are the early adopters of improved varieties.

Among the varietal traits, days to maturity negatively influenced adoption decisions. Farmers perceived that early-maturing varieties would escape drought, as well as pod borer infestation to some extent. The positive sign of the coefficient of yield risk indicates that those experiencing high risks to their chickpea crop are more likely to adopt new varieties.

Increasing farmer experience is expected to positively influence the probability of adoption because more experienced farmers may have better skills and preferential access to new information or technologies through extension services or development projects that work in the villages. The empirical results of the Tobit model indicate the positive sign of farmer experience in explaining their adoption decision.

The three village dummies were significant, indicating that soil type and rainfall pattern influence adoption of improved technologies. Higher negative dummy coefficients for Jaliapuda and Mahunala villages could be attributed mainly to different soil types compared to Bar village, whereas some unknown characteristics could have influenced lower adoption in Sarjumi village. Although market distance was positively related to the adoption of improved cultivation, its influence was not significant. This variable was expected to have a strong influence on adoption, but because KRIBHCO ensured a market, it was not found significant. It is important to remember that market prospects for improved varieties is an important determinant of adoption.

Conclusions

The efforts of KRIBHCO were rewarding in disseminating improved chickpea varieties and influencing their adoption rate. The performance of ICCV 10 was much better than ICCV 2 when both are compared to the dominant local variety, Dahod Yellow.

A significant difference in yield, net income, and labor productivity occurred. Adoption of ICCV 10 and ICCV 2 resulted in reduced unit cost of production. There was a substantial marketable surplus of the improved varieties. ICCV 2 had a price premium if it was sold through KRIBHCO, otherwise the tribal farmers were exploited by middlemen arid traders in the region. To overcome this problem, KRIBHCO is forming cooperative societies in the tribal villages. This initiative will certainly help farmers to reap the benefits of higher market prices.

Breeders' and the active extension role of KRIBHCO in disseminating the seed were highly instrumental in providing farmers with access to the improved varieties of chickpea in the study area.

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Improved Chickpea Varieties in Nepal

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Chickpea is an important pulse crop in Nepal. Based upon official statistics of the Ministry of Agriculture, it ranks fourth in area and fifth in production among the grain legumes. During the period 1985-95, however, chickpea area decreased at an annual rate of 1.8%, while production decreased at an annual rate of 1.7% (Table 1). The decline in chickpea area was due to various biotic, abiotic, institutional, and socioeconomic constraints. Most important were insect pests and diseases, expanded irrigation, competitive crops, and negligible world trade.

Unless the competitiveness of chickpea improves through price and yield advantages, production and area will continue to decline (Jodha and Subba Rao 1987, ICRISAT 1995). In order to halt this decline, chickpea production must improve — better agronomic practices, new varieties with genetic resistance to pests, and grain acceptable to consumers are needed.

Table 1. Area, production, and yield of chickpea in Nepal, 1985-95.

Year	Area (ha)	Production (t)	Yield (kg)
1985-87	28 797	18 437	640
1988-90	28 903	16 443	569
1993-95	25 010	15 191	607

Source: Agricultural Statistics Division, Ministry of Agriculture.

The National Grain Legume Improvement Program (NGLIP), Rampur, is mandated to conduct research designed to alleviate production constraints and increase productivity. Wilt *(Fusarum oxysporum)* and botrytis gray mold *(Botrytis cinerea Pers. Ex Fri)* (BGM) are important diseases of chickpea in Nepal. Reddy et al. (1990) estimated about a 40% yield loss due to BGM during the 1987/88 season. Pod borer *(Helicoverpa armigera)* is another serious biotic constraint. All these constraints are responsible for considerable yield losses that destabilize production. Chemical control measures are known, but most are not economical (Singh et al. 1989), and many farmers lack knowledge of chemicals.

Gurung, R.K. 1998. Improved chickpea varieties in Nepal. Pages 114-125 in Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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Lack of soil moisture at sowing time in the western terai and terminal drought in the central and eastern terai also lower yields. Irrigation could alleviate these constraints, but chickpea is rarely grown under irrigation. In the eastern terai, soil acidity is also a problem.

Since its inception, NGLIP began research projects on chickpea with active collaboration from ICRISAT, emphasizing development of varieties with resistance to pest and diseases, as well as with a high and stable yield. Six improved varieties of chickpea have been released for general cultivation in the country, of which three are ICRISAT varieties — Sita (ICCV 1), Koseli (ICCV 6), and Kalika (ICCV 82108). Two are local selections, Dhanush and Trishul, and one is an Indian line, Radha (JG 74). Sita is performing well in the western terai, whereas Kalika and Dhanush are doing well in the central terai and Kalika in the eastern terai.

The adoption levels of these varieties have yet to be confirmed. This study aims to assess the adoption pattern of three different varieties in three regions where chickpea is grown in Nepal, and to investigate reasons for adoption and non-adoption.

Methodology

Study area

The study area is confined to the seven terai districts — Banke and Bardiya in the western region (1 500 mm annual rainfall); Dhanusha, Mahottari, Sarlahi, and Rauthat districts in the central region (1 700 mm); and Sirha district in the eastern region (1 950 mm). Almost 90% of precipitation occurs during Jun-Sep. The soils of the terai belt of Nepal are alluvial, and this region includes more than 90% of the country's chickpea area. The monsoon rains start earlier in the eastern region, but terminate earlier in the western region. Rainfall in Sep-Oct influences the area sown to chickpea, while winter rainfall affects crop growth and yield because chickpea is cultivated on receding soil moisture.

Information on area, production, and yield of chickpea was collected from the Ministry of Agriculture. Seven districts were selected. Banke and Bardiya districts in the western region include about 36% of chickpea area and 80% of production. Similarly Dhanusha, Mahottari, Sarlahi, and Rauthat districts in the central terai region account for 65% of chickpea area and 74% of production in the region. Only Sirha district was selected in the eastern region, and this district accounts for 65% of area and 70% of production in the region. These selected districts account for about 50% of chickpea area and 45% of production in Nepal.

Sampling

One village from each of the seven districts was selected based on chickpea area and on-farm adaptive trials conducted for one or more seasons since 1992 by NGLIP and ICRISAT through the Cereals and Legumes Asia Network (CLAN). In each village 10-15 chickpea farmers were randomly selected for a total sample of 88 growers for the study. Primary data were collected from the sample farmers through a formal survey using a questionnaire that included general information on the farm households, adoption of improved varieties, sources of seed, farmers' preferences on varietal traits, etc. The data were collected in 1995/96 for the period 1992-95. Besides adoption of improved varieties, farmers were asked to specify the crop grown before and after chickpea, soil fertility, rotation, intercropping, competing crops, etc., in order to understand chickpea production systems in the chosen villages. The study estimated the rate and pattern of adoption of improved varieties.

Sample farm households

The average operated area of the sample farmers ranged from 1.3 ha in Bardiya to 2.9 ha in Sirha district, while the average number of parcels per household ranged from 2.3 in Bardiya to 10.0 in Rauthat (Table 2). These numbers indicate that land fragmentation is higher in the central and eastern terai regions than in the western region. Chickpea is not a very important crop in central terai — the average chickpea area in Sarlahi district of central terai was about 60% of the total operated area. In Bandiya district, however, the area under chickpea was as high as 80%.

Chickpea is generally grown as a rainfed crop, but in the central terai region, all districts except Dhanusha have more than 40% irrigated area during winter season, with the smallest area under chickpea. This supports the notion that the increase in irrigated area caused a decline in chickpea area (Jodha and Subba Rao 1987). Among the surveyed districts, almost 100% of the farm households of Mahottari, Sarlahi, and Sirha with access to irrigation during the winter season grow chickpea under irrigation.

Crop rotation

Except Bardiya district in the western terai, the majority of farmers do not grow chickpea continuously on the same plot. They usually rotate chickpea to improve soil fertility and enhance the productivity of subsequent rainy-season crops. Several reasons were given to support the practice of rotating chickpea —farmers of the central terai rotate chickpea to reduce weed infestation, in the western region it was to escape wilt disease, and in the eastern terai it was to prevent soil acidity because they perceive that continuous chickpea cultivation leads to this problem.

In the western region, about 59% of farmers sow chickpea after maize and 41 % sow it after rice. In the eastern terai, almost 73% of farmers grow chickpea after rice and 21 % grow maize before chickpea, whereas 2.7% of the farmers precede chickpea with finger millet and vegetable crops. The

Table 2. Chickpea production systems of sample farm households.

Parameter	Western terai		Central terai				Eastern terai
	Banke	Bardiya	Dhanush	Mahottari	Sarlahi	Rauthat	Sirha
Average holding (ha)	2.3	1.5	2.4	2.1	2.2	2.4	3.2
Average operated land (ha)	2.2	1.3	2.3	2.3	2.4	2.5	2.9
Average number of parcels	2.5	2.3	3.5	4.2	3.5	10.0	8.8
Average size of parcels (ha)	0.9	0.5	0.6	0.6	0.7	0.2	0.3
Average chickpea area (%)	45	79.3	18.8	6.8	6.2	13.1	36.6
Irrigated winter area (%)	10.3	0	7.3	51.2	43.8	57	1.9
Farm household access to winter irrigation (%)	28.6	0	30	50	54.5	80	8.3
Farm households growing chickpea on irrigated plots (%)	33.3	0	66.7	100	100	62.5	100
Chickpea grown on good quality soil (%)	66.7	55.6	100	100	63.6	60	100
Farmers rotating plots for chickpea cultivation (%)	61.9	44.4	90	83.3	50	81.8	91.7
Crop rotations (%)							
Maize-chickpea							
Rice-chickpea	47.6	72.2			63.6		
Finger millet-chickpea	52.4	27.7	80	100	18.2	100	91.6
Rice-chickpea-rice				10			
Maize-chickpea-pigeonpea				10			
Rice-chickpea-maize					9.1		
Vegetable-chickpea-mustard					9.0		8.4
Crops competing for resources	Lentil, wheat, mustard	Wheat, pigeonpea, Lentil	Vegetables, lentil, wheat	Wheat, mustard, lentil	Vegetables, lentil, pigeonpea	Lentil, wheat, mustard	Wheat, lentil, mustard

majority of farmers in the western and eastern terai perceived that wheat is the most important crop that competes with chickpea in terms of labor, time, land, and other resources, followed by lentil, pigeonpea, and mustard. In the central terai, lentil is the most important crop that competes with chickpea for resources, followed by vegetable crops, wheat, and mustard.

Research process

There is always a gap between the time a research project designed to develop a particular technology begins, and its adoption. This gap includes a research lag between the initiation of research and identification of research output for general recommendation, followed by a gestation period between the generation of a technology and its adoption by its ultimate users.

This study assessed the research lag for improved chickpea varieties released in Nepal. Table 3 shows the research process involved in the development of three varieties in Nepal.

ICCV 1

The research process to develop ICCV 1, a desi type, began in 1973/74 at ICRISAT - Patancheru. After basic research, the germplasm was supplied to an international chickpea cooperative trial at Parwanipur in 1978/79. After rigorous on-station adaptive research and on-farm trials in farmers' fields, NGLIP released ICCV 1 under the name of Sita for general cultivation in 1987. A research lag of 14 years was involved to develop ICCV 1 in Nepal. This cultivar is predominantly basal branching, of moderate height and medium duration, and capable of producing stable yields across the country.

ICCV 6

ICCV 6 is semi-erect, of moderate plant height, basal branching, and resistant to fusarium wilt. It is a *kabuli* type with a cream-colored seed coat. The research process to develop this variety began in 1973/74 at ICRISAT. After completion of basic research, the germplasm was supplied to an initial evaluation trial at NGLDP, Rampur. After on-station and on-farm trials at various locations, it was released as Koseli by NGLIP for general cultivation in 1990. A research lag of 16 years was involved to develop Koseli in Nepal.

ICCV 82108

ICCV 82108 is a medium-duration *desi* type with a semi-spreading growth habit, moderate plant height, high yield, resistance to fusarium wilt and BGM, and tolerance to soil acidity. The research to develop ICCV 82108 began in 1976 at ICRISAT. It was supplied as an entry in the international chickpea cooperative trial at NGLIP, Rampur, in 1985/86. After on-station adaptive research and on-farm trials at various locations, it was released under the

Table 3. Development of ICCV 1, ICCV 6, ICCV 82108, and Dhanush.

Variety/year	Research process
ICCV1	
1973	Single crosses made between H-208 (ICC 4954) and T 3 (ICC 4998). Single plant selection in F_2 and F_3 generation. Bulked in the F_4 generation, as selection number IC-7310-3-2-B-BH.
1978	Germplasm supplied to Agriculture Research Station (ARS) Parwanipur, Nepal as entry number 10 in International Chickpea Cooperative Trial-Desi line (ICCT-DL) in 1978/79.
1987	After rigorous on-station adaptive and on-farm trials at various locations NGLIP, Rampur released it as Sita for general cultivation in 1987.
ICCV 6	
1973/74	Pedigree selection from a cross of L 550 (ICCC 4973) and L2 (ICCC 4965). Single plant selection in F_2 to F_6 generations from wilt sick plot. Bulked in F_7 generations as selection number ICCX 7385-15-1-1H-1P-BR
1987	Supplied as entry in initial evaluation trial to NGLIP.
1990	After coordinated varietal trials on various research stations and farmers' field trials at different locations, released as Koseli in 1990 for general cultivation.
ICCV 82108	
1976	Multiple crosses made between F_2 (JG 62*WR315) * F_2 (P 1363*PRR1) F_2 generation was screened in multiple-disease infested field that had incidence of fusarium wilt, *Rhizoctonia bataticola, Rhizoctonial solani,* and *Fusarium Solani.* Single plant selection was followed until F_5, and bulked as selection number ICCX-761470-BP-IP-BP-BP.
1985	Supplied as entry ICCL 82108 in the International Chickpea Cooperative Trial, Desi, Short Duration, (ICCT-DS) to NGLIP.
1990	After on-station and on-farm adaptive research, NGLIP had released it as Kalika for general cultivation.
Dhanush	
1971	Selection from local germplasm.
1980	Released after evaluation on different research stations and locations through on-station and on-farm research.

name of Kalika in 1990 for general cultivation. A research lag of 14 years was involved to develop Kalika in Nepal.

Adoption of improved varieties

Adoption of improved chickpea varieties varies widely (Tables 4-7). Overall, about half of the sample farm

Table 4. Adoption of chickpea varieties by sample farmers in selected districts of Nepal, 1992-95 (percentage of chickpea area).

Region and variety	1992	1993	1994	1995
Western terai				
Kalika (ICCV 82108)	0.5	4.8		
Koseli (ICCV 6)	1.7	1.3	1.0	2.0
Sita (ICCV 1)	30.0	36.3	46.7	37.0
Dhanush				0.4
BG 256		0.3	3.0	3.0
Local	67.8	57.3	49.2	57.5
Central terai				
Kalika (ICCV 82108)	1.8	10.6	15.2	14.2
Koseli (ICCV 6)	1.5	0.6	1.4	1.8
Sita(ICCV 1)	-	8.4	6.5	1.8
Dhanush	3.6	16.1	25.1	32.3
Local	93.2	64.1	51.8	49.8
Eastern terai				
Kalika (ICCV 82108)		1.8	3.3	3.5
Sita (ICCV 1)			2.8	7.6
Dhanush		4.5	6.2	2.2
Local	100	93.8	87.8	86.8

households in 38% of the total chickpea area are cultivating improved varieties of chickpea. About 50% of the farmers grow local varieties on about 62% of the area.

The spread of Sita in the western terai reached 40% of farm households on 47% of chickpea area in 1994, then dropped to about 37%. At an aggregate level, the share of improved varieties was 42% in 1995 from 32% in 1992.

In the central terai, the high-yielding local landrace (Dhanush) accounted for 32% of the total chickpea area in 1995, followed by Kalika at 14% of the area for 17% of farm households in 1995. Both the high-yielding local variety and Kalika seem to be slowly replacing the traditional local varieties, but the adoption path of Koseli seems to be constant and that of Sita declining. At the aggregate level, their share approached 50% in 1995 from less than 7% in 1992.

In the eastern terai, the traditional local variety still dominates the chickpea area (87%), while Sita has been adopted by only 10% of farm households on 8% of the area. Kalika grew to 4% of the chickpea area for 16% of farm households. The local high-yielding variety Dhanush declined to 2% of the area for 11 % of farm households in 1995 from 6% of the area for 26% of farm households in 1994.

Adoption factors

Many factors constrained diffusion of varieties in different regions, including biotic and abiotic factors, socioeconomic constraints, and institutional bottlenecks.

Table 5. Aggregate adoption of chickpea varieties on sample farms in Nepal, 1992-95 (percentage of chickpea area).

Varieties	1992	1993	1994	1995
Kalika (ICCV 82108)	0.7	5.0	4.5	3.3
Koseli (ICCV 6)	1.3	0.9	0.9	1
Sita (ICCV 1)	18.0	24.6	26.4	24.3
Dhanush	0.7	3.2	7.5	6.5
BG 256		0.2	1.6	1.8
Local	79.4	66	59.2	62.5

Table 6. Adoption of chickpea varieties by farm households, 1992-95 (percentage of households).

Varieties	1992	1993	1994	1995
Western terai				
Kalika (ICCV 82108)	2.5	6.4		
Koseli (ICCV 6)	5.0	8.5	7.1	7.4
Sita(ICCV 1)	30.0	31.9	40.5	33.3
Dhanush				1.9
BG 256		2.1	4.8	5.5
Local	62.5	51.1	47.6	51.9
Central terai				
Kalika (ICCV 82108)	5.7	10.4	13.8	17.2
Koseli (ICCV 6)	2.9	2.1	1.7	3.1
Sita(ICCV 1)		10.4	3.4	1.6
Dhanush	11.4	20.8	34.5	35.4
Local	80.0	56.3	46.6	42.2
Eastern terai				
Kalika (ICCV 82108)		11.8	17.4	15.8
Sita (ICCV 1)			4.4	10.5
Dhanush		17.7	26.1	10.5
Local	100.0	70.6	52.2	63.2

Table 7. Aggregate adoption of chickpea varieties by farm households, 1992-95 (percentage of households).

Varieties	1992	1993	1994	1995
Kalika (ICCV 82108)	3.5	8.1	9.8	10.2
Koseli (ICCV 6)	3.5	4.5	3.3	4.3
Sita (ICCV 1)	14	17.9	16.3	15.3
Dhanush	4.7	11.6	21.1	19
BG 256		0.9	1.6	2.2
Local	74.4	56.3	48	48.9

Biotic and abiotic factors

In the western terai, farmers are cultivating chickpea on a large scale on 45-80% of the total area. Among abiotic constraints are lack of moisture at sowing time and rainfall during flowering, which causes increased infestations of pod borers. Wilt and pod borer *(Helicoverpa armigera)* are major biotic constraints in chickpea production.

Western terai. The preferred variety in the western terai is Sita. Its popularity is mainly due to its stable yield in both normal and bad years, yellowish seed coat, responsiveness to fertilizer, and higher grain yield when sown early (NGLIP 1990). Moisture recedes rapidly because the monsoon rains are short in this region. The area under this variety was highest in 1994 and declined marginally in 1995, mainly due to wilt. Another improved variety spreading in this region, although not so widely, is Koseli. Farmers are cultivating Koseli on smaller plots to judge its performance and determine if it fits their farming systems. Farmers prefer Koseli for its creamy-white seed color and large grain size that commands a higher market price. Although released as a wilt-resistant variety in this wilt-prone western region, Kalika has a dark brown seed coat and lower grain yield than Sita. Majority of sample farmers in this region expressed a preference for a creamy-white seed coat and bold grains.

Central terai. Farmers cultivate chickpea on a smaller scale, 6-18% of their land, in this region. Pod borer *(Helicoverpa armigera),* BGM, and wilt are major problems (Singh et al. 1990). A majority of farmers sow chickpea after harvesting rice in the last week of November, so they preferred short-duration varieties that escape terminal drought. Among the improved varieties, local selection Dhanush was sown on a consistent area during 1992-95, mainly due to its tolerance to BGM (Singh et al. 1989). Other reasons for its preference are the brown seed coat, medium-sized grain, and good yield when sown late. Among the ICRISAT varieties, Kalika showed consistent adoption until 1994, and then a marginal decline in 1995. Kalika is preferred by farmers because it is less susceptible to pod borer and BGM, has a higher grain yield, dark brown seed coat, bold grain size, and good performance when sown late.

Eastern terai. In this region, farmers cultivated chickpea on an average 36% of their land, which is larger than the central terai region. Pod borer and BGM are the major biotic constraints, while terminal drought and soil acidity are important abiotic constraints (Singh et al. 1990). The local variety still dominates the total chickpea area, while improved varieties account for only 14% of total chickpea area. Among the improved varieties, the area under Kalika is increasing. The preferred traits for Kalika are high yield, tolerance to acidic soil, dark brown seed, medium-bold grain (larger than Dhanush), and good performance when sown late. However, the share of the high-yielding local variety Dhanush is declining mainly due to its lower grain yield and smaller grain. Preferred traits in the eastern region are disease resistance (BGM), higher grain yield, early maturity, medium-sized grain, and brown seed coat.

Institutional factors

One of the major stumbling blocks to adoption of improved varieties is the absence of an organized seed industry in Nepal (Singh et al. 1989). The private sector is not involved in seed production and distribution of improved chickpea varieties. The public sector institution responsible for seed distribution is the Agriculture Input Corporation (AIC), but it is limited to cereal crops (wheat, rice, and maize) and vegetable crops. Lack of proper seed production technology for growers of legume crops, low output, and lack of a proper demand forecasting system make grain legumes a low priority for AIC (Parajuli and Sitaula 1990). Research institutes are the only source of quality chickpea seed, but their capacity (Table 8) is far below the estimated demand.

Using the estimated adoption rates in the study area, about 9 t of Koseli, 41 t of Kalika, 103 t of Sita, and 84 t of Dhanush are required in a year at a 60 kg ha^{-1} sowing rate for just the study area. The only means of transfer of improved varieties seems to be through farmer-to-farmer transactions that do not guarantee quality seed.

Lack of information about varieties is another problem for diffusion of improved varieties. Only two or three farmers from a sample population adopt improved varieties immediately after release. A large adoption lag

Table 8. Production and distribution of improved chickpea varieties by different research stations under the Nepal Agriculture Research Council, 1993/94-1994/95.

Variety	Breeder seed (kg)	Foundation seed (kg)
Dhanush	90	2 130
Kalika (ICCV 82108)	25	1816
Sita (ICCV 1)		2 130
Koseli (ICCV 6)		2 763

Source: National Grain Legume Research Program, (NGLIP). Rampur; Regional Agriculture Research Station, Parwanipur; Regional Agriculture Research Station, Khajura, Nepalgunj; National Oilseed Research Program, Nawalpur.

exists. Adoption of improved varieties picked up only after on-farm demonstrations began in a surveyed village. Successful and rapid adoption demands strong links between researchers, extension agents, and farmers to accelerate the rate of diffusion through such on-farm adaptive research.

The overall area sown to chickpea is declining, except in the western terai region. It is difficult to predict whether the area sown to improved varieties will increase because the entire system for seed production and distribution is so poorly established. Farmers who cultivate crops on small plots solely for only household use rarely seek improved production packages that are not immediately available. Chickpea area will also depend on agricultural infrastructure (such as irrigation), and the comparative advantage (for export) and market price for chickpea and its competing crops.

Conclusions

Multiple traits preferred

In the three regions of the terai, farmer preferences differ, but farmers are inclined to adopt varieties with multiple preferred traits appropriate to both the environment and their socioeconomic circumstances.

Research lag

Adoption of improved chickpea varieties suffered a long research lag. It took 14 years to develop ICCV 1 (Sita), 14 years for ICCV 82108 (Kalika), and 16 years for ICCV 6 (Koseli). Research strategies to reduce this time lag must be developed.

Slow diffusion

The diffusion process seems to be slower in the central and eastern regions than in the western terai. A special extension project in the west, the Secondary Crop Development Project of the Department of Agriculture, has a mandate to diffuse improved technologies of various secondary crops, including chickpea. It has played key role in making seed available through extension agencies and has also started a seed production program for important crops, including chickpea at the farmer level.

Extension participation

On-farm adaptive trials played a significant role in diffusion of improved varieties in the surveyed villages. But on-farm adaptive trials by a research program alone do not guarantee the wider adoption of improved technologies. Lack of information about new varieties also constrains adoption, so there is a need for active participation by extension agencies in order to replicate such innovations in other areas.

Seed production

The seed sector, both public and private, is a major player in the diffusion of improved technologies. Lack of quality seed is the major constraint.

In the western terai, one of the reasons for successful diffusion of Indian variety BG 256 was its readily availability at a nearby border market. The public seed sector, together with extension agencies, should enhance seed production, particularly in major growing areas.

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Chickpea in the High Barind of Bangladesh

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Bangladesh is situated on the northern fringe of the tropics and forms the largest delta in the world. It stretches from the Himalaya in the north to the Bay of Bengal in the south. Agriculture drives the Bangladesh economy, contributes 36% of gross domestic product (GDP), and accounts for 68.5% of national employment. At present, agricultural land is about 8.1 million ha, of which 7.6 million ha are cultivated (BBS 1994). The country is divided into three major physiographic units — hills, terraces, and floodplains. The terraces include the Madhupur tract, the Barind tract, and the Akhaura terrace.

The Barind tract covers about 5 382 km^2, about 6% of the country (Hunt 1984). It is further divided into three subregions — the dissected Barind tract, the level Barind tract, and the northeast terrain. The dissected Barind tract, also called the High Barind, covers about 1 002 km^2 of undulating topography and terraced rice fields. This area of northwest Bangadesh is semi-arid (Hunt 1984), and farmers there generally grow a single crop of transplanted rice.

Pulses are a major and cheap source of protein in the daily diet in Bangladesh, and many different ones are grown in the country. Pulses are also important to soil fertility because symbiotic root rhizobia fix atmospheric nitrogen, and the plants contribute significant amounts of organic matter to the soil. Pulses also provide valuable fodder and feed for livestock.

Climate

The High Barind has lowest and most unreliable rainfall pattern in Bangladesh. During the period 1982-93, there were wide variations over both months and years, with a mean annual rainfall of about 1 258 mm with a standard deviation of ±196 mm and a coefficient of variation of 15.6%. Much of the annual rainfall is received during

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the monsoon season (Jun-Sep).

The probability of rain sharply declines during the dry months of Nov-Mar. At the end of the rainy season in October, the probability of 75 mm rainfall is 48% at Rajshahi, 56% at Nawabgonj, and 53% at Naogaon — the three districts chosen for this study (Manalo 1975). Soil moisture depletion begins in October and at the end of December none is available for crop growth. This information helps select an appropriate cropping schedule because moisture requirements vary among crops. The average monthly temperature in the High Barind ranges from 9 to 44°C, while the average humidity is 78%.

Area and production

In Bangladesh, most pulses are traditionally grown during the dry winter months (postrainy, or *rabi* season) under rainfed conditions. Some of the pulses such as blackgram, mungbean, and pigeonpea are also grown during the summer or *kharif* season. The area under summer pulses is, however, small. Most of the pulse crops are concentrated in eight districts, and occupy an area of about 0.7 million ha (Table 1).

Khesari *(Lathyrus sativus)* tops the list of pulse crops in Bangladesh in both area and production. It grows in a range of climatic conditions, is the hardiest pulse crop, and is usually raised with minimum or zero tillage (relay) and management. Lentil is the second most important pulse crop and is popular among consumers. It is the most palatable pulse and is one of the main items in the daily diet. However, the crop cannot tolerate extreme cold or heat. Chickpea is the third important pulse crop, and is one of the best legumes for human and animal consumption. Besides its common use as *dhal,* it is also widely used in the preparation of snacks, sweets, and spiced food items. It is drought tolerant but highly sensitive to excess moisture.

Through continuous support and collaboration from the International Crops Research Institute for the Semi-

Table 1. Area, production, and yield of different pulses in Bangladesh (1990/91 to 1992/93).

Pulse	Area ('000 ha)	Production (000 t)	Yield (kg ha^{-1})	Percentage of total	
				Area	Production
Khesari	242	178	738	34.5	34.7
Lentil	206	158	764	29.4	30.7
Chickpea	85	63	744	12.1	12.3
Blackgram	67	51	762	9.6	10.0
Mungbean	55	32	576	7.9	6.2
Others	46	31	686	6.5	6.1
Total	701	513			

Arid Tropics (ICRISAT), the Pulses Research Centre of the Bangladesh Agricultural Research Institute (BARI) has developed some chickpea varieties that have higher yield potential and are tolerant to insect pests and diseases. BARI has released six improved chickpea varieties since 1987 (Table 2).

Table 2. Chickpea varieties developed and released by the Bangladesh Agricultural Research Institute.

Variety[1]	Pedigree	Year research began	Year of release
Nabin	ICCL 81248	1981	1987
Barichola 2	ICCL 83228	1985	1993
Barichola 3	ICCL 83103	1985	1993
Barichola 4	ICCL 85222	1987	1995
Barichola 5	RBH 228(a)	1987	1995
Barichola 6	ICCL 83149	1987	1995

1. ICRISAT was the source of germplasm for all varieties except Barichola 5, which is a local cross.

Chickpea in the High Barind

Chickpea is a suitable postrainy-season crop to be grown in the High Barind on residual soil moisture after harvesting transplanted rice. In this driest part of the country, most chickpea varieties grown by farmers are local, low-yielding, and susceptible to various diseases and insect pests. Growing postrainy-season crops on Barind soils under rainfed conditions after harvesting long-duration rice is generally difficult because there is insufficient soil moisture.

Despite this adverse situation, the area and production of chickpea have been increasing in the High Barind (Table 3). The area under chickpea more than doubled from 1984/85 to 1993/94, while production more than tripled during the same period. In 1995/96, both area and production of chickpea further increased to almost double of those in 1993/94 and 1994/95. The average chickpea yield was 648 kg ha^{-1} in 1984/85 and increased to 1 009 kg ha^{-1} by 1993/94. It is, however, disappointing that the yield of chickpea has been declining since then. The reason for this is not yet fully

Table 3. Area, production, and yield of chickpea in the High Barind, 1984-96.

Year	Parameter	Total	Change since 1984/85 (%)
1984/85	Area (ha)	1 213	
	Production (t)	786	
	Yield (kg ha^{-1})	648	
1991/92	Area (ha)	1 225	1
	Production (t)	1 062	35
	Yield (kg ha^{-1})	867	34
1992/93	Area (ha)	1 325	9
	Production (t)	1 293	65
	Yield (kg ha^{-1})	976	51
1993/94	Area (ha)	2 666	120
	Production (t)	2 690	242
	Yield (kg ha^{-1})	1 009	56
1994/95	Area (ha)	2 907	140
	Production (t)	2 504	219
	Yield (kg ha^{-1})	861	33
1995/96	Area (ha)	5 452	349
	Production (t)	4621	488
	Yield (kg ha^{-1})	848	31

Source: BBS 1993, 1994.

understood. Because data are not available from 1984/85 to 1990/91, it was not possible to estimate the growth rate of area and production of chickpea in the High Barind. This paper, therefore, calculates production and yield using 1984/85 as the base year.

Considering the importance of chickpea in this drought-prone environment, it is necessary to understand present cultivation practices, profitability, and impact on the rice-based cropping system. The specific objectives of this study were to:

- assess the expansion of chickpea area in the High Barind;
- evaluate farmer preferences for different varietal traits of chickpea;
- identify farmer attitudes toward chickpea cultivation; and
- quantify the impact of chickpea cultivation on the rice-based cropping system in the High Barind.

Methodology

The study was conducted using a formal survey, but some information was also collected from secondary sources. For the survey, three districts in the High Barind were chosen with following *thana* (political subdivision of a district) from each district: Godagari from Rajshahi, Nawabgonj Sadar from Nawabgonj, and Sapahar from Naogaon. They were selected because they had a higher concentration of chickpea cultivation and were more accessible than other *thanas.* Twenty-five farmers who grew chickpea and 15 who did not were selected from each *thana,* thus 120 farmers were selected randomly from both strata.

Among the farmers who did not grow chickpea, 71% cultivated wheat and the remaining 29% cultivated lentil, khesari, barley, and linseed. The chickpea farmers also cultivated such other postrainy-season crops as khesari, linseed, and barley, however, the present study compared the performance of chickpea to that of wheat because a majority of farmers who did not grow chickpea grew wheat.

The survey data were collected by trained enumerators under the direct supervision of researchers using a pretested interview schedule. The survey was conducted in Oct-Mar 1995/96, collecting information about the 1994/95 postrainy season and the subsequent rice crop.

Results and discussion

Farm size and distribution

The average area owned per farm was 1.7 ha for chickpea growers and only 0.7 ha for those who did not grow chickpea. Chickpea growers cultivated an average 2.6 ha, while those who did not grow the crop cultivated an average 1.8 ha (Table 4).

Cropped area and intensity

Farmers who grew chickpea averaged 2.3 ha of transplanted *Aman* rice, while those who did not grow chickpea averaged 1.6 ha (Table 5). *Aus* rice was cultivated on much smaller areas, but

Table 4. Average farm size and distribution pattern of sampled farmers in three areas of the High Barind (ha).

Grow chickpea	Own cultivated land	Rented land		Mortgaged land		Total cultivated land	Homestead area
		In	Out	In	Out		
Yes	1.7	1.1	0.2			2.6	0.1
No	0.7	1.1	0.04	0.01		1.8	0.1

Table 5. Average cropped area and cropping intensity of farmers who do and do not grow chickpea in the High Barind.

Parameter	Chickpea growers	Do not grow chickpea
Postrainy-season crops (ha)	1.1	0.6
Aus rice (ha)	0.7	0.4
Aman rice (ha)	2.3	1.6
Total cropped area (ha)	4.0	2.7
Total cultivated area (ha)	2.6	1.8
Cropping intensity (%)	154	148

the cropping intensity was a bit higher — 154% on the chickpea-growing farms and 148% on the other farms. On average, chickpea occupied 47% of the total area under all postrainy-season crops on the chickpea-growing farms. Among the locations, chickpea growers in the Rajshahi district allocated the highest proportion (55%) of their cultivated land in the postrainy season for chickpea cultivation (Table 6), however, the total cultivated land per farm was lowest in this district

Table 6. Distribution of postrainy-season crops on farms that grow chickpea.

Location	Area of postrainy-season crops (ha)	Area under chickpea (ha)	Percentage of area in chickpea
Rajshahi	0.9	0.5	55
Nawabgonj	1.3	0.7	50
Naogaon	1.1	0.4	36
All	1.1	0.5	47

Employment

The labor required for chickpea was less than that required for wheat —49 days ha^{-1} for chickpea from land preparation through storage, while wheat cultivation required 61 days ha^{-1} (Table 7). The higher labor requirement for wheat was because harvesting, threshing, and storing are more labor intensive. Chickpea cultivation required 19 pair days of animal labor ha^{-1}, while wheat required 27 pair days ha^{-1}. More animal labor was necessary for wheat cultivation because the crop requires better soil tilth, and more time was needed to haul the larger amount of harvested biomass in bullock-drawn carts (Table 8).

Table 7. Average use of inputs for chickpea, wheat, and the subsequent *Aman* rice crop in the High Barind.

	Postrainy-season crop		*Aman* rice	
Parameter[1]	Chickpea	Wheat	After chickpea	After wheat
Human labor (days ha^{-1})				
Owned	36	30	33	38
Hired	13	31	90	92
Total	49	61	123	130
Animal power (pairdays ha^{-1})				
Owned	18	27	28	28
Hired	1			
Total	19	27	28	28
Seed (kg ha^{-1})	49	148	98	93
Manure (kg ha^{-1})	259	683	561	395
Fertilizers (kg ha^{-1})				
Urea	16	185	90	183
TSP	30	131	75	121
Murate of potash	11	64	42	61
Single super phosphate	2			
Gypsum		2	7	1
Zinc oxide		0.26		
Boric acid		0.13		
Insecticide (Tk ha^{-1})	26		337	27
Irrigation (Tk ha^{-1})	21	310	19	7

1. 1 US$ = 42 Tk.

Table 8. Average relative cost of cultivation of chickpea and wheat in the three sample areas of the High Barind (Tk ha^{-1}).

	Chickpea	Wheat
Human labor	2112	2 440
Animal power	1 413	1 840
Seed	1 053	1 591
Manure	54	137
Fertilizers	1 036	2 684
Insecticide	23	
Irrigation	22	310
Interest on operating capital	36	157
Total variable cost		
Cash cost basis	2317	5 825
Full cost basis	5 231	9 159

Cultivation of *Aman* rice following chickpea and wheat needed an equal amount of animal labor, an indication that these two postrainy-season crops left the soil in more or less the same condition. Transplanted *Aman* rice, however, required more human labor when grown on harvested wheat plots, which may be a result of greater weed infestation following cultivation of wheat, which is generally grown with irrigation.

Relative Input use

The average seeding rate used by farmers was 49 kg ha"[1] for chickpea and 148 kg ha^{-1} for wheat (Table 7). Manure use differed not only on chickpea and wheat, but was also applied to rice at different rates following these two crops. Use of other fertilizers also differed (Table 7). Most farmers in Naogaon and some in Rajshahi applied insecticides to chickpea, but none used them on wheat. Most farmers irrigated their wheat.

Some aspects of crop management and input use on *Aman* rice following chickpea and wheat were identical, as was use of animal labor. Chickpea growers, however, used 42% more manure in the subsequent *Aman* rice crop than did the wheat growers. Chickpea growers also spent about 12 times as much on insecticides as wheat farmers and applied some supplementary irrigation to their rice crop, while the wheat farmers used very little insecticide and irrigation on their rice crop (Table 7). Such apattern of input use on the rice crop was actually due to differences in the economic condition of the two groups of farmers. Table 4 shows that the chickpea-growing farms had more cultivated land, and hence were in better economic condition. This enabled them to use higher rates of manure, insecticides, and irrigation on their main crop of rice than did the farmers who did not grow chickpea.

But contrary to these observations, chickpea growers used about 50% less urea on rice sown in the harvested chickpea plots compared to that used by the other farmers who grew wheat before rice. Other fertilizers were also used at lower rates following chickpea (Table 7), an indication that the soil fertility is probably improved after chickpea cultivation (Gowda and Kaul 1982).

Costs and returns of postrainy-season crops

The cost of wheat cultivation was about 75% higher than that of chickpea (Table 8). On average, the total variable cost of chickpea was Tk 5 231 ha^{-1} (full cost) and Tk 2 317 ha^{-1} (cash cost) (At the time of this study, 1US$ = about 42 Tk). On the other hand, the cost of wheat cultivation was Tk 9 159 ha^{-1} (full cost) and Tk 5 825 ha^{-1} (cash cost). In chickpea, about 40% of the total variable cost was for human labor and 27% for animal labor, but for wheat, the highest percentage (about 29%) was for fertilizer (Table 8).

Average yields were 891 kg ha^{-1} for chickpea and 2 201 kg ha^{-1} for wheat (Table 9). Despite the lower yield of chickpea, its gross margin was higher (28% on cash cost and 45% on full-cost basis) than that of wheat because production costs were lower and market price higher. The benefit-cost ratio was also higher for chickpea. The returns to chickpea production were more than double those of wheat (Table 9).

Cost and return **of Aman** *rice*

When full cost was considered, there was no significant advantage in *Aman* rice following chickpea (Tk 13 366 ha^{-1}) and wheat (Tk 13 719 ha^{-1}). But when only cash costs were considered,

Table 9. Average relative profitability of chickpea and wheat in the three sample areas of the High Barind.

Parameter	Chickpea	Wheat
Yield (kg ha^{-1})	891	2 201
Gross return (Tk ha^{-1})	16615	17 000
Variable cost (Tk ha^{-1})		
Cash cost basis	2317	5 825
Full cost basis	5 231	9 159
Gross margin (Tk ha^{-1})		
Cash cost basis	14 298	11 175
Full cost basis	11 384	7 841
Benefit-cost ratio		
Cash cost basis	7.17	2.92
Full cost basis	3.18	1.86
Cost of grain (Tk kg^{-1})	5.87	4.16
Return of grain (Tk kg^{-1})	18.65	7.72

the difference was remarkable. The cash cost of *Aman* rice following wheat was 20% higher than that following chickpea. Most notably, the fertilizer cost for rice following wheat was more than double that of following chickpea (Table 10).

The average yield of *Aman* rice was 4 673 kg ha^{-1} after chickpea, which was 14% higher than that after wheat. Gross margin after chickpea and benefit-cost ratio were also higher (Table 11).

Relative profitability of chickpea-rice and wheat-rice cropping systems

When benefit-cost ratios are considered, the wheat-rice pattern had a 20% higher variable cost than the chickpea-rice rotation (Table 12). The gross margin of the chickpea-rice rotation

Table 10. Average costs in the three sample areas of the High Barind for an *Aman* rice crop following chickpea and wheat (Tk ha^{-1}).

Parameter	After chickpea	After wheat
Human labor	8 727	7 955
Animal power	1 659	1 656
Power tiller	17	
Seed	913	882
Manure	158	112
Fertilizers	1 324	2515
Insecticide	337	277
Irrigation	25	
Interest on operating capital	212	254
Total variable costs		
Cash cost basis	8 491	10179
Full cost basis	13 366	13 71

Table 11. Average profitability in three sample areas of the High Barind for an *Aman* rice crop following chickpea and wheat.

Parameter	After chickpea	After wheat
Yield (kg ha^{-1})	4 673	4 102
Gross return (Tk ha^{-1})	39 147	34 975
Variable cost (Tk ha^{-1})		
Cash cost basis	8 731	10 179
Full cost basis	13 812	13 719
Gross margin (Tk ha^{-1})		
Cash cost basis	30 416	24 796
Full cost basis	25 335	21 256
Benefit-cost ratio		
Cash cost basis	4.48	3.44
Full cost basis	2.83	2.55
Cost of grain (Tk kg^{-1})	2.96	334
Return of grain (Tk kg^{-1})	8.38	8.52

Table 12. Average relative profitability of two cropping patterns in the three sample areas of the High Barind.

Parameter	Chickpea-rice	Wheat-rice
Gross return (Tk ha^{-1})	55 762	51 975
Variable cost (Tk ha^{-1})		
Cash cost basis	11 048	16004
Full cost basis	19 043	22 878
Gross Margin (Tk ha^{-1})		
Cash cost basis	44714	35 971
Full cost basis	36 719	29 097
Benefit-cost ratio		
Cash cost basis	5.05	3.25
Full cost basis	2.93	2.27

Table 13. Reasons cited by farmers for preferring the improved chickpea variety Nabin for cultivation in the three sample areas of the High Barind.

Reason	Percentage of farmers responding
High yield	100
Late sowing possible	100
High market demand	99
Attractive size	89
Attractive color	88
Good taste	67
Increase soil fertility	60
Drought tolerant	45
Short duration crop	44

was about 26% higher than that of wheat-rice. Chickpea farmers of the High Barind earned Tk 5.05 by spending Tk 1.00 in cash on the chickpea-rice cropping pattern, while farmers who did not grow chickpea earned only Tk 3.25 by spending the same amount of cash on the wheat-rice rotation.

Farmer preferences

The Pulses Research Centre of BAR1 has developed some chickpea varieties that have good yield potential and are tolerant of insect pests and diseases. Only one of these varieties, Nabin, has been adopted by farmers of the High Barind. All chickpea farmers preferred this variety for its higher yield, suitability for late sowing, high market demand, and attractive size and color. Farmers also liked its good taste, ability to improve soil fertility, short duration, and drought tolerance (Table 13). A large majority of farmers (80%) in the survey area expressed a desire to grow more chickpea during the next year (Table 14).

Conclusion

Chickpea area increased more than four times and production more than six times during the 10-year period 1984/85 to 1995/96. The gross margin for chickpea was higher than wheat, the predominant postrainy-season crop on farms that do not grow chickpea. Benefit-cost ratios for chickpea were also higher than for wheat cultivation, and the gross margin of a chickpea-rice rotation was about 26% higher than for wheat-rice. Farmers preferred the improved variety Nabin for its higher yield, suitability for late sowing, high market demand, and drought tolerance. Eighty percent of farmers who grew

Table 14. Attitudes of farmer in the three sample areas toward chickpea cultivation in the High Barind, 1994/95.

Parameter	Percentage of farmers responding
Area increase in the next year	80
Area decrease in the next year	1
Area unchanged in the next year	19
Causes of increase	
Easy cultivation	59
Low production cost	80
High market demand	69
More profitable than other postrainy-season crops	77
Increase soil fertility	30
No problem for next crop	10
Others[1]	9
Causes of no change	
Limited land	11
Need other crops	11
Crisis of rental land	4
Lack of irrigation[2]	14
Others[3]	3

1. Crop rotation, variable moisture.
2. Light irrigation after top dressing with urea.
3. Lack of draft power, input not supplied by owner.

chickpea planned to grow more chickpea the next year.

In light of this study, the varieties developed by BARI should be transferred to farmers' fields by collaborative programs of the On-Farm Research Division of BARI and the Directorate of Agricultural Extension. There is scope for increasing chickpea cultivation in the High Barind. The research to develop high-yielding varieties of chickpea is of utmost importance. It was clear from the study that farmers preferred these chickpea varieties — cropping intensity increased, farmer profits increased, and cultivation of chickpea reduced the need for chemical fertilizers on the subsequent *Aman* rice crop.

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Adoption Assessment of Short-Duration Pigeonpea ICPL 87

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The short-duration pigeonpea variety ICPL 87, derived from ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) breeding materials was released in India in 1986. This paper reports on a study of adoption of ICPL 87 in central India. The aims of the study were to:

- determine the rate and extent of adoption,
- document farmer preferences and constraints to adoption, and
- survey the impact of adoption on efficiency, sustainability, and poverty.

This paper focuses on efficiency and sustainability, and aims to determine how the concerns of farmers about sustainable farming influence adoption of short-duration pigeonpea (SDP).

Data were collected from a formal on-farm survey and rapid rural appraisals conducted in a drought-prone area of central India in 1995. The data shows how farmers' concerns about sustainability are addressed via appropriate management — in this case, crop rotation with short-duration pigeonpea — as a process of capturing long-term gains.

Study area

Farm-level surveys were conducted in the pigeonpea-growing districts of central India cutting across the boundaries of two semi-arid tropics (SAT) research domains defined by ICRISAT — Production Systems 7 and 8. These production systems represent:

- the tropical, intermediate rainfall, rainy-season sorghum/cotton/ pigeonpea cropping system located in India's eastern Deccan Plateau (Production System 7); and
- the tropical, low rainfall, primarily rainfed, postrainy-season sorghum/ oilseed cropping system located in

Bantilan, M.C.S., and Parthasarathy, D. 1998. Adoption assessment of short-duration pigeonpea ICPL 87. Pages 136-152 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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the western Deccan Plateau (Production System 8) (ICRISAT 1995).

The region is part of the Vertisol zone of central India. The soil type ranges from medium-black soils in the plains and brown soils in hill slopes, to coarse shallow soils in highlands. The area is classified as a scarcity zone — a drought-prone area, mainly experiencing low to medium rainfall. During Feb-May, the area receives rainfall less than 50 mm monthly, while during Jun-Sep, it receives 50-200 mm monthly. Zones that lie on the eastern and northern borders of the area receive more than 200 mm monthly. During Oct-Jan, the region receives only 0-100 mm monthly, with most of the region receiving less than 50 mm.

The area under pigeonpea in this research domain was estimated at 472 300 ha in 1995, and covers 11 districts in Maharashtra, and the adjacent districts of Bidar and Gulbarga in northern Karnataka. The major rainy-season crops in these districts include pigeonpea, cotton, and hybrid sorghum, in addition to such minor crops as pearl millet, sugarcane, horticulture crops, groundnut, and vegetables. Postrainy-season crops include sorghum, wheat, and chickpea. The region covers much of the postrainy-season sorghum tract of the SAT of India.

The agroecological features of the target area — rainfall pattern, soil type, and cropping system — determine the niche in which short-duration varieties are established. ICPL 87 was expected to be suitable in the drought-prone area of western Maharashtra because it matures early and is more likely to escape terminal drought stress. Medium and shallow soils in this region tend to have low water-retention capacities, so longer-duration varieties would not be suitable.

The survey covered a representative selection of villages and blocks in eight pigeonpea growing districts of western Maharashtra and northern Karnataka, and included 35 villages from which 277 farmers were randomly selected. The selection of the study site was primarily based on background data obtained from a reconnaissance survey of the pigeonpea growing tracts in Production Systems 7 and 8. Initial field observations and interviews with regional research and extension staff gave indications that the adoption of ICPL 87 occurred in the regions around western Maharashtra. Data on sales of pigeonpea seed by the public and private sectors confirmed that adoption was widespread in this region.

Benefits from short-duration pigeonpea research ultimately reach beneficiaries only when the improved variety is adopted by farmers. This condition necessitates considering the rate of technology adoption and factors influencing or constraining it (Bantilan and Johansen 1995).

Results and discussion

Initial extension target

ICPL 87 is of early maturity (120-130) days), determinate, short, and semi spreading. It was developed through pedigree selection from the cross ICPL 73032 (T 21 x JA 277) made in 1973 soon after ICRISAT was established. In 1980, it was included in the All India Coordinated Pulses Improvement Project for 5 years. The variety was initially targeted for release in northern India for cultivation in rotation with wheat, but about 1983, it was tested for possible release in peninsular India.

ICPL 87 was first introduced in the Vidharbha and Marathwada regions in eastern Maharashtra during the mid 1980s, regions that constitute one of the main pigeonpea growing areas in India. These areas were targeted by the LEGOFTEN (Legumes On-Farm Testing and Nursery) technology transfer program — a part of the Government of India's technology mission on pulses implemented in collaboration with ICRISAT. Early adoption studies (Kelley et al. 1990) and subsequent reconnaissance surveys revealed that farmers in eastern Maharashtra did not find ICPL 87 suitable for their cropping system.

The spread of information about SDP to the western part of the state is attributed to further efforts by local research and extension networks beginning about 1990. Institutional factors played a key role in enabling the adoption of ICPL 87. Scientists from Mahatma Phule Agriculture University, whose jurisdiction included western Maharashtra, first recommended the variety as suitable for the multiple-cropping systems in the irrigated tracts of the region, particularly in niches where sugarcane is grown on a large scale. The extension network of the Department of Agriculture in western Maharashtra played a key role in extending information on ICPL 87. Extension workers emphasized that:

- growing ICPL 87 in sequence with wheat and chickpea can improve soil fertility in areas where sugarcane is grown, and
- ICPL 87 can escape terminal drought, often a major constraint for longer-duration varieties.

In collaboration with LEGOFTEN, they introduced ICPL 87 in their on-farm trials and demonstrations, and catalyzed production and multiplication of breeder and foundation seed on a large scale. At about the same time, a government extension program called the National Pulses Development Program (NPDP), was activated to provide funds for subsidies, on-farm (minikit) trials and demonstrations, and extension support with a specific focus on selected varieties, including ICPL 87. Extension was reported to be very active in this region compared to other regions of the state.

Farmer organizations facilitated group decisions about options based on traditional practices and improved technology packages as individual farmers learned and implemented appropriate practices for sustainable farming. Cooperative organizations — especially sugarcane cooperatives — also played a catalytic role in the early diffusion of ICPL 87 by producing seed (in collaboration with the Maharashtra State Seeds Corporation) during the initial period. They made farmers aware of its sustainability in sugarcane-based cropping systems, and its fertility-enhancing benefits to their intensively cultivated fields.

Adoption and diffusion

ICPL 87 was adopted on a large scale, especially in the northern districts of Dhule (98%), Ahmednagar (89%), and Jalgaon (49%) (Fig. 1). Farmers in these three districts are classified as early adopters — they sowed short-duration pigeonpea soon after its introduction in the region in 1987. They cited its short-duration, high yield, ability to improve soil fertility, and high market price as reasons for adoption. Farmers in some villages indicated that pigeonpea is grown mainly to improve soil fertility. Moreover, the relatively short growing period of ICPL 87 fits exactly into farmers' desired cropping patterns allowing them to adopt the variety to sustain and improve the long-term productivity of their soils.

Secondary district-level statistics indicate that the area under pigeonpea in Ahmednagar has doubled from 11 387 ha in 1985 to 23 309 ha in 1992, and from 22 011 ha to 44 839 ha during the same period in Solapur. While the pigeonpea area has been increasing across the whole of Maharashtra, the western region achieved the highest growth rate. This increase is mainly due to the adoption of ICPL 87 (Figure 2). Farm-level data also confirm that the area under pigeonpea has grown by as much as 51 % in many parts of western Maharashtra, especially in the northern blocks. Pigeonpea areas in the neighboring districts of northern Karnataka remained stable.

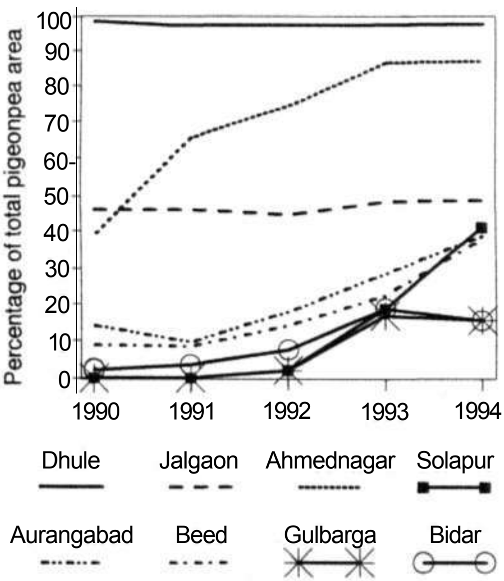

Figure 1. Adoption of ICPL 87 in eight districts of western Maharashtra and northern Karnataka, 1990-94.

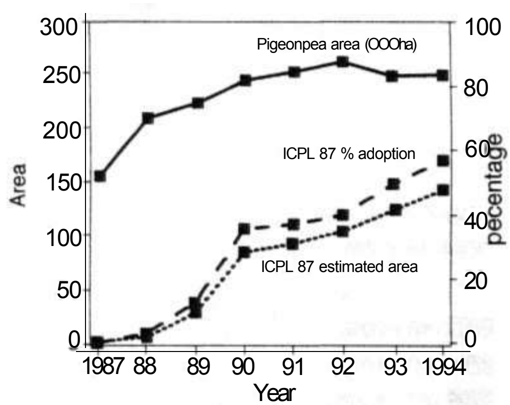

Figure 2. Pigeonpea area, percentage adoption, and estimated area of ICPL 87, western Maharashtra, 1987-1994.

A substantial rise in the adoption level during the period 1988-94 was measured — adoption rates (in terms of percentage of total pigeonpea area) increased in western Maharashtra from 3% in 1988 to 35% in 1990, and to 57% in 1994. In northern Karnataka, the adoption rate rose from 0 to 16% over the 7-year period. In number of farmers, the rate of adoption grew from 2.8% to 71% in western Maharashtra, and from 0 to 25% in northern Karnataka.

Adoption levels varied across districts and blocks (Figs. 3 and 4). Out of 17 blocks covered by the survey, 6 have at least 90% of their pigeonpea area covered with ICPL 87, while 3 blocks registered an adoption rate of 42-65%. ICPL 87 has so dominated the pigeonpea area in this region that farmers in 10 of the 35 study villages reported that "there is practically no other pigeonpea variety grown in their village except ICPL 87". In these 10 villages that are mainly located in Production System 8, the estimated adoption level was 91-100%.

Heterogeneity of soil type, rainfall pattern, and irrigation account for

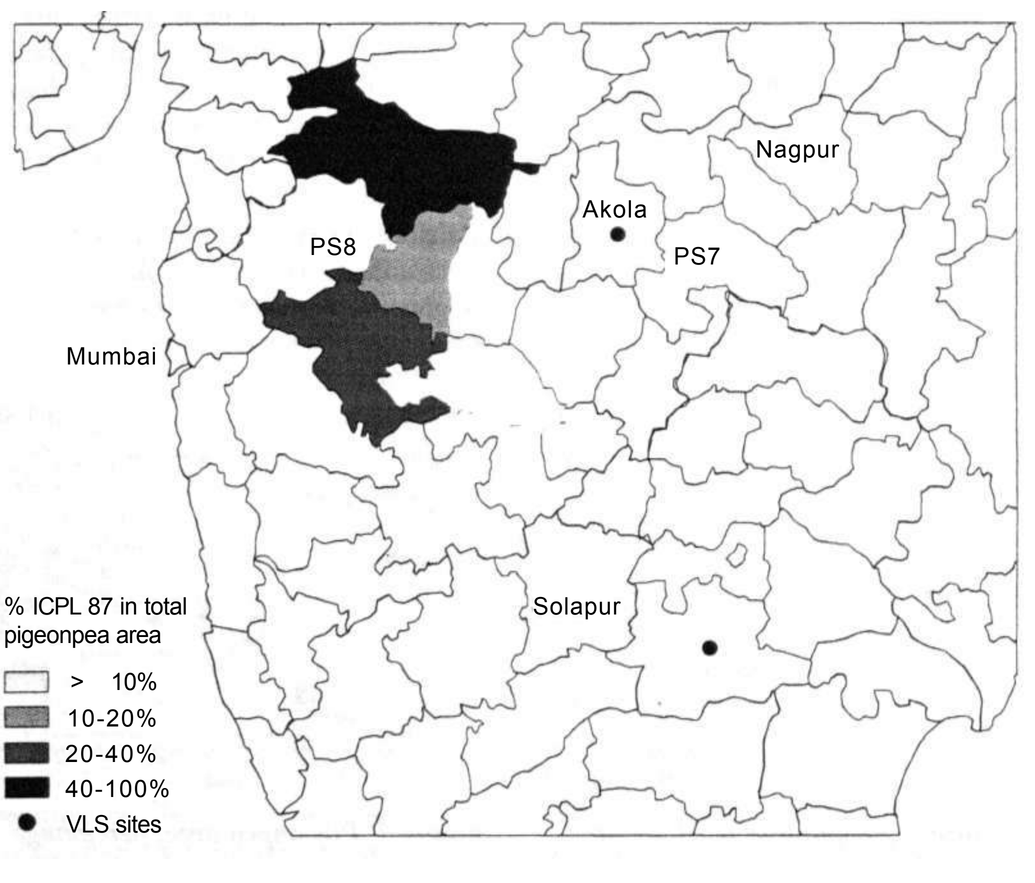

Figure 3. Adoption of ICPL 87, Maharashtra and Karnataka, 1990.

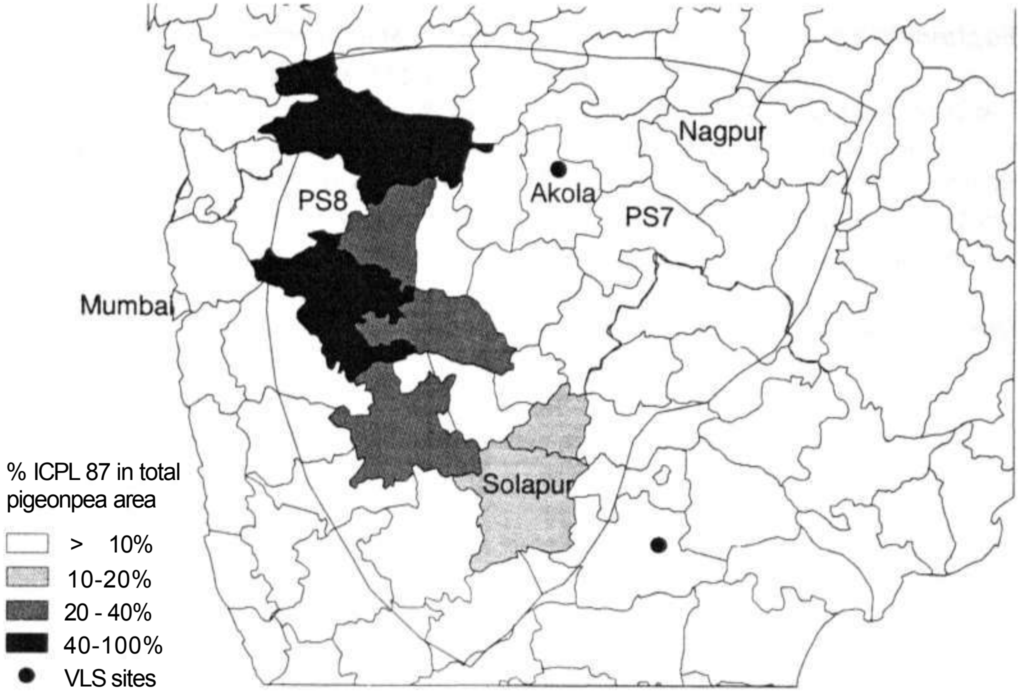

Figure 4. Adoption of ICPL 87, Maharashtra and Karnataka, 1994.

variations in adoption. Furthermore, farmers in different environments manage their farms according to the occurrence of disease. For example, wilt and phytopthora blight occur in the villages located in the Production System 7 sections of Jalgaon district that are characterized by more assured rainfall, and therefore have low adoption levels. Farmers in Bhusaval block in this district find medium-duration cultivars more appropriate in the deep black soils that have waterlogging problems and where phytopthora blight is endemic. Low adoption rates in Aurangabad, Beed, and Solapur districts in the same belt are influenced by serious wilt incidence. Farmers in Akkalkot block of Solapur sought wilt-resistant varieties suitable for intercropping.

The extent of diffusion is also influenced by infrastructure such as access to seed suppliers and markets. The relatively high rates of adoption in the northern districts (Dhule, Ahmednagar, and Jalgaon) are due especially to easy access to the urban markets of Bombay and Pune and southern districts of Gujarat, where there is high demand for pigeonpea grain and green pods. Extension via the National Pulses Development Program also significantly accounts for the variation in adoption.

Sustainabllity

The benefits of growing pigeonpea in rotation with other crops (nitrogen fixation, improved availability of soil phosphorus, and deep rooting), are widely known (Table 1 and Hoshikawa 1991). Studies have shown that pigeonpea root nodules fix atmospheric nitrogen at a rate that reduces the inorganic nitrogen fertilizer required for subsequent crops. Experimental results show substantial residual effects from pigeonpea on succeeding crops

Table 1. Residual effects of growing pigeonpea.

Duration	Rotation	Variety	Residual benefit to following crop (equivalent kg ha^{-1} N)	Yield/biomass/N gain
Medium	Sole pigeonpea-maize		40[1]	57% increase in grain yield; 32% increase in total biomass compared to fallow-maize rotation
	Pigeonpea-sorghum	ICP 1-6	30[2]	
	Pigeonpea+ maize-sugarcane			43% increase in sugarcane yield compared to sole maize; no increase in maize yield; improved soil nitrogen status[3]
	Sole pigeonpea-maize			Substantial nitrogen economy in maize[4]
	Pigeonpea + grain legumes-maize			Substantial nitrogen economy in maize[4]
Short	Pigeonpea-wheat	UPAS 120	Negligible[5]	
	Pigeonpea-wheat	ICPL 151	40[6]	
	Pigeonpea-sorghum	ICPL 87	5[7]	

1. Kumar Rao et al.(1983).
2. Kumar Rao et. ai. unpublished, cited in Kumar Rao (1990).
3.Yadav(1981).
4. Rathnakumar 1983., cited in Ahlawat et al. (1986).
5. Singh and Verma (1985).
6. Johansen, C. unpublished, and ICRISAT (1989).
7. Kumar Rao et al. unpublished, cited in Kumar Rao (1990).

(Kumar Rao 1990). Medium-duration and high-nodulating pigeonpea genotypes provide more benefit to succeeding crops in a rotation than do short-duration types. Field experiments further suggested that while biological nitrogen fixation of short-duration pigeonpea may probably be adequate to meet the nitrogen (N) requirements of the crop grown in Alfisols, Inceptisols, and Entisols, it is not adequate in Vertisols (Kumar Rao et al. 1995).

The substantial residual effects of another short-duration pigeonpea cultivar, ICPL 151, suggest a rapid breakdown and release of N from decomposing short-duration pigeonpea material (Johansen unpublished, quoted in Kumar Rao et al. 1995). The increased beneficial effects of pigeonpea to subsequent crops with higher plant density is also noted (Whiteman and Norton 1981). Since short-duration pigeonpea is usually grown as a sole crop, plant densities are higher than medium- and long-duration varieties.

Ramakrishna et al (1994) summarized on-station trial results showing that pigeonpea provides an equivalent of 30-70 kg ha^{-1} N. Apart from transferring fixed N to the succeeding crop, pigeonpea cultivation also substantially increases the total soil N in pigeonpea-based cropping systems (Wani et al. 1994). Pigeonpea can also be used as a green manure crop (Hoshikawa 1991). Factors other than N also contribute to the beneficial effects of pigeonpea on soil fertility (Arihara et al. 1991), including use of iron bound phosphorus (P). Pigeonpea converts soil P into an available form and thus increases the amount that is available to crops (Ae et al. 1991). After N, P is usually the nutrient most deficient in the soils of the semi-arid tropics (Hoshikawa 1991).

The deep-rooting ability of pigeonpea permits greater extraction of soil water and nutrients deeper in the soil. Deep rooting also increases water infiltration rate for subsequent crops, helps recycle nutrients, and improves soil structure. Pigeonpea also contributes to increased soil microbial activity (Wani et al. 1994) and breaks insect pest and disease cycles (Hoshikawa 1991). Short duration varieties such as ICPL 87 have these properties (Arihara et al. 1991), but have shallower roots than medium-duration varieties (Chauhan 1993).

An important observation that emerged during the survey is that farmers are aware of how ICPL 87 affects sustainability. The formal survey and rapid rural appraisals (RRA) strongly confirm that sustained productivity of the land is an important factor that influenced the decision to adopt ICPL 87 and modify crop rotations. A majority of the farmers from 12 villages where RRAs were conducted were aware of the:

- causes of declining fertility,
- consequences of intensive cultivation, and
- capacity of legume crops to improve soil quality.

In six of the villages, farmers were aware of such soil degradation problems as erosion, waterlogging, and soil salinity.

Based on farmers' responses to the survey, four considerations were involved in the choice of pigeonpea and particularly ICPL 87:

- a short-duration variety provides scope for a second crop in the postrainy season,
- the profitability of ICPL 87 compared to alternative crops,
- the nitrogen fixing ability of pigeonpea, and
- the compatibility of SDP with the desired cropping systems.

ICPL 87 is also frequently mentioned as a boundary crop used to prevent soil erosion. Responses to questions about reasons for adopting ICPL 87 highlight the importance of the sustainability dimension to farmers (Table 2). The four most frequently cited characteristics were:

- short-duration,
- more grain yield,
- improved soil fertility, and
- favorable price.

These four factors were also accorded highest ranks by the majority of the farmers (relative ranks are given in column 4 of Table 2). At least 90% of the respondents cited short-duration and grain yield as desirable traits influencing adoption. Around 49% of the respondents specifically mentioned improved soil fertility as a reason for adoption. Importance is also given to market price (45%).

Table 2. Sample farmers' assessment of desirable traits of ICPL 87,1994.

Trait	Frequency[1]	Percentage	Rank[2]
Short duration	133	93	1.00
More grain yield	128	90	0.96
Improves soil fertility	70	49	0.36
High market price	65	45	0.36
Better taste	19	13	0.09
Disease resistance	18	13	0.10
Less cooking time	15	11	0.06
Insect resistance	5	3	0.03
Color	4	3	0.01
Drought resistance	4	3	0.03
Good fodder quality	2	1	0.01
Larger grain	1	1	0.01
Others	26	18	

1. Multiple responses were provided by a random sample of 143 farmers.
2. Relative importance of traits is weighted by ranks provided by respondents.

The importance of ensuring soil fertility in intensive cropping systems was evident from farmer responses to interview questions. Farmers who intensively cultivated sugarcane, cotton, sunflower, and hybrid sorghum perceived that soil nutrients were being depleted. They observed declining yields despite using more inputs. Management practices to maintain productivity levels were reported. Farmers rotated short-duration pigeonpea with crops such as sugarcane, and in some villages, farmers rotated pigeonpea in all of their plots in turn each year, a practice known locally as *bher phalat.*

A case study undertaken in Manjoor village of Ahmednagar district revealed that farmers saved as much as Rs. 191 ha^{-1} on farmyard manure and Rs.1149 ha^{-1} on fertilizers on average for the

Table 3. Relative costs incurred by sample farmers for farmyard manure and fertilizers for postrainy-season crop in pigeonpea and non-pigeonpea rotations, 1994.

Rotation	Costs for farmyard manure (FYM) and fertilizer for the wheat crop (Rs ha^{-1})[1] FYM	Fertilizer
Pigeonpea + wheat	1 651	1 829
Pigeonpea + wheat	1 778	1 588
Pearl Millet + wheat	2 032	2 667
Hybrid sorghum + wheat	1 778	3 048

1.US$ 1 = Rs 30.9

subsequent wheat crop by adopting pigeonpea-based cropping sytems rather than pearl millet- or sorghum-based cropping systems (Table 3).

The pattern of land ownership among farmers may also explain their degree of concern for the future productivity of their land. Almost all farmers (97%) owned the land they cultivated. Half of those who did not own their land were recorded as non-adopters. Seventy percent of the land sown to ICPL 87 is marginal or inferior (Table 4). To the farmers of this land, it

Table 4. Land quality of pigeonpea plots, western Maharashtra (percentage of area).

Land condition	Pigeon-pea	ICPL 87	Others
Good	33	31	40
Marginal	59	64	48
Inferior	8	5	12

is an important resource and they have a strong incentive to ensure longer-term productivity. Concerns about sustainability are significant where previous farming practices were perceived by farmers to have lowered fertility and increased the cost of inputs to maintain yield levels.

The introduction of ICPL 87 along with the increased availability of irrigation enabled farmers to sow pigeonpea on marginal soils. Pigeonpea was a minor crop in this region until the release of ICPL 87. Initially adopters mostly replaced other varieties of pigeonpea (85%), and the balance replaced other crops or began growing pigeonpea on previously fallow land. Once the initial adoption took place, however, farmers increased the area under pigeonpea mainly by replacing other crops such as sorghum or millet (21 %) or by bringing fallow land under cultivation (65%). Analysis of data from 1990-94 showed that growth of pigeonpea area is mainly due to increased adoption. The area under medium-duration varieties has either remained the same or increased slightly. Thus the initial shift was from medium-duration pigeonpea to short-duration pigeonpea, but with increased awareness about the role of short-duration pigeonpea in long-term sustainability, farmers shifted from other crops (mainly short duration) to SDP.

Sustainability—farmer perceptions vs. research

Research indicates that compared to medium and long-duration pigeonpea, ICPL 87 fixes less nitrogen, especially on Vertisols. It appears that farmers perceive more benefits from growing ICPL 87, or are overestimating its residual value. It is probable that farmers may be benefiting to a much greater extent from short-duration pigeonpea despite its lower nitrogen fixing ability.

Studies indicate that both yields of stalk and fallen leaves and the weight of stems and leaves are higher as plant populations increased above 40 000 plants ha^{-1} the commonly recommended density for medium-duration cultivars (Rao et al. 1981, Chauhan et al. 1984). As a sole crop, ICPL 87 is sown at higher densities. Other factors that can contribute to increased sustainability despite the higher cropping intensity and input use by the introduction of short-duration pigeonpea include:

- rotation of all crops, including those intensively cultivated in different plots every year so that natural resources are not used unevenly;
- adoption of other legumes, particularly chickpea and groundnut, as well as minor pulses that also enhance soil fertility; and
- much higher use of farmyard manure by adopters of ICPL 87.

Scientists are concerned, however, that adoption of ICPL 87 could lead to higher pesticide applications. The high adoption rate in some areas could make ICPL 87 vulnerable to pest attacks, and thus more intensive use of pesticides may detract from attempts to maintain soil fertility. The evidence suggests that the contribution of ICPL 87 to soil-N reserves may be problematic. It would be useful to confirm this view by measuring actual residual effects of ICPL 87 in the study region.

Economic benefits

While the choice of ICPL 87 has been motivated by a need to sustain productivity over the long term and the ability of the cultivar to fit desired cropping systems, profitability from higher market prices and higher yields played a significant role in adoption.

Integration of ICPL 87 into double cropping systems was possible because its early maturity enabled farmers to grow postrainy-season crops such as sorghum, chickpea, and wheat, which are staple foods in this region. Of the adopters, 46% sowed a postrainy-season crop in the pigeonpea plots, compared to only 9% for the non-adopters. Fanners assigned a top rank to the early maturity of the variety, a clear indication of its suitability to fit into the cropping system.

When compared to the previous best available variety, the medium-duration BDN 2, net farm income was 30% higher for ICPL 87 (Figure 5), grain yield advantage was 93%, and unit cost reduction was about 12%. Despite increased costs for irrigation and fertilizer/farmyard manure, ICPL 87 has increased profits at the farm household level. Increased net income has been crucial for adoption of short-duration pigeonpea.

Farmers seem to have bestowed more care on the intensive cultivation

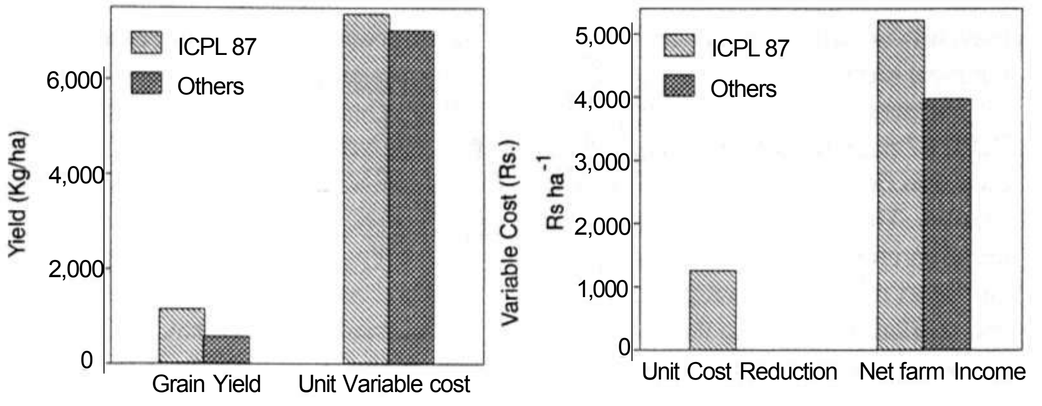

Figure 5. Comparative impact of ICPL 87 in Maharashtra.

of ICPL 87 as a sole crop with the emergence of pigeonpea as a cash crop, especially on small farms. Labor use actually increased with adoption. In general, men specialize in land preparation and interculture, while female labor is more specialized in weeding, threshing, and harvesting operations. When compared to BDN 2, more male labor was used for almost all operations. The female labor requirement was relatively higher for all operations except pesticide spraying and threshing. Adopters also incurred comparatively high costs for irrigation, fertilizer, and farmyard manure. Thus the higher net benefits to farmers are due to ICRISAT's breeding efforts, and to adaptive research on resource management by ICRISAT and NARS.

During RRAs, farmers in most villages expressed a preference for crops that have a duration of less than 4 months for several reasons:

- increasing fragmentation of land holdings makes farmers want to increase productivity and produce more crops;
- farmers want to maintain crop diversity to avert risk and to avoid intensively cultivating the same crop continuously; and
- crop diversification with slightly different maturities enables farmers to avoid labor shortages during peak harvesting periods. By maturing a few weeks after other short-duration crops, ICPL 87 escapes the period of peak labor demand when labor is both scarce and expensive.

The major change in the cropping system in the region over the last 10 years has been the decline in area of crops that have become less profitable and which farmers perceive to deplete soil fertility. Such crops include sugarcane, cotton, sunflower, and hybrid sorghum. Crops that have increased due to their perceived profitability, duration, and/or beneficial effects to the soil, include pigeonpea, soybean, wheat, and to some extent, chickpea. The growing importance of postrainy-season crops (including wheat, chickpea, and vegetables) both for sale and consumption is a major reason why farmers prefer short-duration crops.

Farmers had few options other than ICPL 87 pigeonpea to use as a rotation crop that fits the short window between seasons. They used to grow other short-duration crops such as hybrid sorghum and pearl millet in the rainy season, but low market prices make them less profitable. Farmers who continue to cultivate these crops do so for home consumption. As the price of pigeonpea has increased in recent years, profitability became a key factor in replacing sorghum or millet with pigeonpea ICPL 87. The importance of price both for adoption of ICPL 87 and the increase in pigeonpea area is reflected in the price range of pigeonpea (Rs. 9-13 kg^{-1} during 1995) compared to millet and sorghum (Rs. 3-5 kg^{-1})- Table 5 shows the higher net benefits obtained by pigeonpea-based crop rotations compared to pearl millet- and sorghum-based rotations.

Analysis of the cropping pattern by the landholding class (Figure 6) shows that pigeonpea has the largest share in the gross cropped area among small and medium farms. Small-scale farmers, who constituted 22% of the sample and who owned less than 2 ha, adopted ICPL 87 on a large scale (70%). This group traditionally grows more subsistence crops such as sorghum, pearl millet, wheat, and chickpea. With the availability of ICPL 87, these farmers gained substantially — pigeonpea is their major cash crop because they receive greater benefits from using comparatively fewer inputs on marginal lands. Pigeonpea has the largest share of their gross cropped area. The higher net income that they obtain from pigeonpea is of greater significance to these small-scale farmers, especially compared to other crops such as sorghum or millet. These farmers generally grow pigeonpea on marginal soils where few other crops can grow. Many of them do not have access to irrigation. Any significant positive impact of pigeonpea research therefore is likely to benefit the small-scale farmers more. Large-scale farmers who are looking beyond short-term profitability also perceive that ICPL 87 helps maintain long-term productivity of their soils.

Table 5. Net benefits from different crop rotations in western Maharashtra, 1994.

Crops	Benefits (Rs ha^{-1})[1]
Pigeonpea + wheat	7010
Pigeonpea + wheat	6312
Pigeonpea + onion	26 162
Pigeonpea + postrainy-season sorghum	4 267
Soybean + wheat	9 728
Pearl millet + wheat	686
Hybrid sorghum + wheat	2 540

1.USS 1 = Rs 30.9

Conclusion

This study established an important connection between farmer concerns for sustainability and adoption of improved technologies. Results from a formal on-farm survey and rapid rural appraisals conducted in a drought-prone

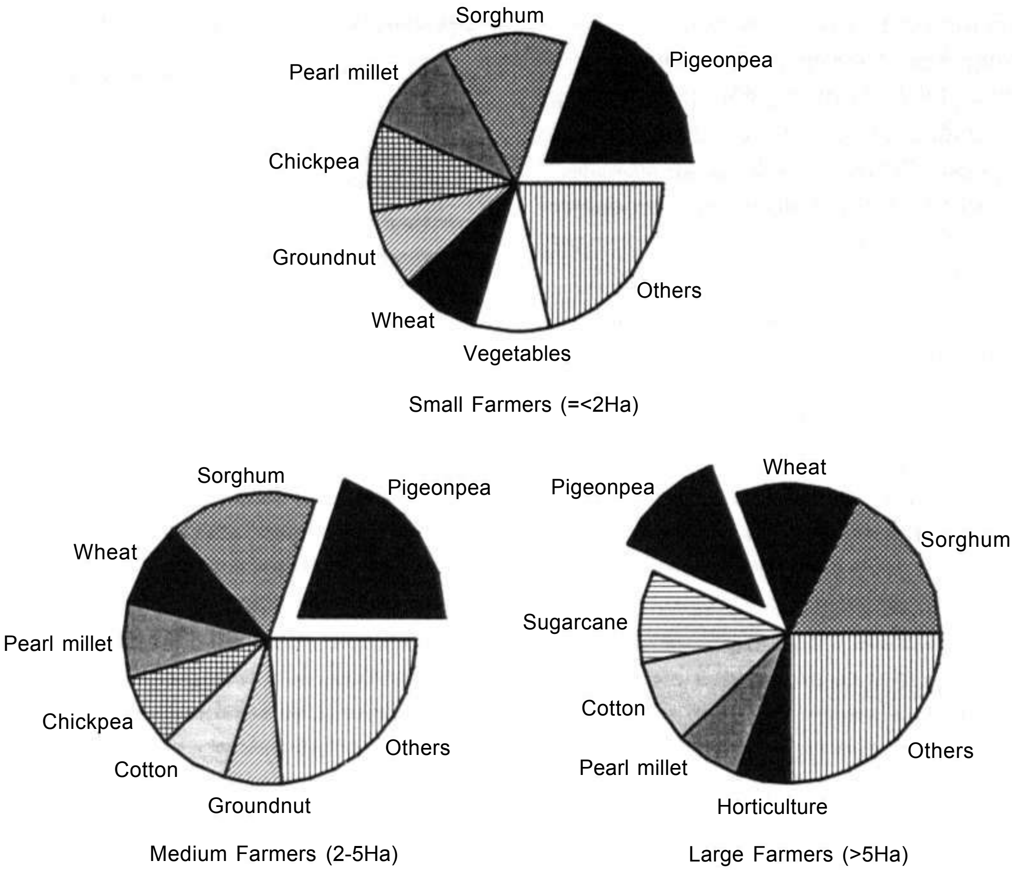

Figure 6. Cropping patterns of small-, medium-, and large-scale farmers, Maharashtra, 1994.

area in central India, confirmed that:

- farmers are well aware that intensive cultivation of cash crops such as sugarcane or cotton on irrigated tracts can reduce yields despite increasing use of inputs;
- appropriate crop/varietal adoption and management practices are consciously followed to maintain long-term productivity for existing and desired cropping systems; and
- farmers strive to increase or maintain soil fertility by including nitrogen-fixing legumes in crop rotations, in this case short-duration pigeonpea.

Widespread adoption of short-duration pigeonpea brought profitable farming in the short term — via cultivation of a second crop in the postrainy season — and farmers expect sustained productivity in the long run via crop rotation to maintain soil fertility.

Feedback from farmers obtained from on-farm surveys revealed a strong relationship between technology adoption and their concerns about sustainable farming. Within the context of maintaining a desired cropping system, farmers aim to make short-term profits and ensure long-term productivity. The survey confirmed that farmers are forward-looking — they plan for the longer-term productivity of their land and have consciously adopted ICPL 87 to achieve that goal.

Adoption of ICPL 87 cultivar was essentially the introduction of a new crop into regions with a traditionally small pigeonpea area. Pigeonpea area increased by as much as 51 % among the sample farmers between 1990-94. Secondary data indicate that the growth rate of pigeonpea area in western Maharashtra is higher than in other pigeonpea growing districts of Maharashtra. Farmers considered ICPL 87 to be a profitable option to improve soil fertility by rotating it with a major cash crop in different plots each year.

Changes in the cropping system in the study area were a result of the introduction of short-duration pigeonpea. Integration of ICPL 87 into the consequent double cropping is the most important change in the cropping system in the last 10 years. ICPL 87 found its way to fallow lands and in rotation with other crops, and has established a niche in central India's western and eastern Deccan plateau.

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Joint Impact of
Resource Management Research: Case Studies

Measuring Returns to Investment in Groundnut Production Technology

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Earlier studies on measuring returns to agricultural research and technology transfer for a wide range of commodities and countries have shown high social payoffs, suggesting that more investments would be beneficial (Akino and Hayami 1975, Lindner and Jarrett 1978, Ruttan 1982). Most of the studies were confined to quantification of research benefits at the aggregate level, with a focus on improved varieties. There is scant assessment of returns to research investments related to crop and resource management, including crop husbandry, soil-water-nutrient management, and plant protection, even though these areas receive a significant proportion of the research resources. At ICRISAT, for example, about 30% of research expenditures were associated with the Resource Management Program in 1991 and 1992 (ICRISAT 1993). Traxler and Byerlee (1992) reported that crop management research accounted for about one-half of all investment in crop research. They attempted to evaluate returns to investments in research on crop and resource management, and reported positive returns (16-23% internal rates of return).

Investment in resource management continues to grow, with expectations to increase agricultural production, alleviate physical constraints, use inputs more efficiently, and improve the sustainability of natural resources. To justify future financial support for crop and resource management research, it is imperative to continuously monitor and evaluate impact. This study attempts to estimate research costs and quantify benefits from investments in crop and resource management research and technology transfer.

The study evaluated groundnut production technology (GPT) — a joint research product of the International Crops Research Institute for the Semi-

Joshi, P.K., and Bantilan, M.C.S. 1998. Measuring returns to investment in groundnut production technology. Pages 155-163 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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And Tropics (ICRISAT) and the Indian national agricultural research system (NARS) on genetic enhancement, crop and resource management, and technology transfer.

History of the technology

The technology was intended to enhance the production of groundnut, an important oilseed crop in India that contributes more than 55% to overall national oilseed production. In 1986, the Government of India introduced a massive program, the Oilseed Technology Mission, by allocating more resources to research and technology transfer activities, and offering attractive prices to oilseed producers. Among other measures, ICRISAT was an active partner with the Ministry of Agriculture and NARS in identifying appropriate technology options to increase groundnut production, demonstrating them during 1987-91. The program was successful — the area under groundnut expanded from 6.8 million ha in 1987/88 to 8.7 million ha in 1991/92, and production increased from 5.9 million t in 1987/88 to 7.1 million t in 1991/92. Production of other oilseeds also substantially increased during the late 1980s.

After reviewing the available research information and identifying constraints to groundnut production in major producing regions in India, a technology package was developed at ICRISAT - Patancheru (Table 1).

Table 1. Important components of groundnut production technology package and local practices.

Component	Improved package	Local practice
Land (seedbed) management	Raised-bed and furrow	Flat
Nutrient management (ha^{-1})		
Farmyard manure	5-12 t	10t
Ammonium sulphate	100 kg	DAP: 100 kg
Single super phosphate	300-400 kg	MOP: 100 kg
Zinc sulphate	10-20 kg every 3 years	20 kg
Ferrous sulphate	2-3 g kg^{-1}	
Gypsum	400 kg	200 kg
Seed		
Variety	ICRISAT varieties	Local varieties
Seeding rate	125-150 kg ha^{-1}	120-125 kg ha^{-1}
Seed treatment	Thiram, Bavistin®, or Dithane M45®	Thiram
Pest management	Bavistin®, dimethoate, monocrotophos	Need based
Water management	Furrow or sprinkler	Flood
Seed drying	60-70% pod maturity	With maturity

Since a specific technological package performs better in one type of environment and poorly in another, after characterizing soil, climate, nutrients, water, insect pests, and diseases, a unique set of technologies was suggested for each location. Several on-farm trials and demonstrations were conducted in eight states — Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, and Uttar Pradesh.

Sampling and data source

A key issue in assessing technology adoption packages was the definition of adopters, primarily because several components of the package were already known and adopted even before the package was introduced. Another issue was that farmers were free to choose and adopt any subset of the technology package. In this particular case, raised-beds and furrows was identified as a key component of the technology.

After consulting relevant officials in each state, it was noted that the raised-beds and furrows component of the GPT was eliminated from the recommendations by all the state departments of agriculture except Maharashtra. Because raised-beds and furrows was a key component of the evaluation, Maharashtra was selected for the study.

Maharashtra is located in western and central India, with about 800 000 ha allocated to groundnut. The state has enormous potential to increase groundnut yield of 736 kg ha^{-1} which is currently well below the national average.

Using a multistage sampling procedure, 355 farm households were selected. Farmers were personally interviewed in 1994/95, and data was collected on:

- adoption during the first year of different components of GPT;
- extent of adoption of different components of GPT in the first year;
- extent of adoption during 1991-94;
- modification of technology components, if any;
- labor and input costs of production; and
- yield and prices of main product and by-product.

Information was also compiled from the Training and Visit section of the Department of Agriculture, the office of the agricultural development officer, and several traders dealing with components of GPT.

Analysis

The main objective of investing in research and technology transfer is to generate an economic surplus. Required information includes:

- adoption rate and spread of the technology,
- research and technology transfer costs, and
- benefits accrued from the research and technology transfer program.

Estimating adoption of GPT

The crop and resource management technologies were recommended as a package that included several components, for example, management of soil, nutrients and water; improved agronomic practices; and use of high-yielding varieties, among others. The package could usually be disaggregated into subsets and adopted independently. Under such circumstances, several distinct technological options were available to farmers — they were free to adopt either a complete package or a subset of a package. Farmers could partially adopt subsets of packages or adopt a modified form of the recommendations.

All components were included to assess their adoption pattern. Each sample farmer was asked whether he practiced the raised-bed and furrow method and other components of the GPT. If he had, then the farmer was asked to recall the year when he first adopted different components, including how much area was allocated to each component, and how much of each component was applied. The same questions were repeated for 1992, 1993, and 1994. Using this information, the adoption path for each component of the GPT was developed and a series of equations were used to estimate research costs and benefits from adopting research recommendations.

Results

Adoption of GPT

Adoption of different components of GPT varied among households (Table 2). About 31% of the postrainy-season groundnut in the study area was cultivated with the raised-bed and furrow method. Adoption of improved varieties (about 84%) and single super phosphate (about 70%) were quite high. It was interesting to note that the sample farmers who cultivated groundnut using raised-beds and furrows adopted ICRISAT varieties for about 65% of their groundnut area. Those who did not use raised-beds and furrows sowed ICRISAT varieties on less than 10% of their groundnut area. Gypsum and seed treatment were becoming popular and their adoption reached slightly above 40%. Use of ferrous sulphate and sprinkler irrigation were at a very early stage of adoption.

Table 2. Adoption of different technology components in selected districts of Maharashtra (percentage of total groundnut area).

Component	1989	1990	1991	1992	1993	1994	Ceiling (%)
Raised-bed and furrow	4	10	14	26	27	31	40
Improved varieties	6	24	23	80	82	84	90
Single super phosphate	10	22	34	62.	65	69	75
Zinc sulphate	4	5	6	8	12	14	20
Ferrous sulphate	2	2	3	3	5	6	10
Gypsum	4	10	17	35	42	42	45
Seed treatment	6	15	19	37	41	46	60
Drying	2	2	2	4	8	9	10
Sprinkler irrigation	0	0.2	0.2	3	3	4	15

The adoption of different components was largely associated with raised-beds and furrows. All those who adopted the raised-bed and furrow method for groundnut cultivation also adopted other components of the GPT. Improved varieties, single super phosphate, seed treatment, and drying were independently released and adopted by groundnut producers prior to the packaging and disseminating GPT, but the rate of adoption of these components was faster when integrated as a package with raised-beds and furrows.

Research and technology transfer costs

Research to design the raised-bed and furrow system began in 1974 at ICRISAT and continued until 1986. NARS were also involved in technology packaging and conducting on-station and on-farm trials. Since actual research and technology transfer costs were not recorded and easily available, they were estimated at three levels — ICRISAT, NARS, and the technology transfer system (the State Department of Agriculture).

The research and technology transfer activities related to GPT at ICRISAT were focused in four programs — Groundnut Improvement, Farming Systems, Resource Management, and LEGOFTEN. While the first three programs were largely credited with developing the technology, the last dealt with packaging crop and resource management practices, on-farm testing, and large-scale demonstrations on farmers' fields.

Salaries of research teams, operational expenses, and overhead costs were estimated after consulting scientists and examining historical evidence (Table 3). After weighting the salary of each member of the research team by time devoted to specific research activities, the annual salary component was estimated at $34 900 (all figures are U.S. dollars). Based on experience, operational expenses to conduct research were assumed to be 35% of the salary component, or $12 215. The overhead cost was assumed to be half of the total cost, or $47 115. Aggregating these three components, the total annual cost of developing the technology at ICRISAT was $94 230. This figure was allocated to groundnut, pigeonpea, and chickpea based on the crop area, thus the annual cost for research on GPT was $45 600. The annual cost for NARS participation in packaging the technology was estimated at 10% of the ICRISAT cost.

Table 3. Annual research and technology transfer costs for groundnut production technology.

Component	Year	Cost (US$)
Research		
Salary	1974 -1986	34 900
Operations	1974 -1986	12 215
Overhead	1974 -1986	47 115
NARS	1974-1991	9 500
Technology transfer		
Packaging/on-farm trials	1987	24 000
On-farm trials	1988-1990	20 000
On-farm trials	1991	10 000
State expenses	1992-2000	7 500

The technology packaging and its transfer started in 1987 through LEGOFTEN. The initial budget for this program was met (1987 and 1988) through ICRISAT core funds, and later (1989-91) through a grant from the International Fund for Agricultural Development (IFAD). The program was responsible for groundnut, pigeonpea, and chickpea. In the first year when different components of technology were integrated, the cost of GPT ($24 000) was computed on the basis of proportionate area under groundnut. In subsequent years, the total budget allocated to LEGOFTEN was distributed according to the number of on-farm trials conducted on groundnut. The budget of the State Department of Agriculture for extension activities for GPT during 1987-91 was also met through the LEGOFTEN program.

The expenses incurred in technology transfer through the State Department of Agriculture after the LEGOFTEN period were calculated using the share of groundnut in total cropped area in the state. On the basis of the salary, operations, and overhead, the annual technology transfer cost during the post-LEGOFTEN period was calculated at $7 500.

Research and technology transfer benefits

The shift in supply function as a result of GPT was assumed to be the saving in unit cost of groundnut production. The cost reduction was about 37% if the full package (improved varieties and management practices) was adopted, and 22% if only management practices (traditional varieties and improved management practices) were followed (Table 4). There was about a 100% yield gain if the total GPT package was adopted, and about 36% if only management practices were adopted.

Table 4. Cost of production and yield of groundnut in on-farm trials using different technology options.

Technology components				
Management	Variety	Yield (t ha^{-1})	Cost (Rs ha^{-1})	Cost (Rs t^{-1})
Improved	Improved	3.5	6 990	2 003
Improved	Local	2	5 990	3 041
Local	Improved	2.6	6 570	2 566
Local	Local	1.7	5 570	3 201

Source: Adapted form Pawar et al. (1993).

Returns to research on GPT and its transfer were determined by comparing the estimates of welfare gains to the costs of research and technology transfer. The economic surplus approach was adopted to quantify the gains due to the technology, assuming a perfect market economy and a parallel shift in supply function. The trajectory of raised-bed and furrow was used to represent the adoption of the GPT package. It was the adopters of raised-bed and furrow, who adopted a nearly complete GPT package. The net present value, internal rate of return, and benefit-cost ratio were estimated assuming:

- an adoption ceiling level of GPT at 40%,
- a demand elasticity of groundnut at -0.5%, and
- a supply elasticity of 0.1 % (Radhakrishna and Ravi 1990).

The economic surplus was computed under three options:

- full adoption of GPT,
- adoption of only management practices, and
- adoption of only raised-bed and furrow, maintaining other practices.

The internal rate of return of GPT was 25% if the total package was adopted (Table 5). The net present value of the research and technology transfer program on GPT was estimated to be $3.45 million. The benefit-cost ratio was 9.37, which means that $1 invested in developing and disseminating GPT produced an average benefit of $9.37 throughout the period.

When only management practices (excluding improved varieties) were adopted, the internal rate of return was 19%. The net present value was about $1.4 million with a benefit-cost ratio of 4.39. The rate of return was low (13.5%) if only raised-beds and furrows were compared with the flat method of cultivation, an indication of the high complementarity between different management practices, especially raised-beds and furrows. These results confirm farmers' perceptions that raised-beds and furrows yield higher returns if adopted along with other technology components, including improved varieties. The internal rate of return for partial adoption was 21 %. Even if the components of GPT were only partially adopted, the research and technology transfer investments were justified. Similar results were obtained by Traxler and Byerlee (1992), who estimated an internal rate of return for crop and resource management research on wheat ranging from 16-23% under a variety of assumptions.

Because all costs were estimates, a sensitivity analysis that increased the estimates by 10% and 20% showed that the internal rate of return is rather insensitive. When the cost of research and technology transfer increased by 20%, the rate of return dropped by about 6% when the full package of GPT was adopted. When only management practices were adopted, an increase of 20% in costs lowered the internal rate of return by about 7%. There was no significant decline in the rate of return when NARS research costs increased by 20%. Additional investments in technology transfer would provide further gains.

The distribution of social welfare between farmers and consumers showed that producers were the primary beneficiaries of GPT because of a shift in the supply function. Their share of total benefits was about 84%. This calls for bringing more area under the improved technology.

Summary

GPT was partially adopted by farmers in the study area. One key component, the raised-bed and furrow method of

Table 5. Costs and benefits related to technology transfer of groundnut technology package or portions of the package ('000 US$).

			Benefits		
Year	ICRISAT costs	NARS costs	Full package	Management only	Raised-beds and furrows only
1974	45.6	4.56			
1975	45.6	4.56			
1976	45.6	4.56			
1977	45.6	4.56			
1978	45.6	4.56			
1979	45.6	4.56			
1980	45.6	4.56			
1981	45.6	4.56			
1982	45.6	4.56			
1983	45.6	4.56			
1984	45.6	4.56			
1985	45.6	4.56			
1986	24.0	4.56			
1987	20.0	4.56			
1988	20.0	4.56			
1989	20.0	4.56	162.57	76.15	36.42
1990	10.0	4.56	460.62	215.75	103.19
1991		7.50	650.29	304.59	145.68
1992		7.50	1 151.56	539.39	257.97
1993		7.50	1 228.33	575.34	275.17
1994		7.50	1 404.45	657.84	314.63
1995		7.50	1 580.57	740.33	354.08
1996		7.50	1 670.89	782.64	374.31
1997		7.50	1 761.21	824.94	394.54
1998		7.50	1 806.37	846.09	404.66
1999		7.50	1 806.37	846.09	404.66
2000		7.50	1 806.37	846.09	404.66
2001			1 806.37	846.09	404.66
2002			1 806.37	846.09	404.66
2003			1 806.37	846.09	404.66
2004			1 806.37	846.09	404.66
2005			1 806.37	846.09	404.66
IRR(%)			25.26	19.15	13.50
Net present value (000' US$)			3 452.94	1 389.06	453.45
Benefit-cost ratio			9.37	4.39	2.10

cultivation, was becoming popular among farmers. Adoption of improved varieties and use of macro- and micronutnents was impressive. Better market access will be necessary to improve the adoption rate of other components, especially sprinkler irrigation and use of ferrous sulphate.

The Government of India has subsidized the purchase of sprinklers, which will encourage farmers to adopt sprinkler irrigation.

Investments in GPT and its extension generated a surplus for consumers and producers. The rate of return ranged between 21 and 35%, certainly an indication that investments in research and technology transfer were worthwhile. There is considerable potential to increase these returns by improving farmer access to inputs.

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Dryland Groundnut Production Technology in Indonesia

T Adisarwanto and M Muchlish Adi[1]

During the last 5 years groundnut production in Indonesia did not meet the growing domestic demand. Although harvested area increased annually by 0.8%, yield declined by 1 % and production showed a downward trend of 0.3%. As a result, groundnut imports increased from 50 t in 1990 to 151 t in 1994 (Munawir 1996, Nur Gaybita 1996).

Groundnut is the second most important grain legume crop in Indonesia, and as an oil seed protein source, it is one of the country's main cash crops. Most groundnut (70%) is a dryland crop, and Tuban is one of the major groundnut areas in East Java province. Although 30 000 ha are annually sown to groundnut, productivity is only 1 t ha"[1]. Groundnut production in Indonesia is characterized by:

- stagnant productivity,
- little adoption of improved technology at the farmer level,
- a center of production concentrated on Java Island, and
- underutilized potential of groundnut production areas in Sumatra, Sulawesi, Bali, and Nusa Tenggara (Erwidodo and Saptana 1996).

Collaborative research over the last 5 years between Indonesia and ICRISAT through the Asian Grain Legumes On-farm Research (AGLOR) project in Tuban district confirmed that technologies are available to improve groundnut production. An improved groundnut production technology (GPT) that produced higher and more stable yields was developed on farmers' fields in the AGLOR project during 1991-95. In the dry season of 1993, for example, GPT was tested on 25 ha with participation by 89 farmers. Yield increased by about 80% over existing farmer practices.

Site description

Environment

Tuban district is located about 100 km north of Surabaya (capital province of

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East Java), and lies between 111°30' and 120°35' E longitude and 6°40' and 7°18 S latitude. It is bounded by the Java Sea in the north, Lamongan district in the east, Lamongan and Bojonegoro districts in the south, and Rembang and Blora districts in the west. The altitude is 5-50 m above sea level, with flat to gently sloping topography. The climate is characterized by an annual rainfall of 1 500 mm (mainly Nov-Apr), and a long dry period in May-Oct.

Soil

The total cultivated area in Tuban is 55 707 ha, of which 36 770 ha is dryland (60%). There are four dominant soil types — red-yellow Mediterranean and Vertisols (38%), alluvial soils (34%), Vertisols (23%), and a complex of red-yellow Mediterranean, Vertisols, and Regosols (5%). Soil fertility of the drylands varies from moderate to poor.

Area, production, and yield

In Tuban, the potential area for groundnut is about 10 000 ha in lowland areas, and 50 000 ha in dryland. During 1985-94, the average harvested area was 25 000 ha, with a productivity 1 t ha^{1} (Table 1). The largest area of groundnut was in 1993 (30 917 ha), but the highest productivity was in 1991 (1.2 t ha"^{1}). Rainfall distribution accounted for variability of area and yield.

Cropping pattern

The cropping season starts with an early rainy season (Nov-Dec) and ends around Aug-Sep. Groundnut is sown during the early rainy season only for seed multiplication, and that seed is used for the main groundnut crop sown

Table 1. Area, production, and yield of groundnut (1985-94) East Java province and Tuban district

	East Java			Tuban		
Year	Area (ha)	Production (0	Yield (t ha^{-1})	Area (ha)	Production (t)	Yield (t ha^{-1})
1985	132 027	135 251	1.0	18 944	18 452	1.0
1986	150 242	138 003	0.9	25 852	27 405	1.1
1987	133 280	120 198	0.9	21 943	22 862	1.0
1988	122 704	113 722	0.9	21 717	21 507	1.0
1989	142 226	142 490	1.0	22 092	22 722	1.0
1990	139 520	147 040	1.1	23 953	24674	1.1
1991	136 615	151 683	1.1	23 627	27 158	1.2
1992	149 075	152 557	1.0	29 759	31 562	1.1
1993	156 080	158 958	1.0	30 917	27 639	0.9
1994	148318	156 975	1.1	30 860	27 477	0.9
Average	141 001	141 688	1.0	24966	25 146	1.0

in Mar-Apr (early dry season) (Table 2). Seed availability for Mar-Apr sowing is still a problem, especially quality seed. Most seed is bought from other farmers whose groundnut crop has been harvested in the rainy season. There is no private-sector investment in groundnut seed production or distribution.

Table 2. Cropping patterns in Tuban district

Village	Dominant cropping pattern
Tunah	maize + groundnut - groundnut - groundnut + maize maize + cassava + groundnut - cassava + maize Upland rice + groundnut - groundnut -maize + maize
Kembang bilo	maize - groundnut + maize - groundnut
Padasan	maize + cassava - groundnut + cassava maize - groundnut + cassava
Karanglo	maize - groundnut + cassava + mungbean maize + cassava - groundnut + cassava + mungbean
Tasikmadu	maize - groundnut groundnut - maize groundnut - groundnut
Talun	maize - groundnut - groundnut + maize
Sumurgung	maize + groundnut - maize + groundnut maize - groundnut - groundnut groundnut - groundnut - maize groundnut - maize

Land holdings

In East Java, 62% of the farmers hold less than 0.5 ha, and 47% hold 0.1-0.4 ha. In Tuban, farmers generally have more land, particularly those who farm dryland areas (Table 3).

Table 3. Average land holdings (ha) of farmers in Tuban district

Land type	Adopter	Non-adopter
Wetland	0.5	0.6
Dryland	1.0	1.1
Total	1.5	1.7

Farmer income

Studies by Muchlish and Adisarwanto (1994) reported that groundnut contributes 65% of farmer income in dryland areas of Tuban.

Farmer characteristics In Tuban

Farm size is generally 0.2-0.5 ha, and most farmers follow 'Tabasan,' a practice whereby the crop is usually sold while still standing in the field. Village cooperatives are limited and farmer group organizations do not work.

Most farmers in the Tuban areas follow traditional methods of cultivation, which include:

- shallow tillage (15-20 cm depth) by bullock- or buffalo-drawn plows;
- sowing on flat beds (no raised beds);
- seed is dropped behind the plow with irregular plant spacing (400 000-500 000 plants ha^{-1});

- farmyard manure is used for the first crop (rainy season), and few farmers use urea;
- a local variety is normally cultivated; and
- weeding is done only once before the crop flowers.

History of the technology

The development of GPT in Tuban aims to enhance groundnut production to meet growing demand and reduce imports. Although the Indonesian government does not have a national program to increase groundnut production, East Java Province (Karyono 1994) has a seven-point program to improve yield:

- enhance use of improved seed varieties,
- improve the seed production agency,
- increase fertilizer use,
- move from tobacco to groundnut cultivation,
- improve soil tillage for seedbed preparation,
- rehabilitate irrigation systems, and
- improve the economic status of farmers.

The Research Institute for Legumes and Tuber Crops (RILET) has conducted research on components of groundnut production technology in the Tuban area since 1981. The GPT package was developed following collaborative research with the Australian Centre for International Agricultural Research (ACIAR), Peanut Improvement Project (1985-89), and ICRISAT's Cereals and Legumes Asia Network (CLAN) and AGLOR in 1990. Development of GPT involved reviews of relevant research information available at ICRISAT, RILET, and other research institutes to address constraints to groundnut production identified by farmers in the Tuban area. On-farm trials were conducted in six villages in Tuban districts to evaluate GPT in 1990/92. Because GPT performed better on farmers' fields in small plots, testing on large areas was suggested. In the 1993 dry season, GPT was evaluated on 25 ha with participation by 89 farmers. The test included these components:

- local Tuban variety (2 seeds per pod);
- seeding rate of 80 kg ha^{-1} with over 90% germination;
- deep plowing followed by harrowing;
- 50 kg ha^{-1} urea, 75 kg ha^{-1} triple superphosphate (TSP), and 50 kg ha^{-1} potassium chloride (KC1) broadcast evenly prior to last plowing/harrowing;
- seed sown in plow rows (spaced at 40 cm) with 10 cm between seeds;
- weeded twice (2 and 4 weeks after sowing);
- Furadan® insecticide applied at 10 kg ha^{-1} prior to sowing to control termites; and
- Topsin-M fungicide applied twice at 49 and 63 days after sowing to control leaf diseases (rust and late leaf spot).

Methodology to assess adoption

Sampling

The technology was targeted at six villages in Tuban district In each village, cooperating and non-cooperating farmers were identified. At the first sampling stage, all villages were stratified into those with on-farm trials and neighboring villages with non-cooperators.

Data

Relevant information was collected from 105 farmers who either did or did not adopt the technology. Any farmer who adopted one or more technology components was defined as an adopter. Farmers were interviewed during early April and mid-July 1996. Primary data collected for the 1996 crop season included:

- size of land holding;
- cropping pattern;
- technology adoption, including adoption area and components;
- yield and income; and
- constraints to adoption of GPT.

Results and discussion

Adoption of GPT

The survey data were analyzed to estimate adoption patterns of GPT components.

Land preparation. Farmers did not follow the recommended practice of deep plowing because in some locations fields are stony and the soil profile is less than 20 cm deep.

Improved varieties. Almost no improved varieties were adopted because the size and seed color were not preferred in the market. A 1990 trial of variety preference showed that three improved varieties (Macan, Pelanduk, and Kelinci) achieved quite high pod yields, but their price was 20-25% less than the local variety. Gajah, which was released in 1950, is still accepted by farmers because the pods have two seeds that are bright red. Two big private companies have influenced the groundnut market in Tuban — they seek premium quality for export with two seeds per pod.

Seeding rate. The recommendation of an 80 kg ha^{-1} seeding rate is based on good quality seed (> 90% germination). Farmers who adopted the technology used the recommended rate, but others used a higher rate (Table 4). Non-adopting farmers used a higher seeding rate because they broadcast the seed and were not sure of its quality. Most farmers who adopted the technology followed recommended techniques.

Table 4. Adoption of recommended seeding rate (kg ha^{-1}).

Farmers	1994[1]	1995[2]	1996[3]	Average	Percentage above recommendation
Adopters (uniform sowing)	82	78	83	81	101
Non-adopters (seed broadcasting)	100	102	92	98	123

1. Two villages. 2. Three villages. 3. Seven villages.

Nutrient management. Efficient nutrient management was one of the objectives of GPT. Farmers already used manure and some urea before GPT. In both 1995 and 1996, farmers applied more urea than recommended, but TSP was applied at only 71% of the recommended rate (Table 5). None of the farmers applied KC1. During 1995 there were some availability and distribution problems with fertilizer that may have accounted for the low rate for TSP usage.

Table 5. Fertilizer applications (kg ha^{-1}) by adopters of GPT, Tuban district, 1996

Fertilzer	Recommendation	1995[1]	1996
Urea	50	76	73
TSP	75	53	53
KCI	50	0	0

1. Three villages

Managements of pests. Seed treatment with Furadan® for termite protection and Topsin-M fungicide for leaf spot diseases was introduced in 1993 but not adopted by fanners in 1996 because the incidence of insect pests and diseases during the previous 2 years was very low.

Labor and gender

Gender concerns are important in regions where unemployment and underemployment exist. The overall labor requirement was similar for both traditional practices and GPT (Table 6). Groundnut cultivation (irrespective of GPT) used more labor than other crops for sowing and harvesting, and use of female labor was 47% higher than male.

Table 6. Labor allocation for groundnut production, Tuban district, 1996 (percentage of total hours)

Farmer	Women	Men	Animals
Adopter	67	13	20
Non adopter	60	18	22

Constraints to adoption of GPT

Important constraints to adoption of GPT were limited capital (39%), lack of inputs (20%), and expensive inputs (17%). Since women farmers are involved for groundnut production, future attempts to generate and introduce GPT should involve women farmers at the very earliest stages.

Adoption factors

Adoption of agricultural technologies largely depends on:

- information about the technology,
- availability of necessary inputs,
- profitability of the technology, and
- suitability of the technology.

The most important reasons for adopting GPT were increased yield and better crop growth.

Impact Assessment

Yield

Pod yield declined from 1.8 t ha^{-1} in 1993 to 1.4 t ha^{-1} in 1996. Rainfall distribution and long-duration hybrid maize delayed sowing of the subsequent groundnut crop and caused the yield decline in 1996. Rainfall in 1996 was lower during the early stages of crop growth but higher after pod development. Average yield of farmers not adopting the recommended technology was 1.1 t ha^{-1} (Table 7).

Table 7. Dry pod yield (t ha^{-1}) in surveyed villages, Tuban district, 1996.

Village	Adopter	Non-Adopter
Talun	1.6	1.3
Tunah	1.3	1.2
Kembangbilo		1.6
Sumurgung		1.5
Karanglo		0.8
Tasikmadu	1.3	1.3
Padasan		0.8
Average	1.4	1.1
No. of farmers	34	71

Table 8. Cost comparison for adopter and non-adopter farmers, Tuban, 1996 (US$).

Item	Non-Adopter	Adopter
Variable costs		
Seed	69	62
Urea		11
TSP		10
KCl		5
Female labor	59	60
Male labor	27	18
Draft power	47	35
Total	203	202
Fixed costs		
Tax on land	4	4
Output		
Dry pods	500	609
Unit cost	185	152
Unit cost reduction		33 t^{-1}
Net income	294	403
Benefit-cost ratio	1.4	2

Farmer income

Improved groundnut production technology will be adopted by farmers if it increases their income. New technology requires capital to purchase inputs such as fertilizer, however, lack of credit and inputs will limit its adoption. In this study only 34 farmers (32%) applied fertilizers.

Variable costs were the same whether or not the technology was adopted. Farmers who did not adopt the technology needed more labor for weeding, while those who did adopt GPT needed cash to buy fertilizer (Table 8). Rainfall distribution was not good and affected the yield in 1996. There was little difference between dry pod yield (1.1 t ha^{-1} vs 1.4 t ha^{-1}) because fertilizer was probably of little benefit due to low rainfall during early crop growth. Even under these circumstances, the unit cost of production declined by US$ 33 t^{-1} (Table 8).

Although there was a low rate of adoption of GPT, the District Agriculture Extension Office indicated its interest and willingness to increase adoption efforts. A private sector company has shown an interest in developing the technology and working with farmers for its adoption. During interviews, especially in Tunah village, farmers said that the 'Tabasan' system puts them in a good position to bargain for higher prices because a better crop is expected.

Conclusions

Three conclusions were reached as a result of this study:

- The adoption of GPT is significantly influenced by farmers' management decisions, especially profits and their ability to purchase inputs.
- Information on the improved technology is not easily available to farmers, and interactions between scientists, extension agents, the private sector, and farmers needs to be strengthened.
- The extent and pattern of adoption varied between villages due to environmental conditions, land-holding status, and gender roles for household budget decisions.

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Identifying Indicators of Gender-Related Impacts of Improved Agricultural Technologies

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Gender is increasingly recognized as an important socioeconomic variable in shaping and designing improved agricultural technologies. Gender also plays a vital role in tracing welfare gains derived from technology adoption. It has remained unclear, however, how gender-related impacts are identified and what indicators can be used to measure them. This paper draws from a systematic analysis of gender-targeted case studies to explore development of key gender-related indicators. These indicators can provide directions to measure the effects and benefits of improved agricultural technologies and identify situations where gender is likely to be a constraint to technology.

Methodology

On-farm survey results of gender-targeted case studies were used to identify and analyze key indicators of gender-related impacts of improved agricultural technologies. Specific 'with' and 'without' technology situations were studied in the context of a package of a groundnut production technology (GPT) introduced to farmers in the late 1980s. The package was introduced through the Legumes On-farm Technology Evaluation Network (LEGOFTEN) in the state of Maharashtra in western India.

This analysis followed the dynamics that emerged within and among farm households after technology intervention. Selected hypotheses involving gender-related consequences of technology adoption were verified. Based on two village-level studies, evidence is presented to clarify and to raise questions about gender roles, access, and benefits. Implications for future technology development are discussed.

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Case studies

Two surveys specifically targeted for gender analysis were used in this study. They were designed to compare 'with' and 'without' technology situations and analyze changes in intrahousehold relationships as a result of adoption of improved technology options.

The surveys were carried out in prime groundnut-growing areas of Maharashtra where improved GPT was introduced in the late 1980s. Technology introduction was implemented through the International Crops Research Institute for the Semi-Arid Tropics/national agricultural research system (ICRISAT/NARS) collaborative program LEGOFTEN. Under this initiative, technology options advocated for groundnut production included various components covering improved varieties and an improved package of practices. The comprehensive package included technology options and recommendations about:

- land preparation,
- rate for manure and fertilizers,
- seeding rate,
- seed treatment,
- plant spacing,
- weed control,
- insect pest and disease control,
- irrigation, and
- harvesting.

A major recommendation for land preparation was shaping the land after tillage into a raised-bed system. In particular, the raised-bed system was recommended for growing crops with sprinkler irrigation. Improved varieties were recommended under the program, including cultivars developed at ICRISAT that were either released or likely to be identified for release for cultivation in India. Detailed explanations and justifications were offered for each recommended technology option (Amin et al. 1987).

Two villages within Nanded district in Maharashtra, Umra and Karanji, were sites for the surveys conducted during 1992-94. Umra represented the 'with' technology situation where the GPT package was successfully adopted by groundnut-producing households. Karanji represented the 'without' technology situation, where GPT technology diffusion had not occurred. These two villages were carefully selected after considering their homogenous social structure, agroclimatic environment, and cropping patterns (Table 1).

A representative sample of 26 farm households was randomly chosen from each village. These two samples were drawn from farm households that either owned or hired land for cultivation. An additional sample was drawn from the population of agricultural wage laborers from the two villages to analyze employment patterns that may have changed as a result of technology adoption.

Gender-related impacts

Labor allocations and activity patterns

Men and women cooperated in certain aspects of groundnut production, for example, transportation of manure in

Table 1. Profile of two study villages, Maharashtra, 1991/92.

Characteristic	Umra[1]	Karanji[1]
Farm households	92	143
Agricultural labor households	66	93
Other households	12	45
Total households	170	281
Farm households growing groundnut	44	39
Farm households growing groundnut in summer	34	29
Farm households adopting GPT	31	
Farm households adopting GPT included in sample	26	
Agricultural labor households included in sample	15	21
Major crops	Cotton, high-yielding sorghum, groundnut, pigeonpea, wheat	Cotton, high-yielding sorghum, groundnut, pigeonpea, rice, wheat
Major income sources	Crops, wage labor, livestock, trade	Crops, wage labor, livestock, trade

1. Both villages have deep black soils, annual rainfall of 817 mm, and irrigation from wells.

the village of Umra and field cleaning and clod crushing during land preparation, sowing, and harvesting in the village of Karanji. But in all other activities, specialization is overwhelming (Table 2). Men concentrated on plowing and harrowing, soil bed preparation, application of organic manure, seed treatment, irrigation, cultivation, purchasing inputs, applying micronutrients, spraying pesticides, packing, fodder production, and marketing. Women were primarily responsible for field cleaning, top dressing with chemical fertilizers, sowing by dibbling, hand weeding, harvesting, shelling pods, and sorting kernels for seed.

The pattern indicates that men performed those activities that required use of agricultural tools and equipment, while women's activities were performed by hand or with the use of small tools such as hoes or sickles. Men performed heavier jobs, while women did lighter jobs that may not even require tools (Kolli 1990, World Bank 1989). Equipment for the more demanding tasks that men do has been commercialized, however, women's tasks are more time consuming and involve bending, necessitating the patience that women usually have. Hand sowing and manual shelling of groundnuts are examples.

Table 2. Summer groundnut production activities by gender, Maharashtra, 1991/92 (percentage of households reporting participation).

Activity	Umra			Karanji		
	Males	Females	Joint	Males	Females	Joint
Land preparation						
Field cleaning		100		4	64	32
Clod crushing	12	7	81	11		89
Plowing	100			100		
Harrowing	100			100		
Making broadbeds and furrows	100			100		
Manure and fertilizer						
Transportation of manure			100			
Application of manure	100			100		
Chemical fertilizer (basal)	38	58	4	91		9
Chemical fertilizer (top dressing)	4	96		15	85	
Seed						
Seed treatment	100			100		
Dibbling	100				90	10
Seed drill				20	40	40
Irrigation						
Sprinkler/traditional method)	100			96		4
Cultivation						
Intercultivation				100		
Hand weeding		96	4		100	
Plant protection						
Application of gypsum	40	60				
Application of micronutrients	100					
Spraying pesticides	100			100		
Harvesting						
Pulling groundnut plants		92	8		60	40
Stripping pods from plants		100			96	4
Drying/cleaning pods	84	8	8	50	20	30
Transportation and marketing						
Packing and transportation	96	4		100		
Marketing	100			100		
Purchasing inputs				100		
Transportation of fodder	100			100		
Fodder						
Collecting from field	100			96		4
Stacking	100			100		
Processing						
Shelling pods and sorting kernels for seed		100			100	

While division of labor was observed in Umra ('with' technology) and Karanji ('without' technology), sharper differences and a more clearcut task specificity were noted between male and female activities in the latter case. Umra women reported a higher percentage of participation in field cleaning, fertilizer application, and sowing by hand dibbling. Basal application of chemical fertilizers and gypsum application tended to be women's activities after adoption of GPT in the village. Gypsum application was a new activity created by the technology, and women in almost 60% of the farm households in Umra performed this task.

Interesting changes were noted for harvesting activities. While the women in Karanji continued their traditional responsibility in all harvesting activities —uprooting plants, stripping pods, and drying/cleaning pods — Umra women concentrated on the first two tasks while men helped with pod drying and cleaning activities. This pattern may have evolved because of the increased demand for harvesting labor brought about by the significant yield gains from adoption of GPT (Table 3).

On the whole, Umra women reported their exclusive participation in 12 of 28 activities, while Karanji women reported their exclusive participation in only 9 activities. GPT gave Umra women added primary responsibilities for basal chemical fertilizer and gypsum application.

Gender roles remained more or less the same with the introduction of GPT. New activities as a result of technology adoption were divided or assigned to gender according to old principles — heavier tasks for men and lighter tasks for women. As a result, gypsum application, hand dibbling, and application of chemical fertilizers became women's activities, while preparation of raised-beds and furrows and sprinkler irrigation systems were assigned to men. Tasks tended to become concentrated on the basis of gender. Only 6 activities in Umra were reported as joint activities, while 10 continued to be undertaken jointly in Karanji.

Important implications emerge from this analysis. First, adoption of new technologies may enhance task specialization where activities are performed exclusively by one gender in order to optimize the available household labor (Kolli 1990). There were more joint activities in Karanji (10) than in Umra (6), and joint activities

Table 3. Yield of summer groundnut crop (kg ha^{-1}) in the study villages, Maharashtra, 1992/93.

Village	Variety	Yield
Umra		
(including GPT)	ICGS 11	1 762
	ICGS 21	2 061
	ICGS 76	1 814
	Mean	1 878
Umra		
(prior to GPT)	SB 11	667
Karanji		
(without GPT)	SB 11	922
	Local varieties	1 063
	Mean	867

performed by Karanji households (such as field cleaning and sowing) were performed exclusively by women in Umra. The increasing tendency to specialize clearly identified potential changes in gender roles for targeting during technology design and development.

A second issue to emerge is that technology development may be bypassing tasks performed by women, a concern strongly voiced by women farmers in Umra during informal discussions. Hand dibbling and manual shelling of groundnuts were repeatedly labeled as tedious by the women, who called for improved technologies and equipment designed to lessen the drudgery of these activities. The design and recommendations of GPT obviously did not take into consideration this aspect during development.

Time allocation for groundnut production

The adoption of recommended GPT options in Umra may have increased labor requirements by more than 107 hours for the entire summer crop — about 65 hours more for male labor and 42 hours more for female labor (Table 4).

Female labor was in higher demand than male labor after technology intervention. The demand for men increased significantly for transport and application of manure and spraying. The female labor demand was significantly higher for operations such as shelling pods and sorting kernels for seed. For the rest of the operations, there was a marginal rise in both male and female labor that was broadly in line with the previous activitity patterns. The labor increases may not appear substantial, but since they occurred in only one crop, the time had to be reallocated from other activities.

Table 4. Use of male and female labor in two study villages, summer groundnut crop, Maharashtra, 1992/93.

	Umra		Karanji	
Labor	Hours ha^{-1}	Percentage of total	Hours ha^{-1}	Percentage of total
Family male	769	32	704	33
Family female	354	14	312	14
Hired male	333	14	334	15
Hired female	980	40	810	37
Total	2 436	100	2 160	100

Use of hired labor

Hired labor is an important component of groundnut production in both Umra and Karanji. Hired labor, especially women, increased in Umra due to new technology. The requirement for female hired labor was 980 hours ha^{-1} in Umra, while only 810 hours in Karanji, Male hired labor was about the same in both villages. Thus the overall demand for labor — family or hired — increased after technology intervention (Table 5).

A rapid rural survey of a sample of households in Umra showed that women laborers found 20% of their employment in groundnut crop activities within the village, but in Karanji, it was only 13%. Men had a similar

Table 5. Employment and wages of labor households in two survey villages, Maharashtra, 1991/92.

Village, activity, location	Males: Total working days[1]	Males: Average wage (Rs day^{-1})[2]	Females: Total working days	Females: Average wage (Rs day^{-1})[2]
Umra (in the village)				
Groundnut crop activities	125 (2)	13.85	884 (20)	8.44
Other crop activities	622 (12)	12.40	3 068 (68)	7.42
Other activities[3]	4 523 (84)	10.50	373 (8)	11.16
Umra (outside the village)				
Groundnut crop activities				
Other crop activities				
Other activities[3]	120 (2)	25.83	180 (4)	10.10
Total	5390		4505	
Karanji (in the village)				
Groundnut crop activities	55 (1)	16.60	687 (13)	8.60
Other crop activities	1 186 (19)	17.00	4 297 (80)	6.66
Other activities[3]	2 255 (36)	10.76	233 (4)	11.10
Karanji (outside the village)				
Groundnut crop activities	6(10)	25.00		
Other crop activities	297 (5)	16.35	146 (3)	7.42
Other activities[3]	2 433 (39)	25.12	32 (1)	13.00
Total	6 232		5 395	

1. Figures in parentheses indicates, percentage of total working days.
2. 1 US$ = Rs 30.
3. Other labor activities include digging wells, building fences, construction, tending grazing animals, road work, cutting and selling firewood, house work, helping in a shop, fishing, etc.

advantage in Umra, but at a lesser level (Table 5). Men were also paid less in Umra than in Karanji.

Wage laborers in Umra appreciated GPT because they felt it brought them more employment within the village, as well as higher wages. Thus the technology had positive effects, but women said they would prefer further improvements to help mitigate the extra burden that the technology imposed on them. They said that the additional labor requirements could be satisfied with hired labor or by diverting their own labor from other activities.

Decisionmaking for resource allocations

Decisionmaking in the households reflected household gender distinctions.

One striking feature was that women did not have exclusive decisionmaking power in either village (Table 6). In 63% of the situations, men could make exclusive decisions in Umra, while Karanji men had this power for only 47% of the decisions. In addition, men and women in Karanji could decide about their resource allocation in consultation with each other in 53% of the situations, but Umra women and men could do that for up to 36% of the decisions. Technology influence was seen in the exclusive decisions made by men in Umra related to special chemicals, manure, pesticides, sprinkler sets, tools, and implements. The highest percentage (73%) of joint decisions was reported for credit, which was considered an important resource for technology adoption in Umra. In contrast, 100% of decisions about credit were made jointly in Karanji. This suggests that as technology created a greater need for market-related activities, men could gain control by virtue of their traditional roles. Technology thus contributed to reinforcing stereotyped gender roles and reduced the control of women over resource allocations.

Decisionmaking for distribution of benefits

Ideally, adoption of new technology should help farm households increase their benefits. From an equity point of view, households would be better off if the household benefits and neither gender is worse off. Information about who makes decisions on how different products of the crop should be used provided an indication about who benefited from different products.

It appears that gender roles were reversed between Umra and Karanji due to new technology. In contrast to what was observed for resource allocations, women in Umra could

Table 6. Male and female decisions on resources required for groundnut production in two survey villages, Maharashtra, 1992/93 (percentage of the number of households reporting use of resource).

	Umra			Karanji		
Resources required	Exclusive male	Exclusive female	Joint decisions	Exclusive male	Exclusive female	Joint decisions
Cash	50		50	77		23
Credit	27		73			100
Seed	45		55	42		58
Manure	75		25	27		73
Special chemicals (gypsum/micronutrients)	86		14			
Pesticides	76	4	20	73		27
Sprinkler sets	53		47			
Tools and implements	81		19	50		50
Percentage total by gender	63.3	0.4	36.3	47		53

not only make exclusive decisions (45% main product, 30% by-products), but also could decide jointly with men on several other items. On the other hand, Karanji women could make exclusive decisions up to 27% of the time for main products and none for the by-products. Women's decisions centered around items used for consumption and fuel, and to a lesser level, they could even decide about pods to be saved for seed. This directly related to their intensive shelling work prior to sowing, hence this decisionmaking power.

Higher yields resulting from new technology allowed the households in Umra to diversify uses of products from the groundnut crop. Women gained control over those products that were retained for household use. Although this was a gain for Umra women compared to Karanji women, more than 82% of the product was set aside for sale in the market. Considering the quantities involved due to higher yields, men in fact retained control of a considerable portion of crop. Since marketable quantities were controlled by men, there was a strong possibility that men decided how much should be set aside for marketing.

Technology development has strenthened conventional gender responsibilities. As technology interventions transform traditional farming systems, examination of household dynamics will become more crucial.

User perceptions of gender roles

GPT was introduced as a package that included high-yielding varieties and recommendations for crop management practices. Farmer experience with such a comprehensive package and its evaluation will yield valuable information about its usefulness, as well as constraints that hinder adoption. Adding a gender perspective to the evaluation will add an important perspective as scientists continue to develop, refine, and diffuse new technologies.

When different components of GPT were evaluated by both men and women, they agreed about certain traits of the technology, but perceptions that were gender-specific revealed the criteria that guided their opinions.

Men's concerns centered around issues related to economic viability of the package such as kernel yield, shelling percentage, percentage of hollow pods, cost of cultivation, etc. Women, however, were more concerned with the specifics of their tasks, including feasibility and drudgery, and hence their evaluation included such aspects as shelling, ease of weeding, weak stems, employment prospects, tediousness, hazards, etc.

Conclusions

This analysis clearly indicated who performed what tasks after technology adoption, information that should be considered as technology is developed.

Further, two categories of women emerged — farmers and wage laborers. The workload of the former has increased, while the employment prospects for the latter expanded. The question of when the availability of labor becomes a constraint to technology adoption needs to be examined in the context of farms of different sizes.

New activity patterns suggest that technology intervention led to gender-specific tasks along the lines of a conventional division of labor. This raises the question whether stereotyped gender roles are desirable to satisfy women's strategic needs in agriculture (Moser 1989).

Technology intervention enhanced the unequal power relationship between men and women, thus reinforcing stereotyped responsibilites within households. Women tended to lose in resource allocations, but marginally gained in benefits distribution, but there was a tendency to push women into the domestic sphere and men to marketing.

User perspectives of the technology were closely related to their roles and responsibilites in labor use, resource allocation, and benefits distribution. Evidence from this paper suggests that male farmers understand the crop production process, and their perceptions of technology and ability to evaluate it are related to the level of adoption. Women farmers were equally capable of such diagnosis, in fact, they also considered occupational hazards and not just the financial analysis of the male farmers.

Technology development should incorporate the perceptions of both male and female members of farming communities prior to forming a research agenda. Further studies are required in India to measure the effects of gender inequities on the productivity and efficiency of technology.

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Adoption of Vertisol Technology in the Semi-Arid Tropics

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One of the significant research contributions of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is the development of crop and resource management technology to alleviate production constraints and improve sustainability of natural resources in Vertisol areas. An integrated package of technology options became known as Vertisol technology, and was tested on farmers' fields in microwatersheds in the early 1980s.

The on-farm trials demonstrated substantial increases in productivity and profitability. Since sizable research resources were allocated to develop this technology, its ex-post evaluation in terms of enhancing agricultural production, improving resource use efficiencies, and conserving natural resources presents an opportunity to justify past funding of Vertisol research management.

Dryland agriculture in the semi-arid tropics (SAT) faces two major constraints — stress from inadequate water and nutrients, and degradation of natural resources — if it is to be a sustainable enterprise. Dryland areas need special attention to increase productivity by exploiting underutilized resources, as well as conserving land and water resources that are highly prone to degradation. These objectives are essential in dryland regions because expansion of irrigation is now stagnating, and farmers of the SAT who depend on rainfall are lagging far behind than those who enjoy irrigation facilities. Rainfed regions have considerable potential to increase agricultural production if improved technologies are adopted by farmers.

To alleviate production constraints in dryland areas, a technology package

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approach was adopted by a multidisciplinary team of agricultural and social scientists at ICRISAT in 1974. The team developed a package that was later known as Vertisol technology. This package specifically targeted Vertisol areas in regions with relatively dependable rainfall where land was fallow during the rainy season (Flower 1994). In India it is estimated that Vertisol technology may be suitable for an area of 5-12 million ha, largely covering the states of Karnataka, Andhra Pradesh, Maharashtra, Madhya Pradesh, and Gujarat (Ryan et al. 1982). During the early 1980s, ICRISAT selected a few sites where it was possible to conduct on-farm trials and demonstrate the potential benefits of the technology over traditional practices. The on-farm trials of the early 1980s now provide an opportunity to assess adoption of the technology after a significant period of time.

The purpose of assessing the Vertisol technology was to:

- identify the extent of adoption,
- identify reasons why improved and tested management practices were not being adopted, and
- quantify returns to investment on Vertisol research management.

A preliminary study was undertaken to examine adoption of different components of the Vertisol technology and constraints to adoption of those components that were discontinued or only partially adopted by farmers. The focus was to assess what motivates or constrains adoption of improved practices that are expected to increase productivity, improve drainage, reduce soil erosion, and improve use of rainfall, among other benefits. This preliminary investigation will form a base to conduct an adoption and impact assessment of Vertisol technology in a larger area of the SAT.

Method

The study was based on three Production Systems (PS) characterized as:

- tropical, high-rainfall, rainy- plus postrainy-season rainfed soybean/ wheat/chickpea, confined to central India (PS 4);
- tropical, intermediate rainfall, rainy-season sorghum/cotton/ pigeonpea, largely in the eastern Deccan Plateau (PS 7); and
- tropical, low rainfall, primarily rainfed, postrainy-season sorghum/ oilseeds, covering the western Deccan Plateau (PS 8).

These PS were among those developed by ICRISAT based on agroclimatology, soil, major cropping systems, length of growing season, etc, to better target research and technology transfer. Globally, 29 Production Systems were delineated (ICRISAT 1994).

Four locations from PS 7 and one each from PS 4 and PS 8 were selected to help understand the dynamics of adoption of various components of the Vertisol technology (Figure 1 and Table 1):

- Taddanpally and Sultanpur in Andhra Pradesh, Kanzara in

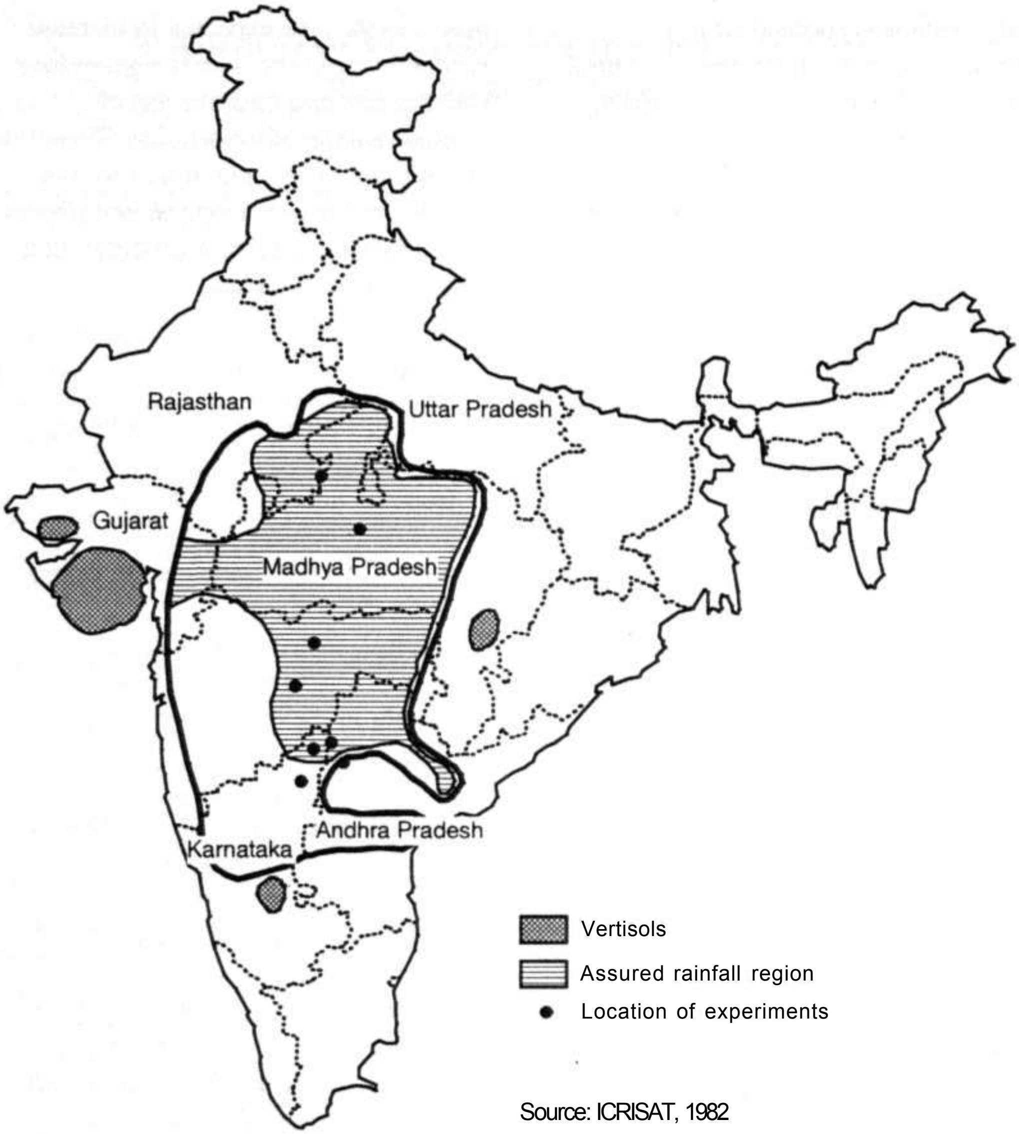

Figure 1. Location of ICRISAT on-farm experiments in the deep Vertisol, assured-rainfall regions of the Indian semi-arid tropics

Maharashtra, and Farhatabad in Karnataka (PS 7);

- Shirapur in Maharashtra (PS 8); and
- Begumganj in Madhya Pradesh (PS 4).

The subsequent introduction of surface irrigation in Shirapur has completely changed the agricultural situation there.

Information for the study was collected through a rapid rural appraisal conducted in 1995/96 with different groups of farmers located in

Table 1. Soil type and annual rainfall in selected villages.

State	District	Location	Soil type	Rainfall (mm)
Andhra Pradesh	Medak	Taddanpally	Deep Vertisols	764
Andhra Pradesh	Medak	Sultanpur	Deep Vertisols	764
Karnataka	Gulbarga	Farhatabad	Deep Vertisols	753
Madhya Pradesh	Raisen	Begumganj	Deep Vertisols	1 300
Maharashtra	Akola	Kanzara	Medium-deep Vertisols	840
Maharashtra	Sholapur	Shirapur	Deep Vertisols	742

the six different locations. Discussions were conducted with those farmers who participated in different watersheds to evaluate the technology during the on-farm trials in the early 1980s. They were well aware of the technology and its various components, and their perceptions of the components, adoption, constraints to adoption, etc. were gathered during group discussions following a prepared discussion guide.

Vertisol technology

Sustainable development of the SAT has been one of ICRISAT's major objectives since its inception. Several research programs sought technologies to conserve soil and water in order to maximize agricultural productivity on a sustainable basis in a microwatershed. (A microwatershed is an area of 3-25 ha developed to facilitate effective management and improve resource use efficiency.) Research on Vertisol technology as a package of options started at ICRISAT in 1974 with two major experiments. The aim was to evaluate traditional practices in terms of productivity and soil and water losses, and then develop and test approaches to improve productivity through more efficient use of rain water and minimizing land degradation (Virmani et al. 1989). This package of technology options primarily targeted:

- effective drainage of excess water when it is not possible to capture and store it;
- better use of rainfall by conserving most of it in the soil profile; and
- capturing, storing, and using excess water for irrigation during drought periods.

Success with these objectives opens up the enormous potential for double cropping or crop intensification of Vertisols in the SAT.

The technology options developed were a system of land and water management — with moderate inputs, bullock power, and within the reach of a small farmer in the SAT — that effectively improved drainage, reduced soil erosion, and increased and stabilized crop productivity. The main components of the Vertisol technology (Ryan et al. 1982) for a watershed were:

- cultivating immediately after the postrainy.season crop when the soil still contained some moisture and

was not too hard (summer cultivation);
- improving drainage with the aid of field and community channels and the use of graded broadbeds and furrows (BBF);
- dry seeding crops before the monsoon rains arrive;
- using improved seeds and moderate amounts of fertilizers;
- improving crop mixtures and row arrangements;
- improving placement of seeds and fertilizers for better crop stands; and
- improving plant protection, particularly for legume crops.

The technology components were first tested and demonstrated on farmers'fields in 1981/82 at Taddanpally, and later expanded to eight sites in 1982/83. The on-farm trials were quite encouraging and the State Departments of Agriculture included the technology components in their extension agenda for wider testing and demonstration. In 1994, the program was extended to 28 locations on more than 2 000 ha in similar climatic conditions in Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra (Table 2).

Adoption of Vertisol technology

The technology components were recommended as a package. Under such circumstances, several distinct technological options were available to farmers. They were free to adopt the complete package, a subset or part of a subset of components, or modified forms of the recommendations (Byerlee and Polanco 1986, Ryan and Subramanyam 1975). Farmer responses to the technology and its components varied from region to region, and certain components needed adjustment to suit regional soil, crop, and agroclimatic characteristics. In the present study, farmer responses to adoption of individual components were examined.

Table 2. Districts selected for disseminating Vertisol technology in four Indian states.

State	Districts	Area (ha)
Andhra Pradesh	Adilabad, Karimnagar, Khammam, Medak, Nizamabad, Warangal	614
Karnataka	Bellary, Belgam, Bidar, Dharwad, Gulbarga	277
Madhya Pradesh	Bhopal, Raisen	Not available
Maharashtra	Ahamadnagar, Akola, Amravati, Aurangabad, Buldhana, Dhule, Jalgaon, Jalna, Nagpur, Nanded, Parbhani, Sangli, Satara, Yeotmal, Wardha	1 158

Source: Virmani and Tandon 1984.

Summer cultivation

Vertisols are very hard when dry and plastic and sticky when wet, with a very narrow moisture range during which tillage takes place (Virmani et al. 1989). Under dry conditions, tillage is difficult and requires extremely high levels of draft power. To overcome this difficulty, farmers wait for rain, but persistent rains constrain timely tillage and sowing. To alleviate this major constraint and effectively use the soil moisture, one important recommendation of the Vertisol technology was to plow the land immediately after harvesting the postrainy-season crop. Plowing then is easier because the soil still contains some residual moisture.

This practice was adopted by farmers in two high rainfall locations — Kanzara in Maharashtra, and Begumganj in Madhya Pradesh. They said that this practice:

- made the soil easier to cultivate because it still contained some residual moisture,
- avoided soil cracking and clotting,
- reduced labor and costs because cultivation was easier,
- improved conservation of rain water because more was absorbed into the soil profile, and
- solved the problem of weeds during the rainy season.

Farmers said that any delay after the harvest of postrainy-season crops allowed the soil to harden. They perceived that these practices decreased the cost of cultivation, increased land productivity, and improved sustainability of soil and water resources.

In Taddanpally and Sultanpur in Andhra Pradesh and Farhatabad in Kamataka, this practice was not adopted by farmers. These locations are still dominated by a fallow regime during the rainy season followed by a postrainy-season crop or a short-duration rainy-season crop (such as black gram or green gram). The main crops were grown during the postrainy season, and tillage operations began after the monsoon rains settled and the soil had adequate moisture for land preparation and seed germination. Obviously, under such a situation summer cultivation may not be desirable.

Shirapur in Maharashtra now has irrigation, therefore farmers do not depend upon rain for tillage.

Double cropping

In Vertisols, where rainfall is greater than 750 mm year[1], two crops are feasible without irrigation. The introduction of double cropping on an estimated 5-12 million ha of dryland has the potential to increase production by exploiting existing underutilized resources. Traditionally, only one crop is grown each year, with land remaining fallow for the following season. During on-farm testing, several new cropping systems were recommended and verified for feasibility and adaptability on farmers' fields.

Both sequential crops and intercrops that require both seasons to mature were considered as options, but there was not enough moisture to germinate a postrainy-season crop. There was, however, opportunity to increase the intensity of an intercrop.

Immediately after on-farm trials concluded, in many cases farmers reverted to their traditional cropping system (one crop in a year). The main reason was that they preferred postrainy-season sorghum over rainy-season sorghum. Another important reason reported by farmers was the higher risk attached to the rainy-season crop. Despite their past decisions, the concept of intercropping was attractive and would be more likely to be adopted by the farmers if improved varieties, higher prices, and better marketing facilities were available. Important double crops in the selected locations are listed in Table 3.

In Taddanpally, although a sorghum/pigeonpea intercrop produced the best yields and highest returns in the first year (1981/82) of on-farm trials, it was not more widely adopted in the second and third years. Farmers tended to revert to their previous system based on postrainy-season sorghum (ICRISAT 1984). The situation has changed during the last 5 years. Crops such as black gram and green gram are emerging as important rainy-season crops because of their higher prices and early maturity (about 80 days). In addition, these also fit in a crop rotation with postrainy sorghum, which is the main crop in Taddanpally, where about *30*-35% of the area is double cropped. For the last two years, double cropping increased because the market for blackgram and greengram was good. In some cases, cotton or sorghum was intercropped with pigeonpea.

In Farhatabad, the most popular intercropping system is groundnut/pigeonpea followed by cotton/pigeonpea. In some cases, sesamum is cultivated after pigeonpea. In a very limited area where irrigation is available, soybean-postrainy season sorghum was a new crop rotation. Traditionally, groundnut was the important crop during the rainy season. This was initially replaced by pigeonpea, and finally converted to a groundnut/pigeonpea intercrop. Medium-duration pigeonpea was grown on about 50% of the total area.

In Kanzara, more than 50% of the total cultivated area was under double cropping. Cotton/pigeonpea was the

Table 3. Most important traditional and newly adopted cropping systems in selected locations.

Location	Traditional system	Adopted system
Taddanpally	Postrainy sorghum	Blackgram or greengram-postrainy sorghum
Sultanpur	Postrainy sorghum	Blackgram or greengram-postrainy sorghum
Farhatabad	Rainy-season groundnut	Groundnut/pigeonpea
Begumganj	Rainy-season fallow-wheat	Soy bean/pigeonpea
Kanzara	Rainy-season sorghum	Cotton/pigeonpea
Shirapur	Postrainy sorghum	

1. Surface irrigation has been introduced in the village.

most important intercrop, and in such cases, these crops occupy both seasons. Both are long-duration crops, and hence increase productivity. Sorghum-wheat and sorghum-chickpea are the most common sequential crops. In some cases, cotton-wheat and soybean-wheat are also grown. Traditionally, rainy-season sorghum was the most important subsistence crop.

In Begumganj, soybean was intercropped with long- or medium-duration pigeonpea. This system covered about 30% of the area in the entire village. An early adoption study within the watershed (covering 25 ha) showed that the area under this system increased from 12% in 1982/83 to 65% in 1983/84 (ICRISAT 1985). In some cases, soybean-wheat or soybean-chickpea were important crop rotations to increase cropping intensity. In Begumganj, land was traditionally left fallow during the rainy season.

In Shirapur prior to introduction of canal irrigation, about 25% of the area was under double cropping if there was timely rainfall. In the past 2 years, irrigation has significantly increased the area under double cropping to about 50%. Traditionally, postrainy-season sorghum was the most important crop grown in the village.

Dry seeding

Dry seeding before the monsoon rains was recommended, and while a majority of the farmers appreciated the concept and its potential benefits, few adopted the practice. Dry seeding was reported to increase yields of sorghum and cotton by about 200-300 kg ha^{-1}.

Adoption of dry seeding was not very encouraging at any location, and was only adopted to a limited extent in Kanzara (15%) and Begumganj (2%), mainly in cotton using seed saved from a previous crop. Farmers faced three major constraints to dry seeding:

Uncertain rainfall. Farmers do not have access to reliable rainfall predictions.

Risk of seed damage. Prices of hybrid and high-yielding varieties of cotton were high (Rs. 600-650 kg^{-1}) and any delay or excess rain damaged purchased seed. Rats also damaged the seed, which reduced germination.

Weeds. Farmers faced severe weed problems in plots that were dry seeded. Weeds and crops germinated together with the onset of the monsoon rains. Weeds grew much faster than the crop, and the cost of weed control was higher than the crop value. During on-farm testing, weed management in the rainy-season was also reported to be a serious problem for many farmers. Cultivation with a wheeled tool carrier was only a partial success. More research on weed management was recommended (ICRISAT 1984).

Besides these problems, farmers also reported that dry seeding was difficult because the soil became very hard after the postrainy-season crop was harvested if it was not cultivated immediately. Existing implements were not appropriate for cultivating and sowing before the rains. Heavy-duty tractors may help land preparation and dry seeding, but adoption depends on the rainy-season crop. With the introduction of black gram and green gram during the rainy season, farmers felt that it was not necessary to dry seed because these crops do not delay the sowing of the subsequent postrainy-season sorghum.

Broadbeds and furrows

The system of broadbeds and furrows (BBF) is a land preparation technique with beds 105-cm wide alternating with furrows 45-cm wide at a gradient of 0.2-0.4%, depending on soil type. This component was designed to improve surface drainage to avoid waterlogging during the rainy season. Run-off water can be drained out of the watershed or collected for supplemental irrigation. Although the system provided better results during on-farm trials, farmers did not adopt it. Farmers reported benefits from BBF, including reduced labor requirements for such operations such as sowing, fertilizer application, and cultivation by as much as 50%, and increasing water retention in the soil.

Despite the benefits of BBF reported by farmers, they all discontinued the practice and either used traditional methods to drain excess water or made furrows between rows during cultivation. These were more convenient than BBF, primarily because the Tropicultor (an implement specifically designed to make BBF) was expensive to buy and difficult to operate. Farmers said that if BBF must be constructed every year, the returns may not justify the labor expense unless more profitable subsistence crops or cash crops (vegetables, oilseeds) were grown. Maintenance is important and expensive because the beds were invariably damaged by heavy rains. In some other parts of India, however, farmers are adopting BBF for postrainy-season groundnut to increase yields and save labor (Joshi and Bantilan 1996). In areas where traditional postrainy-season sorghum was grown, farmers did not face the problem of excess water and waterlogging in the fields. Under such situations, farmers felt that BBF were not required. Multilocational trials also indicated that BBF may not be essential at all locations, and that the technology should be considered on a case-by-case basis (ICRISAT 1983).

Improved varieties

Improved varieties are also an important component of the Vertisol technology and have become popular during the past decade. In all the villages, farmers grew improved varieties of cotton such as LRA 5166, LRK 516, or Nanded 44. One improved variety of pigeonpea, ICP 8863, was grown in all villages except Taddanpally. Adoption of ICP 8863 was launched by the farmers of Kanzara in 1987 and now covers 300 000 ha, and farmer-to-farmer seed distribution of this variety also began in this village (Bantilan and Joshi 1996). Local chickpea varieties were grown (Annigeri and Chaffa), as well as improved varieties (ICCV 2 and ICCC 37). All farmers grew improved varieties of soybean in Begumganj.

A majority of all farmers at all locations were still growing local sorghum varieties. M 35-1 (Maldandi), which was grown during the postrainy season, was still favored. Farmers generally avoided hybrids and high-yielding varieties for postrainy-season sorghum because prices and quality were low for both grain and fodder. In Kanzara, farmers grew hybrid sorghum during the rainy season.

Fertilizer applications

Dryland agriculture traditionally receives no mineral fertilizer (Jha and Sarin 1980). Desai et al. (1995) used 9 years of data from a panel of farmers in the SAT to show that the vast proportion of nonirrigated land did not receive either manure or fertilizer. Recently, it was noted that the majority of farmers applied whatever manure was available for crop production, but it was not sufficient to meet the crop requirement and nutrient mining. To improve soil fertility and overcome nutrient mining, one recommendation of the Vertisol technology was to apply moderate amounts of mineral fertilizer that could be complemented by manure.

At all locations, a majority of farmers used moderate amounts of mineral fertilizers, and their use is increasing over time. Most of the farmers applied fertilizer to sugarcane and cotton, and about 20% used fertilizer on pigeonpea and less than 10% on chickpea.

In most of the cases, composite fertilizer (N 19:P 19:K 19) was applied as a basal dose, with urea as a top dressing. When fertilizer prices rose, there was a marginal decline in the consumption of potassium and phosphate fertilizers. Ironically, use of manure decreased in all the villages as fodder became scarce and the animal population declined. Cash crops such as sugarcane and cotton were the priority for manure.

Placement of seed and fertilizer

Appropriate placement of seed and fertilizer can substantially increase crop yields. The traditional practice in dryland agriculture was to broadcast seed, but placement of seed and fertilizer was one part of the technology package designed to minimize nutrient losses and make optimal use of available moisture. Farmers were convinced of the benefits of sowing in rows and placing fertilizer with seed. Dibbling and use of a seed drill became common practices for sowing seed and fertilizer placement. All farmers used dibbling and maintained proper row arrangements for cotton and groundnut, while a seed drill was commonly used to sow sorghum, wheat, pigeonpea, and chickpea.

In Begumganj, seed and fertilizer were mixed and sown using either a drill or plow, which placed them at the same depth. Although unusual, this modified form of the technology component indicated that farmers accepted the concept of placing seed and fertilizer together.

Plant protection

Use of pesticides was rapidly increasing in all villages except Taddanpally. For the last 5 years, pesticide use almost doubled in cotton, pigeonpea, and chickpea to control insects (particularly podborer *Helicoverpa armigera).* In Taddanpally, farmers discontinued pesticide use because it was ineffective against heavy podborer infestations.

Farmers at other locations were concerned about the indiscriminate use of pesticides. The majority of farmers sprayed cotton and pigeonpea an average of 5 or 6 times in a season, sometimes as often as 10 times. In Farhatabad, farmers were spending an amazing Rs. 5 000 ha^{-1} to control pigeonpea pests, while two decades ago they were unaware of pesticides. In the early to mid-1980s farmers started using small amounts of insecticides, but over the years their use has steadily increased, particularly on cotton and pigeonpea.

In Kanzara, farmers now use a power sprayer to apply pesticides. The controlled droplet application (CDA) sprayer is very popular in Farhatabad because its water requirement is low (ICRISAT 1985). Conventional knapsack sprayers require much larger volumes of water, presenting a considerable hardship for SAT farmers because they usually must carry clean water for long distances to their fields. Before the introduction of the CDA sprayer, farmers were using a foot sprayer that required more time and labor.

Future research

Several important issues emerged from this work.

Differential adoption of components

Improved varieties was the most important component of the technology package, and was adopted first and most widely. This component was followed in stages by application of moderate amounts of fertilizers, use of pesticides, and proper placement of seed and fertilizers (Table 4). Similar results were reported by Foster (1988) when assessing early adoption of Vertisol technology options in Begumganj. These components were widely adopted at most locations, and to some extent where double cropping suited the environment, farmers reduced the area of fallow land.

Post-harvest plowing

Although cultivating the land immediately after harvest of the postrainy-season crop was practiced at several locations, its potential benefits were not being realized by adopting the concept of dry seeding. These two components (summer cultivation and dry seeding) facilitate double cropping in dryland agriculture and increase cropping intensity. There was evidence that farmers were adopting double cropping, not as a result of summer cultivation and dry seeding, but rather because short-duration crops that sell at an attractive price became available.

Table 4. Adoption intensity of components of Vertisol technology.

Technology	Taddan-pally	Sultanpur	Farha-tabad	Begum-ganj	Kanzara	Shirapur
Summer cultivation	None	None	None	Moderate	Moderate	None
Double cropping	Low	Low	Low	High	High	Moderate
Dry seeding	None	None	None	Low	Moderate	None
Broadbed and furrow	None	None	None	None	None	None
Improved varieties	Low	Low	Moderate	High	High	Low
Fertilizer application	Low	Low	Moderate	High	High	Moderate
Seed and fertilizer placement	Low	Low	High	High	High	Moderate
Plant protection	None	None	High	High	Moderate	Low
Use of CDA	None	None	High	None	None	None

Constraints to dry seeding

Constraints to adoption of dry seeding need to be mitigated before it will be more widely adopted. Among the most important constraints are lack of good rainfall predictions, weed growth, and seed damage before germination. Computers that can analyze climatic information are available, but a mechanism to disseminate the information they generate is missing. More research on weeds in necessary. Earlier studies (Binswanger and Shetty 1977) recommended manual weeding over chemical control because unemployment was high and labor costs low. Over the years, however, wages have increased substantially and employment opportunities in other areas limit the labor supply. Various other technological options to control weeds may overcome this constraint. Seed damage, the third major constraint, is also a candidate for more research.

Broadbeds and furrows

One of the most important components of the technology package, BBF, was discontinued by farmers at all locations. Abandoning this component raises the issue of targeting technology appropriately and considering economic feasibility within an existing cropping system. Waterlogging was perceived as a major problem in the watersheds at the target locations, but apparently it wasn't. Walker et al. (1989) assessed farmers' perceptions about BBF after the first year of on-farm trials in Taddanpally, and reported that a majority of the farmers did not observe any problem with waterlogging. Waterlogging may be more narrowly location-specific and the concept of BBF may be recommended and introduced in areas where it poses a constraint to double cropping.

To better understand the second issue, it is necessary to reassess the economic feasibility of crop production with and without BBF. It might be adopted if the benefits are greater than the losses due to waterlogging.

Ryan et al. (1980) analyzed the comparative economics of BBF and flat systems using data from watershed experiments in deep and medium-deep Vertisols. The BBF system with a maize/pigeonpea intercrop was about 20% more profitable than the flat system of the same intercrop. Under a maize-chickpea sequential system, the advantage of BBF was reduced to 10%. The BBF system was less profitable than a flat system on a medium-deep Vertisol. Perhaps these results were slighted while packaging the Vertisol technology for the on-farm trials.

One possible reason for including this component may be its contribution toward improving the sustainability of soil and water resources. There are reports that the soil loss in a BBF and double-cropping system was 1 500 kg ha^{-1} while it was 6 400 kg ha^{-1} in a flat and single-cropping system. Similarly, total rainfall loss in the BBF and double-cropping system was 33%, but 70% for the flat and single-cropping system (ICRISAT 1985). These hidden benefits may not enhance yields in the short term, but certainly have long-term implications. The benefits of BBF should be reassessed considering a long-term perspective, economic feasibility, and sustainability issues with different intercrops and crop sequences.

Independent components

Components of the Vertisol technology were tested in a microwatershed. Each component can be adopted independently, and thus should be examined for both technical and economic feasibility at different target locations depending on localized constraints.

Conclusions

It is time to undertake a detailed investigation of the returns to investments in Vertisol management. Sampath (1989) reported, " . . . adoption of ICRISAT's improved system of land management and crop production increased yields in operational research blocks during 1982/83 and over a much larger area of 277 ha during 1983/84, resulting in their wider acceptance among farmers in Vertisol tracts of Karnataka. The technology influenced not only the farmers involved within the watershed but also those outside."

Assessing the preliminary results, it is clear that the Vertisol technology as a full package was not adopted, but different components were widely adopted by different groups of farmers at different locations. Among important components adopted by farmers were improved varieties, application of fertilizers and pesticides, use of CDA spray equipment, and appropriate placement of seed and fertilizer. Adoption patterns and impact assessments of one or more technology options could justify investments in Vertisol management research. Their impact may be seen in terms of more double cropping; increased agricultural production, income, and resource-use efficiency; and conservation of soil and water resources. The impact may also be more broadly assessed in terms of transforming agriculture from subsistence to commercial, with implications for food security and poverty alleviation.

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Dry Seeding in the Vidarbha Region of Maharashtra

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This study tested the hypothesis that dry seeding in medium to deep Vertisols where rainfall is greater than 700 mm $year^{-1}$ maximizes use of rainfall and available soil moisture, improves yields, and increases net returns to cotton and sorghum.

The study was carried out in Buldana and Akola districts of the Vidarbha region of Maharashtra, an area that receives 800-850 mm of rain in about 47 days. Cotton and sorghum are the major crops in this region, and each occupies about 30% of the gross cropped area. Other important crops are pigeonpea, greengram, blackgram, sunflower, and safflower.

Data from the 1995/96 cropping season were gathered in a survey in October 1996 by field assistants working for Dr Panjabrao Deshmukh Agricultural University (Krishi Vidyapeeth), Akola. Farmers were divided into four groups — those who adopted dry seeding in cotton and sorghum, and those who did not adopt this practice for the two crops (Table 1).

Table 1. Number of farmers adopting or not adopting dry seeding of cotton and sorghum in two districts of Maharashtra, 1995/96.

	Adopters		Non-Adopters	
District	Cotton	Sorghum	Cotton	Sorghum
Buldana	9	6	9	6
	9	6	9	6
Akola	15	0	15	0
	15	0	15	0

Data

Cropping pattern. Cotton covered 35% of gross cropped area where farmers adopted dry seeding, and sorghum occupied 21%. Where it was not adopted, cotton covered 39% of the

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Table 2. Land holdings and cropping patterns of selected farmers in survey area, 1995/96, Vidarbha region, Maharashtra.

Area (ha)	Adopters	Non-adopters	Total
Total land held	209	191	400
Average size of holding	3.5	3.2	3.3
Net sown area	199	183	382
Area occupied by			
Cotton	78 (36)[1]	75 (39)	153 (37)
Sorghum	47 (21)	57 (29)	104 (25)
Pigeonpea	13 (6)	12 (6)	25 (6)
Greengram and blackgram	37 (17)	8 (4)	45 (11)
Other crops	45 (20)	42 (22)	87 (21)
Gross cropped area	221(100)	194 (100)	415(100)
Cropping intensity	111	106	109

1. Figures in parentheses indicate percentage of gross cropped area

area and sorghum 29% (Table 2). Pigeonpea was primarily grown with cotton, whereas sorghum was grown as a sole crop.

Crop varieties. In Buldana district, adopters and non-adopters sowed H 6, H 8, LRA 5166, Nanded 44, and PKV Rajat varieties of cotton on about equal areas. In Akola district, however, only two varieties, AHH 468 (80%) and AKH 4 (20%), were grown by the adopter farmers. The non-adopters sowed AHH 468 (90%), with the remaining 10% divided among AKH 4, Nanded 44, and LRA 5166. Sorghum was dry seeded only in Buldana district, with the variety CSH 9 predominating with both adopters (83%) and non-adopters (75%).

Impact

Cotton. The use of labor, seed, and pesticides did not differ among adopters and non-adopters, but there was a 15% reduction in fertilizer use by the adopters, and their cotton yields were 27% higher (Table 3).

Production costs for dry seeding cotton were 3% higher for the adopters, but gross returns were 22% higher and net returns 17% higher than the non-adopters (Table 4).

Sorghum. Farmers adopting dry seeding technology used higher levels of almost all inputs — human male labor (27%), bullock labor (49%), fertilizer (22%), and manure. They were well rewarded for their efforts with a grain yield 38% higher than the non-adopters (Table 5).

Adopter farmers incurred costs about 20% higher than non-adopters, but their gross returns were 38% higher and they saved 17% per unit of production compared to the non-adopters (Table 6).

Table 3. Use of inputs (ha^{-1}) by adopters for dry seeding of cotton compared to non-adopters, 1995/96, Vidarbha region, Maharashtra.

Parameter	Non-adopters (65.5 ha)	Adopters (66.4 ha)	Percentage difference (adopters over non-adopters)
Human labor (days)			
Male	40.10	4131	
Female	99.71	96.27	-3.45
Total	139.81	137.58	-1.60
Bullock labor (days)	17.81	19.76	+10.95
Machine labor (days)	1.81	1.23	-32.04
Seed (kg)	6.29	5.99	-4.78
Manure (100 kg)	18.01	2.68	+ 15.10
Fertilizer (kg)			
N	40.42	33.80	-16.38
P	27.94	24.40	-12.67
K	3.05	2.64	-13.44
Total	71.41	60.84	-14.80
Pesticide cost (Rs.)	324.14	323.36	
Yield (kg)			
Seed cotton	551	698	+26.7
Pigeonpea	140	138	-1.4

Table 4. Economics of cotton cultivation by adopters and non-adopters of dry seeding (Rs ha^{1}), 1995/96, Vidarbha region, Maharashtra.

Parameter	Non-adopters (65.5 ha)	Adopters (66.4 ha)	Percentage difference (adopters over non-adopters)
Human labor			
Male	1 137	1 217	+7.0
Female	2 181	2 174	-0.3
Bullock labor	1526	1 725	4-13.0
Machinery	219	168	-23.3
Seed	372	373	
Manure	466	565	+21.2
Fertilizer	1265	1 153	-8.9
Plant protection	324	323	
Other	85	82	
Interest on W.C.	424	467	+ 10.1
Total cost of cultivation	8 029	8 247	+2.7
Returns			
Cotton	10 688	13 558	+26.9
By-products	1 909	1 802	-5.6
Gross return	12 597	15 360	+21.9
Net return	4 568	7 113	+55.7
Cost of production (Rs 100 kg^{-1})	1 111	923	-16.9

Table 5. Use of inputs (ha^{-1}) by adopters for dry seeding of sorghum compared to non-adopters, 1995/96, Vidarbha region, Maharashtra.

Parameter	Non-adopters (15.4 ha)	Adopters (11.9 ha)	Percentage difference (adopters over non-adopters)
Human labor (days)			
Male	45.18	58.14	+26.99
Female	47.27	47.60	
Total	93.05	105.74	+13.64
Bullock labor (days)	8.83	13.16	+49.04
Seed (kg)	9.02	9.28	+2.88
Manure (kg)		2 068	
Fertilizer (kg)			
N	74.55	92.49	+24.06
P	24.48	28.52	+ 16.50
K	0.97	0.84	-13.40
Total	100	121.85	+21.85
Insecticide cost (Rs.)			
Yield (kg)			
Grain	1 592	2 203	+38.37
By-products	2 402	3 165	+31.76

Table 6. Economics of sorghum cultivation by adopters and non-adopters of dry seeding (Rs ha^{-1}), 1995/96, Vidarbha region, Maharashtra.

Parameter	Non-adopters (15.4 ha)	Adopters (11.9 ha)	Percentage difference (adopters over non-adopters)
Human labor			
Male	1 515	1 851	+22.2
Female	1 111	1 146	+3.2
Bullock labor	704	929	
Machinery	621	823	+32.5
Seed	548	589	+7.5
Manure		82	
Fertilizer	1 143	1 347	+17.9
Plant protection			
Interest on W.C.	339	339	+19.8
Total cost of cultivation	5 981	7 173	+19.9
Returns			
Sorghum	5 922	8 259	+39.5
By-products	1 802	2 373	+31.7
Gross return	7 724	10632	+37.7
Net return	1 743	3 459	+98.5
Cost of production (Rs 100 kg^{-1})	263	218	-17.1

Technology adoption

Cotton. Farmers reported that they adopted dry seeding because:

- seed can remain in the soil for a longer period and unlike seed of many other crops, it is not affected by ants and other insects;
- the crop matures earlier than if sowed after the monsoon rains;
- labor is less expensive in the summer;
- scarce rain water is used to full advantage;
- grain quality is improved;
- prices were higher for an early crop; and
- yields were higher.

Sorghum. Farmers reported dry seeding of sorghum was advantageous because:

- it enabled double cropping,
- sowing was not delayed by the erratic nature of the monsoon rains,
- yields were higher, and
- labor is less expensive in the summer.

Constraints

About 95% of the farmers who did not adopt dry seeding technology were aware of the technology, but cited reasons why they chose not to adopt it:

- germination is substantially reduced because Vertisols dry out and crack (90% of non-adopters in Buldana district, cotton);
- sowing is more expensive when initial low rainfall is followed by a dry spell (66% of non-adopters in Buldana district, sorghum); and
- financial risk if dry seeding fails (73% of non-adopters in Akola district, cotton).

Conclusions

Based on the survey data, researchers arrived at three main conclusions:

- dry seeding technology increased yield and financial return of cotton and sorghum;
- the technology was not suitable where Vertisols are subject to cracking; and
- farmers lack the money to resow their fields if germination is poor or fails altogether.

Towards a Formative Approach to Assessment of Integrated Pest Management Strategies

P G Cox[1]

Integrated pest management (IPM) is a significant improvement in the management of insect pests and diseases of crops, and an important component of the research programs of both national agricultural research systems (NARS) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The progressive incorporation of a socioeconomic component in research, development, and extension (RD&E) processes leading to technology development and implementation is a recent phenomenon.

This paper first outlines certain aspects of program evaluation and impact assessment in relation to emerging technologies in IPM that provide a beginning framework for research in this area. Second, some specific problems with the greater integration of socioeconomics and biological work on component technologies that affect novel pest management technologies will be addressed. Third, a short case study of IPM evaluation will indicate some of the issues in an empirical, rather than a theoretical, fashion. And last, some general lessons for program evaluation and impact assessment will be suggested as these concepts begin to be applied to more complex technologies. These technologies are more social in nature, and the technology generation process is based increasingly on collaboration between different groups of actors (both NARS and ICRISAT, farmers and scientists).

Impact analysis for program evaluation

The crux of impact analysis is a comparison of what did happen after implementing the program with what would have happened had the program not been implemented (Mohr 1992). This comparison is the impact of the program. What-would-have-happened (what Mohr calls the counterfactual or 'C') is clearly problematic because it cannot be observed directly. The other major component of impact assessment

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is the actual state of the world after a program has been implemented ('R'). The simplest quantifier of program effectiveness is R - C. This may be expressed as the difference of means, a difference of proportions, or a regression coefficient. However, in general, a standard is needed to interpret whether an impact is substantial or weak. The planned impact of the program provides one standard. This defines the effectiveness ratio as:

$$Effectiveness = \frac{R-C}{P-C}$$

where:

P = planned state of the world on the outcome of interest.

This has additional problems because it is difficult to get program personnel to do the planning needed to specify P, and it is difficult to estimate the counterfactual ahead of time.

An alternative to the planned state of the world as a quantifier is the extent of the problem (the counterfactual). The adequacy ratio is defined as:

$$\textbf{Adequacy} = 1 - \frac{R}{C}$$

Thus adequacy quantifies effectiveness by conceptualizing it as the proportion of the problem eliminated by the program. It is directly applicable only when complete elimination is relevant. For this to make sense, the counterfactual must be seen as an undesirable condition. Thus, measures of R and C may need to be redefined in terms of a gap, for example, a yield gap or pesticide levels to be reduced.

Scriven (1972) divided evaluations into the formative and the summative. The latter are studies that yield information only on simple impacts. In contrast to summative evaluations, formative evaluations help to give guidance to improve, or 'form' the program itself by providing periodic summative feedback and by answering the question 'why'. Recent work at ICRISAT has concentrated on summative evaluations to estimate the historical impact of previous innovations (for example, Bantilan and Joshi 1996).

A program can have multiple impacts. Mohr (1992) identifies five functions connected with the effectiveness of a multiple-outcome program:

- *finding* which outcome dimensions are affected;
- *limiting* the analysis to some impacts, and not others;
- *assessing* the impact on each outcome;
- *common-scaling* to put different, measures of impact together so that the effectiveness of the whole may be appraised; and
- *weighting* to assign relative importance to different impact scores.

Mohr discusses, and largely dismisses, cost-benefit analysis (CBA) as one way to approach this issue. In CBA, little attention is paid to finding and limiting, although care is taken to admonish against double counting. The function of assessing impact is central to CBA. The concept of economic surplus is frequently used. Mohr writes:

The heart and soul of benefit-cost analysis lies in the creative application of economic theory to pertinent, retrievable, existing data for the purpose of assessing impact by inferring what would have happened under a variety of conditions.

Common-scaling and weighting functions are handled quite simply in CBA by using money. Sometimes the income accruing to different groups (for example, the rural poor or illiterate women) is weighted differently. Impact evaluation addresses these five functions in a more comprehensive way than CBA.

Program evaluations are not used as extensively as one might expect. Mohr notes several issues:

- the need for comprehensiveness in the presentation of outcomes;
- the correct choice of the outcomes that are to be submitted to actual research;
- the need for quality in the selection and execution of research designs; and
- recognition that, in most cases, the evaluation should be formative.

Guba and Lincoln (1989) describe the four generations of evaluation. The first generation was concerned with generating measurements. The role of the evaluator was technical and evaluators were expected to know about different evaluation instruments so that any variable named for investigation could be measured. The second generation approach was characterized by descriptions of patterns of strengths and weaknesses with respect to certain stated objectives. The role of evaluator was that of describer. Measurement was considered to be one of several tools that could be used in evaluation. In third generation evaluation, the evaluator assumed the role of judge while retaining earlier technical and descriptive functions as well. All three generations, according to Guba and Lincoln, suffer from serious defects:

- With a tendency towards managerialism, the manager is held harmless. The typical manager/evaluator relationship is disempowering and unfair, disenfranchising, and likely to become a cozy one.
- The pluralism of values is not accommodated. If it is accepted that science is not value-free, then findings are subject to different interpretations and facts are determined in interaction with the value system the evaluator brings to bear. Every act of evaluation becomes a political act.
- An overcommitment to the scientific paradigm of inquiry has led to context-stripping. The resources needed to institute and maintain controls offset other uses to which the inquiry might have been put, thus restricting the range of available information. According to Guba and Lincoln, the effort to derive general truths through context-stripping (control) is one of the reasons why evaluations are so often found to be irrelevant at the local level.
- An overdependence on formal quantitative measurement. Guba and

Lincoln note the coerciveness of truth (both evaluator and manager are rendered unassailable). This closes out alternative ways to think and relieves the evaluators of any moral responsibility for their actions.

Guba and Lincoln present an alternative approach which they call fourth generation evaluation. They describe this as 'responsive constructivist evaluation'. The features of constructivist methodology include:

- truth is a matter of consensus among informed and sophisticated constructors, not of correspondence with objective reality;
- facts have no meaning except within some value framework, hence there cannot be an objective assessment of any proposition;
- causes and effects do not exist except by imputation;
- phenomena can be understood only within the context in which they are studied;
- interventions are not stable;
- change cannot be engineered;
- evaluation produces data in which facts and values are inextricably linked;
- accountability is a chaiacteristic of a conglomerate of mutual and simultaneous shapers;
- evaluators are the subjective partners with stakeholders in the literal creation of data;
- evaluators are orchestrators of a negotiation process that attempts to culminate in consensus on better informed and more sophisticated constructions; and
- evaluation data derived from constructivist inquiry have neither special status nor legitimacy — they represent simply another construction to be taken into account in the move toward consensus.

For us, it is a key design issue whether a more traditional economic CBA (for example, along the lines described by Alston et al. 1995), conducted either ex-post or ex-ante, provides a sufficient basis to guide a progressively unfolding research and development process in which:

- several groups of actors (who contribute different aspects to the technology) take part;
- the technology is continually changing;
- the context in which the technology is being used varies and is constantly changing; and
- continual feedback is required as we move toward a goal which is also under continual renegotiation.

Cox et al. (1997) discuss the indeterminacy of the communication environment within which such technologies are developed. They point out that sustainability can be reconstructed as a process improvement tool and can be equated with a quality process. Impact assessment also has a role as a process improvement tool.

Impact assessment of IPM technologies

Agriculture is an activity that converts rainfall (and other inputs) into income. The crop is the tool used to achieve this transformation. How well it does depends on many different constraints such as labor supply, availability of credit and markets, demands of competing crops, and a large number of biotic and abiotic factors. Insect pests and diseases are important biotic constraints to crop production. In recent times, the way of reducing these constraints (and thus promoting crop production) has often been through the use of synthetic chemical pesticides. These contribute significantly to the cost of crop production. They also generate other costs which economists often describe as 'negative externalities' because they affect the production and/or consumption activities of people other than those making specific pesticide applications in crop production. Two kinds of negative externality are associated with pesticide use — environmental pollution (which is generally held to be undesirable and which society would prefer to reduce because of concerns about public health and ecological damage); and the development of resistance to pesticides in insect and pathogen populations (which directly affects others who use the particular chemistries against the same pest population).

IPM poses special problems for impact assessment. The standard model of the research-extension continuum does not apply in the same way as for seed-based technologies taken in isolation (e.g., Bantilan and Joshi 1996) nor, for that matter, for investments in the development of chemical pesticides. Some reasons for this assertion will be discussed, along with implications for how research and extension in IPM are conducted and evaluated.

Standard model

The standard model used in impact assessment studies at ICRISAT assumes a research-extension continuum that distinguishes basic, applied, and adaptive stages in the research process. Times to pass through these stages can be assigned to the research program, which eventually results in a product that emerges from the research station gate that can be multiplied and distributed, then adopted by farmers. The expected increase in yield provides an estimate of the value of the technology on a unit area basis in any given year. Impact assessment surveys indicate how widely the technology is used. Multiplication of these two factors gives an (historical) annual value of the benefit associated with the technology.

A discounted cash flow analysis, taking into account both the costs of research and development, and the increasing benefits associated with the progressive adoption of the technology within a temporal map, indicates in a single figure the value of the return on research investment (net present value) assuming a particular rate of discount (usually a standard value used by local planners). Thus, the standard model makes certain assumptions about the way research and development are conducted, the temporal pattern of costs and benefits, the legitimacy of using estimates of averages in place of distributions, and the stability (both spatially and temporally) of the benefits imputed to the technology. Few of these assumptions fit easily with IPM technologies.

IPM technology

IPM is a complex technology involving several components; some may be seed-based, but other components (especially management strategies) are also included. The problems this causes for impact assessment are associated with three characteristics of IPM — integration, pests, and management.

Integration problems

Integration poses several problems for evaluation. The various technological components that are 'integrated' in an IPM package usually have different histories — they come from different people and organizations and are in different stages of development. The overall response to IPM is a response to all components combined in different ways, and it is difficult to separate individual treatment effects. In addition, there may be synergistic effects between components. The overall effect is multiplicative rather than additive — only if one aspect of the problem situation is solved can a response to other components be demonstrated. Components can be combined in different ways, adopted or not adopted separately, and incorporated in different ways with existing practices. The technology is flexible and adaptive.

Pest problems

Pest are living organisms that exist in a dynamic relationship with host plants. This relationship is changing continuously because of pest population cycles, the response to previous interventions (for example, previous pesticide applications), and random fluctuations associated with weather patterns. Pest populations evolve within the time frame required for impact assessment, for example through the development of resistance to pesticides. There are often several different pest populations available to attack a crop; if one problem is solved, another will take its place.

Management problems

Unlike seed-based technologies, which are either adopted or not, management technologies can be adopted to a greater or lesser extent. They can be changed and are likely to adapt very quickly to local and changing circumstances. They are thus relatively unstable and additional inputs mean that it is difficult to attribute particular local variations to any specific intervention. Also, much of the process of IPM is about substituting information, knowledge, and skills for physical inputs, for example, estimating threshold levels for particular pest species rather than routine calendar spraying. The development of human capital is inherent in the IPM approach.

Implications

Use of a discounting model attaches different values to the temporal pattern of costs and benefits. Yet, compared to seed-based technologies, the benefits are distributed less evenly because they depend on the severity of pest attacks and efficacy of the controls (both variable, and both with larger spatial and temporal correlations).

Cumulative probability density functions (CDF) of the net present value can be used to capture some of the stochastic nature of these interventions, such as the annual variability of pest incidence. In addition, the rate of development of other pest problems (such as greater exposure to attack by other pest species and the rate of development of resistance) is indeterminate.

Different technological components will typically have different risk profiles, some of which will be captured by comparing respective CDFs. It is important to cover all costs. This applies particularly to extension costs because the introduction of IPM typically involves a substantial training component and the development of trust between different groups of actors.

It will be more difficult to generalize about what constitutes the technology because components of the integrated technology will be adopted piecemeal and at different rates, and adapted in different ways. The components of the technology will be at different stages in their own development, for example, off-the-shelf chemicals and seeds, locally-adapted changes in farming practices, and progressive substitution of information inputs for physical inputs (use of thresholds and identification of pests; knowledge of efficacious pest-pesticide combinations). It will be difficult to specify the benefits associated with component technologies apart from the other technologies progressively implemented as part of an ongoing IPM program. The technology changes as the implementation proceeds — fanners experiment with and modify recommended practices, adopting some components and not others, and integrating the imported components with existing practices.

In general, there are multiple stakeholders, all of whom can claim to have made a contribution to the realization of benefits. Typically it will be difficult to attribute the benefits of the technology to a single group of key originators because the players are diverse — NARS, international agricultural research centers, non-governmental organizations, pesticide manufacturers and dealers, and farmers. IPM should be seen as a process and an ideology, as well as a technology. Thus the development and implementation of IPM technologies argues for participation in research and extension, the progressive substitution of knowledge inputs for chemical inputs, the integration of technological components at several levels, continual learning and modification as both research and extension proceed, and impact assessment.

All this provides an argument for much greater use of ideas and concepts from program evaluation, both qualitative (Guba and Lincoln 1989, Patton 1990, Wads worth 1991) and quantitative (Mohr 1992), as part of the research process. It argues for a formative rather than a summative approach, and perhaps for the deliberate choice of a constructivist rather than a more traditional (positivist) paradigm.

Case study — IRM in Australia

Management of insecticide resistance can be approached through integrated resistance management (IRM). From an economic point of view, susceptibility in insect populations to specific insecticidal chemistries is a common property resource with open access. Property rights are poorly defined and likely to lead to over use, often referred to as 'the tragedy of the commons'. Insect susceptibility is analogous to air and water resources, and faces similar problems for effective management. One approach is to tax use of the resource, for example, taxing insecticides so that the outcome achieved by people making individual decisions about their use is closer to the 'social' optimum in which the use of uncosted resources such as susceptibility is taken into account. Another approach is for people to manage such resources collectively so that the benefits which accrue to the group (rather than the sum of individual benefits) is maximized. The insecticide resistance management strategy for Australian summer crops attempted to do this (Cox and Forrester 1992).

The IRM in eastern Australia to manage *Heliothis armigera* in summer crops (mainly cotton) was a response to the development of resistance to pyrethroids at Emerald in the early 1980s. The IRM strategy defined three stages based on calendar dates. The use of endosulfan® was restricted to the early stages of cotton growth (stages 1 and 2); use of pyrethroids to stage 2; neither chemistry was to be used in stage 3. There were some other rules, but these were the main ones. The objective was to alternate the use of different chemistries in a concerted way across the entire cotton (and other summer crop) industries in eastern Australia, and to allow time for the stock of susceptibility to recover before drawing on it again in the following year. Both endosulfan® and pyrethroids were seen as valuable chemistries (in terms of efficacy, specificity, and low human toxicity) that were worth preserving. The entire summer crop industries collaborated in implementing the strategy.

It is difficult to assess the value of such an intervention because of its large scale and one-time use. Economists usually compare 'with' and 'without' situations, but there was not straightforward 'without' situation for comparison. Cox and Forrester tried to do this in two ways — by estimating the increased cost of obtaining similar control using other available chemistries, and by comparing the situation with what cotton experts believed would probably have happened if endosulfan® and pyrethroids were lost to the cotton industry because of the rapid development of resistance and if nothing else was done. Both estimates suggested that the investment in IRM had provided a substantial economic return throughout the 1980s. The IRM in Australia is seen as an example of a successful strategy for the management of insecticide resistance.

There were many reasons for the success of the IRM in Australia. Four sets of contributing factors can be distinguished:

- *Biological* factors include the prior implementation of IPM (scouting, spraying on threshold, using soft chemistries where appropriate, not using the same chemical again after a spray failure); and the availability of a cheap and effective way to monitor resistance.
- *Historical* factors include the recent memory of the collapse of the cotton industry on the Ord River in Western Australia in the 1970s, and the comparatively recent development of the cotton industry in eastern Australia.
- *Economic* factors include the high capitalization of the Australian cotton industry, the overall value of the crop and the importance of the cotton industry in Australian agriculture, and the practice of forward-selling cotton.
- *Social* factors include the small size of the cotton industry (in terms of the number of farms and farmers), the use of consultants to advise on spray decisions, the frequent use of third parties to apply insecticides from the air, the innovative nature of the industry (it is well-integrated and forms a cohesive network of growers, ginning companies, pesticide distributors, and RD&E professionals), the willingness of the industry to listen to and accept professional advice from others, the availability of continual monitoring information so people could see how resistance was developing, and the perceived threat from environmental lobbyists.

It is clear that the IRM strategy, as implemented in Australia, was a social technology based on the participation of many actors in conformity with an agreed pattern of behavior. The rules of the strategy were simple and straightforward. Voluntary compliance was the key to its technical and economic success, which depended on many factors peculiar to the Australian cotton industry at that time. It seems unlikely that the strategy can be transferred in any simple way to more complex situations in other cropping systems and in different parts of the world. It does, nevertheless, suggest valuable lessons about the need for industry-level collaboration to manage insecticide susceptibility in an effective way, and that this is feasible through voluntary means, and can be effective.

Lessons for assessment of IPM strategies

The case study outlined in the previous section incorporates several examples of the issues raised in a general context in the introductory sections of this paper. The potential consequences in this example, perhaps even more striking than other IPM examples, were cast in the negative (increased costs, collapse of the cotton industry if nothing were done). It was hypothetical — there was no experimental or quasi-experimental design, nor was this possible because of the scale on which the intervention was introduced, dictated in turn by the nature of the problem. The hypothetical consequences were estimated in a fairly rough way based on assumptions about the change in cost structure needed to achieve adequate control in other ways, or by analogy with roughly comparable situations elsewhere about which little was known. Thus the estimates of economic return on investments were subjective in the sense that they were based on subjective estimates (expert opinion) of key coefficients.

The economic analysis used by Cox and Forrester was cast within a simple CBA framework using the concept of economic surplus. This provided coarse estimates which set wide limits to the estimated returns. Several estimates, obtained in different ways, were used in an attempt to specify the returns. But, in any case, the analysis was subjective because it was based on assumed consequences. On the other hand, the social context of the intervention was complex. It is difficult to define a simple cause-effect relationship that can be generalized to other situations.

The intervention was agreed to have been a success and to have been achieved in a cost-effective manner. But numerous factors contributed to its success in various ways. The attempted formal evaluation was formative — it occurred before the end of the intervention and contributed toward its continuation. It was a political act used to endorse a particular set of values about the way pest problems should be managed in order to match the aspirations of a wider community.

The time scale was about 10 years. The IRM had maintained insect susceptibility to pyrethroids and endosulfan® for continued use about this time. At the end of this period, new chemistries were starting to become available. Sustainability for 10 years might appear modest by some standards, but this may be the sort of time scale needed for other kinds of IPM intervention. The resistance levels and the nature of the response changed within that time scale. The susceptibility was progressively used up, and by that time other options had emerged and the situation was very different from that at the start of the planning period.

Although 100% achievement of the program objective (if this is stated simply in terms of maintaining the susceptibility) is theoretically possible, in practice partial achievement is likely to be the norm. In this case, there was no standard by which to gauge the 'normal' level of success. The intervention can be construed as action research — it was not known at the start whether the arrangements would work or not.

The case study emphasizes the importance of continual feedback to the participants, in this case feedback about the current levels of resistance obtained through monitoring resistance levels. These were not formally converted into monetary values, although farmers could do this informally by noting the number of pyrethroid and endosulfan® sprays that they could use before a spray failure curtailed their continued use in a particular season. This feedback was formative in that it contributed to the continued adherence to the technology. Indeed, the technology was modified (for example, by shortening the stage 2 window) partly in response to this feedback. The IRM strategy had specific objectives — to contain the development of resistance in a target insect population to specific categories of chemicals. The success (or otherwise) of the project could thus be assessed directly against these prespecified criteria.

The technology was technically simple, but still required significant negotiation of meanings — about resistance, its implications, what can be done about it, and how to go about doing it. Social mobilization was critical for the success of the technology. Evaluation was part of this formative process, reinforcing certain courses of action rather than others.

Conclusion

IPM poses certain challenges for program evaluation and impact assessment compared to relatively simple technical interventions such as those associated with seed-based technologies. Formative evaluation (continual, with a view to modification of future behaviors) will be an important part of developing novel technological components, as will incorporating these into integrated patterns of behavior tailored to the requirements of particular situations. Although detailed costing of certain components is part of this, an appreciation of the goals and aspirations of different groups of actors, and of the constraints within which they operate, requires a wider perspective. The need to negotiate progressive learning and novel configurations argues for a richer interpretative framework, including the use of experimental design and program evaluation. Impact assessment in this sense is an active research tool for guiding collaborative action in the development and implementation of novel strategies for IPM. It is not something done at the end when the action is all over and the problem has been solved.

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Utilization of ICRISAT Intermediate Products by Seed Sector and NARS, and Value of Networking

Use of ICRISAT/NARS Pearl Millet Germplasm

M C S Bantilan[1], K N Rai[1], and K V Subba Rao[1]

The fundamental approach to genetic enhancement research at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is to develop parental materials — male-sterile lines, segregating materials, and improved resistance sources — to facilitate the breeding programs of national agricultural research systems (NARS) and the private seed sector. With an ultimate aim to improve production worldwide, ICRISAT has freely made its germplasm and breeding materials available to both developing and developed country NARS. The NARS evaluate these materials from ICRISAT, select promising lines for direct use and/or incorporate them into breeding programs to develop improved varieties. Many of these have been successfully released and adopted by farmers.

From an institutional point of view, it is important for ICRISAT to assess the value of improved germplasm and parental lines to NARS and the private seed sector. Systematic documentation and analysis of the use of ICRISAT-bred improved germplasm is required. With the cooperation of its collaborators — NARS and the private seed sector — ICRISAT can better understand the role of its improved germplasm in varietial development worldwide; it will also learn about their constraints and limitations.

Tracking germplasm utilisation

A three-pronged approach (Fig. 1) was employed to track usage of pearl millet parental lines and varieties by the NARS:

- Requests for breeder seed and distribution data were traced from the sources (ICRISAT and NARS) through the seed sector channels (both private and public) to farmers (Approach 1).

Bantilan, M.C.S., Rai, K.N., and Subba Rao, K.V. 1998. Use of ICRISAT/NARS pearl millet germplasm. Pages 217-223 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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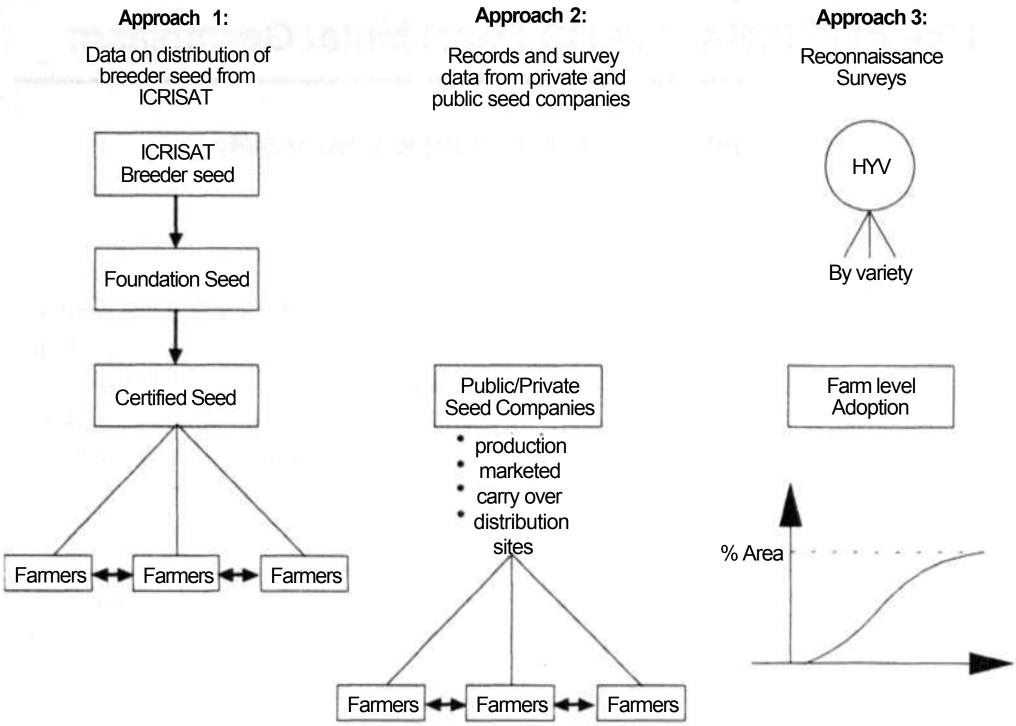

Figure 1. Three approaches to track the adoption and impact of investments in research and development.

- Private and public seed companies may be surveyed to obtain information on the extent of utilization and value of ICRISAT-bred open-pollinated and parental lines in terms of seed production, multiplication, and distribution (Approach 2).
- On-farm surveys may be undertaken to determine the extent of adoption and impact of improved cultivars in farmers' fields (Approach 3).

Results

This paper reports data generated through this three-pronged approach. Under the first approach, records of breeder seed dispatch registers available at ICRISAT were used to document the distribution of released cultivars (open-pollinated varieties and hybrid parents) from the ICRISAT breeding program to NARS seed multiplication agencies (public or private). For example, Table 1 lists the volume of pearl millet breeder seed of hybrid parents and open-pollinated varieties distributed by ICRISAT to public and private seed multiplication agencies in India during the period 1991-95. This supply has been substantial, with trends showing an increasing number of requests. It is noted that the volume of seeds demanded from the agencies normally

Table 1. Supply of pearl millet breeder seed from ICRISAT to seed multiplication agencies in India, 1991-1995.

	Seed supplied in kgs											Number of agencies per year	
	1991		1992		1993		1994		1995				
Genotype	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Total	Maxi-mum	Mini-mum
Hybrid parents													
81A	126	104	125	234	116	108	96	133	19	25	1086	63	91
81B	63	47	57	116	55	55	42	55	7	1	498	63	31
ICMP 451	95	29	37	86	47	53	52	56	43	78	576	52	27
834A	0	1	0	2	0	2	0	3	0	0	8	1	0
834B	0	1	0	1	0	1	0	2	0	0	5	1	0
ICMP 501	0	1	0	1	0	3	0	1	0	0	6	1	0
841A	61	112	76	81	59	73	51	73	78	144	808	48	35
841B	30	65	37	40	27	38	26	36	49	66	414	46	35
ICMP 423	2	40	3	11	0	9	0	2	0	0	67	18	0
842A	—	—	—	—	—	14	21	52	110	45	242	22	7
842B	—	—	—	—	—	7	11	24	17	21	80	22	7
843A	25	56	31	62	10	26	48	82	47	54	441	42	22
843B	14	30	15	31	6	8	22	42	20	29	217	42	22
ICMA 88004	—	—	—	—	13	43	13	29	20	24	142	24	17
ICMB 88004	—	—	—	—	5	24	7	14	10	12	72	24	17
ICMR 356	—	—	—	—	5	24	7	17	60	10	123	22	7
Subtotal	416	486	381	665	343	488	396	621	480	509	4785		
Open-pollinated cultivars													
WC-C75	48	20	45	39	84	62	89	65	7	2	461	38	41
ICMS 7703	6	2	15	2	4	12	4	3	4	7	59	6	2
ICTP 8023	63	141	47	154	67	176	45	94	24	37	848	60	211
ICMV 155	22	35	56	71	27	47	53	59	25	24	419	38	12
Raj 171	—	—	—	—	—	—	15	55	30	17	117	5	4
ICMV 221	—	—	—	—	15	51	95	120	116	88	485	29	23
Subtotal	139	198	163	266	197	348	301	396	206	175	2389		
Total	555	684	544	931	540	836	697	1017	686	684	7174		

determines the volume of seeds supplied. The figures in Table 1 reflect the relatively higher proportion that is supplied to the private sector, both for ICRISAT-developed hybrid parents as well as ICRISAT-bred open pollinated varieties. Among hybrid parents, 81 A, 81B, 841 A, 841B, 843A, and 843B are the most frequently requested, and therefore supplied to research agencies, both public and private. The small amounts of hybrid parents 834A and 834B that was supplied during 1991-95 were received by the private sector. The volume of 841A and 843A supplied in the recent years have been increasing, replacing 81A and 81B which dominated earlier. It is noted that the volume required of the latter materials remained high, but the responsibility for production and supply of breeder seed of 81A and 81B was turned over to public sector seed corporations in India in 1995.

Table 2 lists the specific lines in the

Table 2. Pearl millet hybrid parents and open-pollinated varieties supplied as breeder seed from ICRISAT in India.

Line/cultivar	Remarks
Seed parent (A/B line)	
81A/B	Female parent of ICRISAT-bred hybrid ICMH 451 released in 1986; Harayana Agricultural University-bred hybrids HHB 50 released in 1986 and HHB 60 released in 1988
841A/B	Female parent of Indian Agricultural Research Institute-bred hybrids Pusa 23 released in 1987 and Pusa 322 released in 1993; ICRISAT-bred hybrid ICMH 423 released in 1987
842A/B	Female parent of Harayana Agricultural University-bred hybrid HHB 68 released in 1993
843A/B	Female parent of Harayana Agricultural University-bred hybrid HHB 67 released in 1990
ICMA/B 88004	Female parent of ICRISAT-bred hybrid released in 1993
Pollen parent (R-line)	
ICMP 423	Male parent of ICRISAT-bred hybrid ICMH 423
ICMP 451	Male parent of ICRISAT-bred hybrid 451
ICMR 356	Male parent of ICRISAT-bred hybrid 356
Open-pollinated variety	
WC-C75	ICRISAT-bred variety released in 1982
ICMS 7703	ICRISAT-bred variety released in 1985
ICTP 8203	ICRISAT-bred variety released in 1988
ICMV 155	ICRISAT-bred variety released in 1991
ICMV 221	ICRISAT-bred variety released in 1993

Source: Rai, K.N. and Hash, C.T. 1995. Handout on breeder seed of pearl millet distributed by ICRISAT to seed-producing agencies in India. Presented at Study Program on Methodology for Adoption and Impact Evaluation, 25 Oct-7 Nov 1995, ICRISAT, Patancheru, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)

breeder seed production program at ICRISAT. Figure 2 shows the seed volume of ICRISAT parental lines distributed starting 1990 which was maintained during the subsequent years. It is observed that the supply of open-pollinated varieties (OPV) consistently rose up to 1994. The decline noted starting 1995 is explained by the

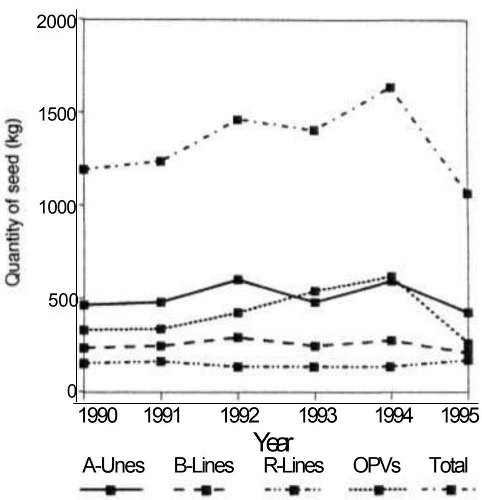

Figure 2. Parental lines and open-pollinated varieties of pearl millet distributed to public and private seed agencies in India, 1990-95.

Source: Rai, K.N. and Hash, C.T. 1995. Handout on breeder seed of pearl millet distributed by ICRISAT to seed-producing agencies in India. Presented at Study Program on Methodology for Adoption and Impact Evaluation, 25 Oct-7 Nov 1995, ICRISAT, Patancheru, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)

fact that the responsibility for production and supply of two popular OPVs, ICTP 8203 and WC-C75, have been largely turned over to public sector seed corporations. ICRISAT maintained responsibility for newly released cultivars like ICMV 155,and ICMV 221.

The second approach produced vital information about the role of ICRISAT parental lines in breeding programs and the seed sector. A survey of private seed companies gave interesting information on the extent of utilisation and value of ICRISAT-bred open pollinated and parental lines in terms of seed production, multiplication, and distribution. Out of 49 private seed companies in India who responded to the mailed-in questionnaires, 37 were involved in pearl millet production. 34 companies reported using ICRISAT-developed breeding lines while 3 companies reported not receiving ICRISAT breeding materials at all.

A summary of the sources of breeding materials reported by the respondents, along with the level of importance, is presented in Table 3. The three main sources were reported: ICRISAT, own collection, and ICAR/ SAU. The utilisation of ICRISAT breeding materials in the companies[1] research programs is shown to be extensive: 71% reported usage of materials by selections from ICRISAT materials; 65% as parents in crossing; 59% use materials directly as parents of hybrids; and 24% use them directly as varieties. The list of varieties and hybrids produced by the companies during the period 1989-94 revealed the

Table 3: Sources of breeding material of pearl millet and level of importance (frequency)

	Preference		
Source	Very important	Some importance	Not important
ICRISAT	28	6	1
Own collection	17	12	6
ICAR/SAU	12	10	13
Parent CoVJoint venture	3	6	26
Foreign company	1	5	29
Other company	0	10	25

Note: 2 firms did not respond to this question

dominance of ICTP 8203, BK 560, ICMH 179, HHB 67 from the public sector and a series from Mahendra, PROAGRO, and Pioneer Seed Companies from the private sector in India.

On-farm surveys were used to determine the extent of adoption of improved cultivars in farmers' fields. Figure 3 illustrates an aggregate picture which highlights two phases showing the changing share of ICRISAT, NARS and the private sector among the cultivars adopted in farmers' fields. Phase 1, before 1991, represents the phase where ICRISAT and the public sector shares dominated the market. Phase 2 (after 1991) represents the period where the private seed sector has grown and flourished.

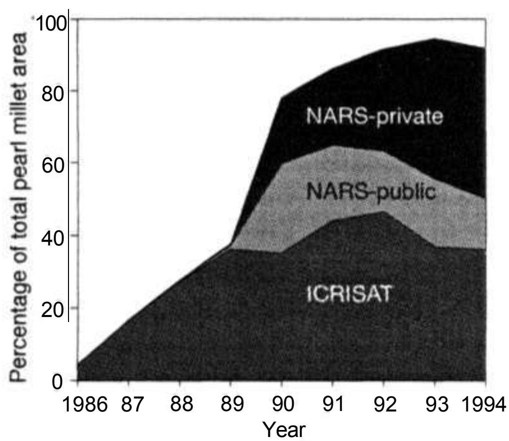

Figure 3. Adoption of pearl millet varieties from ICRISAT, public and private sector germplasm in Maharashtra, India.

In totality, the results put together highlights the role ICRISAT has played in: 1) providing final products to farmers through the NARS; and 2) supplying parental materials to the seed sector which now (in India and other countries) has the capability of delivering the seeds to farmers. This specific result shows that the partnership by ICRISAT, NARS and the private seed sector achieved joint impact. The collaboration is of many dimensions, including a huge payoff to strong partnership among international, national and private sector research communities; effective use of the global gene pool; and application of cutting-edge science using molecular markers for gains in breeding efficiency, towards the control of downy mildew epidemics. This pearl millet-downy mildew story provides a striking illustration of how an international research investment can trigger subsequent waves of investment by the national public and private sectors, creating a local research base to underpin further progress.

Use of ICRISAT Intermediate Products by the ProAgro Seed Company

P Verma and R Sehgal[1]

ProAgro is a leading seed company in India dedicated to serving Indian farmers by producing and marketing seed of genetically improved high-yielding varieties and hybrids. The company was registered in 1977 as a research and technology company and started working on major field crops. The company is engaged in breeding, production, and marketing of hybrid seed of maize, sorghum, sorghum sudan grass, pearl millet, forage millet, sunflower, cotton, mustard, rice, tomato, eggplant, okra, chillis, cabbage, cauliflower, watermelon, cucumber, ridge gourd, bitter gourd, capsicum, among others. ProAgro is also working on applied biotechnology research and is ready to commercialize its transgenic hybrids in mustard and vegetables in India.

ProAgro's strengths

ProAgro has a strong research program, with over 50 scientists and 15 research stations across India. Some of the strengths of the research program include:

- Management commitment to research— ProAgro's chairman, Suri Sehgal, is an undisputed leader in the global seed industry and is himself a renowned scientist.
- Strong research and development infrastructure that includes scientific manpower, rich germplasm resources, and excellent laboratory and field facilities. Each crop program has at least three scientists, two breeding stations, and eight testing locations across the country.
- International links — both technical and commercial — with public institutions (International Crops Research Institute for the Semi-Arid Tropics, Centro Internacional de Mejoramiento de Maiz y Trigo, International Rice Research Institute, Asian Vegetable Research and Development Center, national agricultural research services, and universities), as well as with corporate partners.

Verma, P., and Sehgal, R. 1998. Use of ICRISAT intermediate products by the ProAgro Seed Company. Pages 224-227 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

1. Field Crops Division, ProAgro Seed Company Ltd., 8-1-39 Toll Chowki, Hyderabad 500 008, Andhra Pradesh, India.

- Strong interaction with the Indian Council of Agricultural Research (ICAR), Indian universities, etc., and active participation in ICAR sponsored-workshops, meetings, and seminars.
- Global access to technology from several public and private institutions.
- Commitment to new technologies, especially in the areas of applied biotechnology and information technology. ProAgro is working to commercialize transgenics in mustard, tomato, cabbage, cauliflower, and eggplant, and have begun research on marker-assisted selection to supplement traditional plant breeding research.

Direct benefits to ProAgro from ICRISAT

ProAgro's sorghum and pearl millet research programs have benefited tremendously from ICRISAT research projects related to these two crops. The most direct benefit is, of course, easy access to improved germplasm. Nonetheless, ProAgro has benefited from more than just ICRISAT germplasm (Table 1).

Germplasm, especially the segregating material received from ICRISAT, is a very valuable resource in our research programs. ICRISAT works with a broader perspective because its mandate areas extends to different regions in the world. It also collects and maintains a large number of germplasm accessions in its gene bank from all

Table 1. Benefits to ProAgro from its association with ICRISAT.

Pearl millet	
1989	188 breeding lines
1990	11 germplasm lines 167 breeding lines
1991	15 germplasm lines
1992	30 germplasm lines 163 breeding lines
1993	85 germplasm lines 43 breeding lines
1994	132 germplasm lines 146 breeding lines
1995	8 germplasm lines
Total	988
Sorghum	
1990	97 high-tillering accessions 18 inbred lines
1992	32 inbred lines 36 segregating lines
1993	68 inbred lines
1994	42 germplasm lines 2 grain mold resistant lines
1995	43 germplasm lines
Total	338
Cooperative testing	
1991/92	Seed producers' hybrid trials in sorghum and pearl millet

- Participation in sorghum and pearl millet field days
- Cooperative field screening of pearl millet for downy mildew resistance at Gurgaon
- Access to information — library services, SATCRIS services, ICRISAT publications, and discussions with scientists
- Cooperation in application of biotechnology tools for crop improvement — marker-assisted selection for accelerated breeding, management of resistance to downy mildew in pearl millet, and manpower training

over the world. We therefore have easy access to this valuable germplasm and elite material from other parts of the world, which would not otherwise be possible for a company like ours with limited resources.

Downy mildew screening techniques developed at ICRISAT are being used by ProAgro to screen our breeding material. ProAgro is actively collaborating with ICRISAT in its downy mildew resistance program. ICRISAT is utilizing the sick plot developed on ProAgro's research station at Gurgaon to screen its elite nursery material for downy mildew resistance.

ICRISAT took the initiative to conduct and coordinate cooperative testing of public- and private-bred hybrids of pearl millet and sorghum at different locations in India. This provided an unbiased evaluation of our elite hybrids in comparison to those of the competition. ProAgro contributed to these trials for 2 years (1991 and 1992). Later these trials were discontinued by ICRISAT. The company feels that such trials are highly useful and should be started again.

ProAgro also participated in ICRISAT's multilocational testing of two parental line trials of pearl millet during 1993 and 1994. These trials were also visited by ICRISAT scientists. Regular feedback was provided to ICRISAT about these trials.

ProAgro is also working very closely with ICRISAT to develop a marker-assisted selection protocol to be used in its disease resistance breeding program. One of ProAgro's employees received training at ICRISAT to familiarize himself with the techniques involved. Increased cooperation between ICRISAT and the private sector for such activities will be of tremendous benefit to the Indian seed industry.

We have also used ICRISATs Semi-Arid Tropical Crops Research Information Service (SATCRIS) to obtain information about the ongoing research work on these two crops. This service is very useful to keep us abreast of new research work and update our knowledge about sorghum and pearl millet research. We have also received photocopies of articles from the ICRISAT library based on our requests after going through SATCRIS information. We have also used the literature search program at the ICRISAT library. ICRISATs books, brochures, and bulletins on sorghum and pearl millet have been of immense help to our research workers.

ICRISAT has provided important inputs to our sorghum and millet research programs, and has indirectly contributed to the growth of ProAgro (Table 2).

Table 2. Percentage increase in quantity of seed sold by ProAgro over the previous year.

Crop	1993	1994	1995	1996
Pearl millet	17	35	18	15
Sorghum	63	141	37	40
Sudan grass	5	5	18	20

Conclusion

The link between ProAgro and ICRISAT has been of tremendous benefit, especially because we have the commitment and scientific and technological capability to make use of ICRISAT technologies to benefit the Indian farmer. We are committed to further strengthening these links and look forward to further cooperation in areas of mutual interest.

Use of ICRISAT Genetic Materials by the Maharashtra Hybrid Seeds Co.

S C Sawe[1], P S Kharche[2] and P N Tupekar[3]

Seeds carry genetic improvements in crops, and therefore a continuous supply of genetically superior varieties and hybrids is critical to the agricultural development of any country. For over 30 years, the goal of Maharashtra Hybrid Seeds Company (MAHYCO), has been to meet the increasing food, oil, and fiber requirements of India by providing the Indian farmer with high-quality seed of improved hybrids. The majority of hybrids marketed by MAHYCO are products of company research. Current research efforts involve more than 30 crop species, of which the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has been a valuable supplier of germplasm for pearl millet (bajra), sorghum (jowar), and pigeonpea (tur).

ICRISAT is a valuable partner with national and regional agricultural research programs through international training and other enabling extension activities. There is a growing concern about conservation of biological diversity, the sustainable use of its components, and fair and equitable sharing of the benefits derived from these resources. Emphasis on shared genetic resources has been fundamental to ICRISAT's mandate, with a recognition that enhanced agricultural productivity in the developing world cannot be sustained without both availability and continuous access to crop genetic resources. ICRISAT has played a critical role in supplying improved germplasm and technologies to Indian national scientists, private sector industries, and ultimately farmers.

MAHYCO has benefited from use of ICRISAT germplasm in its research efforts to develop superior hybrids of pearl millet, sorghum, and pigeonpea in India. Broad-based germplasm for each

Sawe, S.C., Kharche, P.S., and Tupekar, P.N. 1998. Use of ICRISAT genetic materials by the Maharashtra hybrid seeds co.. Pages 228-230 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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2. Pigeonpea breeding, Maharashtra Hybrid Seeds Co. Ltd., Jalna Research Centre, Post Box 52, Jalna, Maharashtra 431 203, India.
3. Sorghum breeding, Maharashtra Hybrid Seeds Co. Ltd., Jalna Research Centre, Post Box 52, Jalna, Maharashtra 431 203, India.

of these crops has been used in breeding programs aimed at development of new inbred parents leading to hybrids. The greatest impact of ICRISAT germplasm has been in MAHYCO's pearl millet program. The era of pearl millet hybrids in India began in 1962 with the introduction of cytoplasmic male-sterile (CMS) line Tift 23A, developed at the University of Georgia Experiment Station in Tifton, Georgia. Five hybrids based on this CMS source were released in India during the 1970s, however, because male sterility was based on Tift 23A, outbreaks of downy mildew were of concern.

Because Tift 23A derivatives were susceptible to downy mildew, a program to diversify the germplasm base of male sterility in pearl millet began at MAHYCO. In 1973, the Serere 10LA and 10LB stocks were obtained from ICRISAT, which eventually gave rise to 13 new male-sterile lines, all of which were based on A, cytoplasm. One of these lines, MS 2, was used as a parent of hybrid MHB 110, which became a benchmark for agronomic productivity of pearl millet hybrids in India. Improvement of the pearl millet male-sterile germplasm base is an ongoing goal of MAHYCO research, with inputs from other ICRISAT materials, including MS 81 A, MS 863A, MS 841 A, MS 88006A, MS 842A, MS 91777A, MS 843A, and various selections from ICRISAT's pearl millet B-line nursery.

Efforts are continuing to develop a broadened germplasm base through incorporation of ICRISAT materials containing male-sterile A_4 and A_5 cytoplasm. Development of MAHYCO's fertility restorer lines has also been enhanced by use of ICRISAT germplasm, and materials from various Indian, African, and U.S. sources. ICRISAT pearl millet germplasm sources that have been useful in development of superior restorer lines include bold-seeded early composite, Nigerian composite, Barmer population 1994, improved world composite, early Rajasthan population 1091, dwarf composite, western Rajasthan population 1988, Ex Bornu short composite, and early composite.

These and other materials have been valuable contributors of genes that control dwarf stature, early flowering, glossy leaves, white seed color, fodder traits, and other morphological features important for adaptation to local Indian conditions.

In pigeonpea, ICRISAT materials have been used to develop new male-sterile sources and lines with resistance to insects and pathogens. The germplasm MS Prabhat has been used in development of male-sterile parents. Populations ICP 8863, ICP 83024, ICP 2376, and ICPL 87119 have been useful as sources of wilt resistance. ICPL 83024 and ICP 7035 have been used as sources of insect resistance or tolerance to *Atylosia scaraboiedies, Atylosia sericea, Atylosia albicans,* and *Atylosia playticarpa.*

In sorghum, ICRISAT materials have been evaluated for their utility in controlling the insect pests, midge, stem borer, and shoot fly, and various pathogens, including the parasitic weed *Striga.* Forty male-sterile lines and 75 genotypes conferring varying levels of insect resistance have been evaluated for their utility in breeding new parental lines.

To summarize, ICRISAT germplasm research and development has been useful in assisting both public and private breeding efforts within India. For MAHYCO, the impact of ICRISAT germplasm has been particularly strong in the pearl millet research program aimed at development of improved parental lines and hybrids based on CMS systems.

Evaluating Hybrid Technology for Pigeonpea

S K D F F Niranjan[1], M C S Bantilan[2], P K Joshi[2], and K B Saxena[2]

Pigeonpea *(Cajanus cajan* [L.] Millspaugh) is an important pulse crop grown mainly in tropical areas, especially south Asia, eastern Africa, the Caribbean region, and south and central America. Also known as redgram in south Asia, about 90% of world pigeonpea production is grown in India (Nene and Sheila 1990), where it is cultivated on 14% of the land area and provides 20% of the national pulse crop. Pigeonpea varieties differ in terms of their yield advantages and unit cost reduction, but the discovery of genetic male-sterility (GMS) at ICRISAT in 1974 offered exciting new potential for plant breeders (Saxena et al. 1996). Ultimately ICRISAT developed the world's first hybrid pigeonpea in 1991.

This paper examines the use of hybrid pigeonpea technology by national agricultural research systems (NARS) and seed companies. The study also investigates present GMS technology and its further development toward pigeonpea hybrids based on cytoplasmic male-sterility (CMS).

There are four main users of hybrid pigeonpea technology — farmers/seed growers, NARS, public seed companies, and private seed companies. In this study, all four users were assessed to:

- examine the use of GMS pigeonpea hybrids by NARS and seed companies in their breeding programs;
- assess the role of ICRISATs GMS lines in their hybrid pigeonpea breeding program; and
- identify constraints faced by NARS, seed companies, and seed growers in adopting the hybrid pigeonpea technology.

Hybrid technology for pigeonpea

In the process of searching for new avenues in pigeonpea breeding, there were several important milestones. In 1974, a wide search was undertaken at

Niranjan, S.K.D.F.F., Bantilan, M.C.S., Joshi, P.K., and Saxena, K.B. 1998. Evaluating hybrid technology for pigeonpea. Pages 231-240 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

ICRISAT Conference Paper No. 1354

1. Sri Lanka Council for Agricultural Research Policy, Wijerama, Mawatha, Colombo 7, Sri Lanka.
2. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

ICRISAT to identify genetic male-sterility among 7 216 germplasm lines and 124 F, derivatives of crosses between *C. cajan* and its wild relatives. In 1977, nine genetic male-sterile based hybrids were tested at ICRISAT-Patancheru, of which two performed better than the others with 33% and 24% heterosis over the best varietal control (ICRISAT 1990, Saxena et al. 1996). During 1978, studies indicated that male sterility in pigeonpea is controlled by a single recessive gene ms_1, and the anthers are translucent (Reddy et al. 1978). In 1981, another source of male sterility controlled by a non-allelic single recessive gene ms_2 was identified in Australia, which has brown arrowhead-shaped anthers (Saxena et al. 1983).

In 1988, a study was undertaken by ICRISAT and Tamil Nadu Agricultural University (TNAU) to determine the cost of producing hybrid pigeonpea seed (Murugarajendran et al. 1990). In 1989, a special project was launched by the Indian Council of Agricultural Research (ICAR) at nine centers in India to strengthen research and development of pigeonpea hybrids (Saxena et al. 1996). These nine centers are the Indian Institute of Pulses Research (IIPR), Kanpur; Punjab Agricultural University (PAU), Ludhiana; Haryana Agricultural University (HAU), Hisar; Indian Agricultural Research Institute (IARI), New Delhi; Gujarat Agricultural University (GAU), S K Nagar; Panjabrao Krishi Vidyapeeth (PKV), Akola; Tamil Nadu Agricultural University (TNAU), Coimbatore; Narendra Dev University of Agriculture and Technology (NDUAT), Faizabad; and Rajasthan Agricultural University (RAU), Dholi. In addition, other centers such as Banaras Hindu University (BHU), Varanasi; University of Agricultural Sciences (UAS), Bangalore; Bhabha Atomic Research Centre (BARC), Trombay; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru; and Maharashtra Hybrid Seed Company (MAHYCO), Jalna collaborated as voluntary centers (Srivastava and Asthana 1993, ICAR 1996).

First three hybrids

In 1991, ICPH 8, the world's first commercial hybrid pigeonpea, developed by ICRISAT, was released by the Indian seed release committee (Saxena et al. 1996). This was a breakthrough in plant breeding. Scientists at TNAU released another hybrid, CoH 1 in 1994 (Rathnaswamy et al. 1994). In the same year, a third pigeonpea hybrid, PPH 4, was developed and released by PAU in Ludhiana for cultivation in Punjab and the northern belts in India (Verma and Sidhu 1993, ICAR 1996).

All three GMS pigeonpea hybrids were short-duration, high yielding, and drought tolerant, with vigorous growth and wide adaptation to different agroclimatic conditions. They all have the same weakness, however, of a high labor requirement for seed production. At ICRISAT, the male-sterile gene was transferred into the diverse genetic background of different maturity groups. A mid to late disease-resistant male-sterile line *ms* ICP 3783 was used to develop disease-resistant medium- and late-maturing hybrids. Hybrids have a demonstrated 20-30% yield advantage in farmers fields.

Research on ICPH 8

The total R&D time from searching for genetic male sterility to seed production and technology exchange for hybrid pigeonpea ICPH 8 was about 22 years (Tables 1 and 2). Private and

Table 2. Research lag for development of ICPH 8.

Period	Activity	Years
1974-77	Basic research	4
1977-83	On-station adaptive research/applied research	6
1984-89	On-farm adaptive research/applied research	6
1991	Release of hybrid ICPH 8	2
1991	Seed multiplication and technology transfer	4
Total research lag		22

Table 1. Steps in the research process leading to the release of pigeonpea hybrid ICPH 8.

Year	Research step
1974	An extensive search was made at ICRISAT for male sterility among 7 216 germplasm lines and 124 F_4 derivatives of crosses between *C. cajan* and its wild relatives (Saxena et al. 1996)
1977	Nine genetic male-sterile based hybrids were tested at ICRISAT, of which two were found to perform well with 32% and 24% heterosis over the best varietal control (ICRISAT 1990)
1977 onwards	Experimental hybrids that exhibited high heterosis were subsequently tested in multilocational trials for stability and adaptability to different environments (Saxena et al. 1996)
1984-89	Multilocational testing under ICAR's collaborative trials and ICRISAT's 41 on-farm trials found 40-50% superior to control cultivars UPAS 120 and Manak (ICRISAT 1990)
1989	Tested in minikit trials at 12 locations in the Central Zone (Saxena et al. 1996)
1990	Submission of proposal to release to central sub-committee on crops standards, notification, and release of varieties (ICRISAT 1990)
1991	ICPH 8 released as the first hybrid in Central Zone of India

public seed companies have been producing hybrid seed since 1992.

Cytoplasmic male-sterility

Commercial hybrid pigeonpea seed producers using the GMS technology faced several problems, including timely removal of about 50% of fertile flowering plants, maintenance of male-sterile lines in a heterozygous state, and additional costs of labor, land, and supervision (Verma and Sidhu 1993). To overcome these problems, researchers at all the cooperating institutions are attempting to develop cytoplasmic male-sterility through mutagenesis and wide hybridization. In mutagenesis, gamma radiation and mutagenic chemicals are used, while wide hybridization uses wild pigeonpea species (Kumar et al. 1995;Saxena et al. 1996).

The first consultative group meeting on CMS in pigeonpea was held at ICRISAT in 1994, and several major priority issues for future research were identified (Saxena 1996):

- characterization of available CMS sources using cytological studies, DNA marker studies, and field testing;
- identification of new cytoplasmic sources;
- studies on stability of CMS and sensitivity to temperature;
- use of diverse pollinators to identify new maintainers and restorers;
- studies on the extent of pod setting through open pollination in isolation;
- use of pigeonpea derivatives from wide hybridization involving wild cytoplasm to investigate use in a CMS system; and
- preparation of a protocol for isolation of CMS in pigeonpea through wild hybridization, mutagenesis, and other methods.

Research activities to develop a CMS system are in progress at most of the research institutes (ICAR 1996). Results at ICRISAT confirmed that around 99% of male sterility is always obtained through CMS research in five progenies at ICRISAT. Crosses with 2-33 line appeared most promising (Table 3) (Saxena 1996).

Table 3. Developments in CMS breeding at ICRISAT.

Progeny	Total plants	Sterile plants	Percentage of steriles
2-33 x 85010-15	19	18	95
2-33 x 85010-109	6	6	100
2-33 x 85010-62	16	16	100
2-33 x 85010(OP) Bulk	32	32	100
Total	73	72	98

Source: Saxena 1996.

Research methods

This study drew on diverse sources of data — selected scientists from NARS, private and public seed companies, and seed growers. Primary data were gathered through personal interviews with scientists, officers in public and private seed companies, and seed growers. An open-ended questionnaire facilitated data collection. Secondary data were gathered through reports, publications, newsletters etc., available in all the research institutions, and seed companies.

Results and discussion

Scientists from NARS, seed companies (private and public), and seed growers had varying perceptions of the hybrid pigeonpea program.

Seed companies

The National Seed Corporation tried to produce hybrid pigeonpea in the early 1990s, but stopped due to technical difficulties.

MAHYCO has developed four pigeonpea hybrids — MTH 22, MTH 23, MTH 9507, and MTH 9343, and in addition, two experimental hybrids, METH 104 and METH 115, were identified. During the period 1990-95 they produced 16 t of seed and sold 9.5 t at the rate of Rs. 100 kg^{-1}.

Suraj Seed Company purchased 10 kg of a GMS line and 5 kg of a pollinator line from the Central State Farm, Raichur, Karnataka in 1993/94. Their experiments were conducted in Yavatmal district, Maharashtra during 1993/94, but the company discontinued work for the next two years because the program failed. In 1996, they obtained parental lines from ICRISAT —2 kg of *ms* Prabath DT (GMS line) and 1 kg of the pollinator line ICPL 161. Trials were conducted at Nandyal, Andhra Pradesh.

National agricultural research systems

Department of Agriculture, Andhra Pradesh. The biggest problem farmers face in this area is that pure seed is seldom available. Farmers are reported willing to pay even higher prices for authentic hybrid seed.

Panjabrao Krishi Vidyapeeth. Long-duration pigeonpea is usually inter-cropped using a relatively low seeding rate (about 6 kg ha^{-1}), which farmers can afford to buy. All of the GMS hybrid pigeonpeas thus far mature early and are intended for sole cropping at a seeding rate of 40 kg ha^{-1}. The average farmer can not afford the cost of this hybrid seed when facing an uncertain profit margin. A pigeonpea crop is highly susceptible to pod borer damage, therefore yield is more uncertain than with other semi-arid crops. A yield advantage of 30% in pigeonpea hybrids over varieties is not very encouraging for farmers.

At Akola during 1996, 25 farmers were given parental materials of hybrid pigeonpea for seed production. This was an opportunity for them to compare their own varieties to the hybrid.

Gujarat Agricultural University. GAU obtained parent materials of ICPH 8 from ICRISAT for hybrid seed production and produced some hybrid seeds. But in 1996 they were not growing ICPH 8 because:

- farmers in Gujarat prefer relatively large seeds, about 10 g per 100 seed, while the 100 seed mass of ICPH 8 is about 7 g, and
- Farmers prefer white seeds, but ICPH 8 is red.

Banaras Hindu University. The normal practice in this northeastern plain zone is to grow long-duration pigeonpea (245 days) as an intercrop. Bahar is the predominant variety grown in this zone. Basic research on hybrid pigeonpea technology through GMS was started in 1989. ICRISAT male-sterile line ICP 383 was used for producing experimental hybrids. The male-sterile line for producing experimental hybrids was *ms* 3783. Based on multinational trials beginning in 1991, hybrids VPH 1145, VPH 1164, and VPH 1184 were identified as promising and showed 30-40% superiority over Bahar. These hybrids had to be entered in ICAR's coordinated trials that required large quantities of seed. A funding shortage and lack of isolated land for seed production prevented production of the necessary bulk seed.

The main contribution from Banaras Hindu University to hybrid pigeonpea technology was the development of a long-duration GMS, HUA 7, which is brown, bold-seeded, and resistant to sterility mosaic disease. Basic research was undertaken during 1989-95, and bulk seed was produced in 1996/97 at GAU, Sardar Krishi Nagar. This seed is now available.

Basic research was started in 1989 on CMS through wide hybridization using wild species of pigeonpea. In the process of CMS development, male-sterile plants were isolated in progenies derived from wide hybridization, but when tested, were genetically male sterile. The development of CMS through mutagenesis required a large land area, hence no such work was initiated because there was not enough area at the research station.

Cost of hybrid seed production

Primary information. Cost of production data on hybrid pigeonpea were collected from a progressive farmer (Viswambhar Anna Kale) in Wahegaon village, Jalna, Maharashtra in October 1996. The farmer owned 5.6 ha of operational land on which nine crops were cultivated. Hybrid pigeonpea (MTH 9507) was sown in 0.4 ha in 1996 using parental materials from MAHYCO. Marketing of the hybrid seeds was not a problem because MAHYCO had already arranged to purchase the crop. The company also provided advice to the farmer.

Based on the farmer's data, labor and costs were calculated:

- Roguing, spraying, and fertilizer application were the main labor-demanding operations. Of the total labor requirement (in days), 58% was for roguing, 17% was for spraying (Endosulfan®), 11% was for fertilizer application, and the balance (14%) was for other operations.

- Of the total variable costs, 55% was spent on fertilizer (diammonium phosphate and farmyard manure), 20% on a pesticide (Endosulfan®), 13% was for labor, and the remaining (12%) was on other inputs.

Secondary information. Several studies have indicated the cost of hybrid seed production in different years. These studies are based on three hybrids that were released by ICAR (Table 4).

Constraints to use of hybrid technology

Several constraints to the adoption of hybrid technology were reported.

Roguing fertile female plants. About 50% of the female plants have to be rogued out at flowering to maintain genetic purity of the hybrid seed. Farmers usually do not like to rogue out the flowering plants because they think they lose money; they do not realise that roguing maintains the purity of hybrid seed.

High seeding rate. Usually long-duration pigeonpea is intercropped with a fast-growing crop. In that situation, the seeding rate for pigeonpea is relatively low, about 6 kg ha^1. But when hybrid pigeonpea is grown as a sole crop, the seed requirement is about 30 kg ha^{-1} which the average farmer cannot afford.

Shortage of parental seed. Because production of parental materials (male sterile and pollinator) is still mainly with scientists, it will require some time before seed companies routinely produce hybrid pigeonpea seed.

Heavy damage from pod borer. Most of the current GMS lines are susceptible to pod borer damage, thus farmers must use heavy doses of pesticides for control, an added cost of production.

Knowledge of seed production. Farmers lack knowledge about seed production, including use of several pollinator lines at the same time to produce hybrid seed.

Knowledge about input use. As a new crop in non-traditional areas, farmers apply too much pesticide and fertilizer, which in turn increases the cost of production.

Table 4. Cost of hybrid seed production based on the literature.

Year	Hybrid	Cost (Rs kg^{-1})	Source
1978/79	ICPH 8	1.54	Saxena et al. 1996, ICRISAT 1979
1979/80	ICPH 8	2.00	Saxena et al. 1996, ICRISAT 1979
1988	ICPH 8	6.25	Murugarajendran et al. 1990
1990	*ms* 3783 x ICP 11231	6.25	Srivastava and Asthana 1993
1992	PPH 4	13.80	Srivastava and Asthana 1993
1994	CoH 1	28.35	Rathnaswamy et al. 1994

Low price to hybrid seed growers. Growers do not like to sell their product at the rate set by the seed companies, therefore there is always a conflict between grower and seed companies.

Problems in grow-out test for genetic purity. Seed companies require 90% or higher genetic purity from growers, and most of the time the seed lots do not reach this level. Farmers must then sell their seed for a lower price, and hence will not contract to grow hybrid seed again.

Scarce labor for roguing. Roguing female plants is a labor-intensive operation. During the peak roguing period, most laborers are engaged in other crop cultivation operations from which they earn a considerable amount of money. It is very difficult to find laborers at the peak roguing period.

Competition from other crops. Cereal crops have a higher profit margin than pigeonpea hybrids.

Impact of ICRISAT hybrid pigeonpea technology on NARS

The hybrid pigeonpea program was initiated by a group of scientists at ICRISAT. There was no NARS research program at the time, and both basic and applied research results were disseminated to the Indian NARS (Table 5). In this manner, ICRISAT played an important role in the development and improvement of research capabilities in the Indian NARS for hybrid pigeonpea technology. Further, ICRISAT acted as a catalyst by creating an awareness among administrators, researchers, and farmers about hybrid pigeonpea technology. This collaboration paved the way for ICAR to begin research on hybrid pigeonpea.

In addition to basic and applied research, seed production technology was also disseminated to NARS and seed companies through training sessions, consultations, group meetings, field visits, and demonstrations.

Table 5. Parental materials and their sources for pigeonpea hybrids.

Hybrid	Parents	Source of female parent	Source of male parent
ICPH 8	*ms* Prabhat DT x ICPL 161	ICRISAT	ICRISAT
PPH 4	*ms* Prabhat DT x AL 688 NDT	ICRISAT	PAU
CoH 1	*ms T 21* x ICPL 87109	ICRISAT	ICRISAT
MTH 22	*ms T 21* x PL 173	ICRISAT	MAHYCO
MTH 23	*ms* T 21 x PL 653	ICRISAT	MAHYCO
MTH 9507	*ms* Prabhat DT x PL 927	ICRISAT	MAHYCO
MTH 9343	*ms* BDN 1 x PL 043	Unfinished *ms* lines supplied by ICRISAT	MAHYCO
METH 104	*ms* BDN 1 x PL104	Unfinished *ms* lines supplied by ICRISAT	MAHYCO
METH 115	*ms 3a 275 x* PL 115	Unfinished *ms* lines supplied by ICRISAT	MAHYCO

Basic research on CMS hybrid pigeonpea technology was started in 1990 and is likely to be completed by 1999 (10 years). Since GMS technology has already been completed, it provides a solid platform for replacement by CMS technology. Seed production technology is similar, and one could replace the other with the added benefit of the elimination of roguing. Reduced costs of seed production would boost adoption at the farmer level (Table 6).

Table 6. Latest developments in CMS research.

Type of hybrid	Fertile plants (%)	Sterile plants (%)
GMS	50	50
CMS	0	100
New ICRISAT lines		98.6

Recommendations

Application of three broad recommendations would increase the adoption of hybrid pigeonpea:

- farmer education about hybrid technology is important so that multiple and perennial production systems of hybrid pigeonpea can be followed;
- incentives should be given to seed companies to adopt hybrid technology, with benefits extended to seed growers by paying higher prices for their hybrid seeds; and
- male sterile hybrid technology should be introduced to seed growers so that most constraints could be overcome.

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Screening Techniques to Identify Resistance to Downy Mildew of Pearl Millet and Sorghum Midge

S D Singh and K V Hari Prasad[1]

Host plant resistance is the most economical method to control insect pests and diseases, and the technique most friendly to the environment. One prerequisite to producing disease- and insect-resistant cultivars is the availability of effective and reliable field and greenhouse screening techniques. These techniques allow identification of resistance sources and enable their transfer into agronomically elite backgrounds to produce high-yielding cultivars. At ICRISAT in India, screening techniques have been developed for two highly devastating biotic constraints — downy mildew *(Sclerospora graminicola* [Sacc.] Schroet.) in pearl millet, and midge *(Stenodiplosis sorghicola* [Coquillette.]) in sorghum. This paper describes the research process for these techniques.

Pearl millet downy mildew

Downy mildew is the most widespread and destructive disease of pearl millet in India and western Africa. The disease is a major constraint in attaining the yield potential of single cross F_1 hybrids. The disease is systemic and plants that are infected early either fail to produce earheads or produce malformed earheads, resulting in total yield loss. In the past, the disease occurred several times in epidemic forms in India and severely affected food grain production and food security of rainfed farmers. With the advent of downy mildew resistant cultivars, the disease has been controlled.

Maintenance and production of inoculum

The availability of viable inoculum in sufficient quantity is the key requirement

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for successful operation of a disease resistance screening technique. The downy mildew pathogen is an obilgate parasite and the sporangia that are used as inoculum are short-lived and therefore maintained on living host plants. At ICRISAT, the pathogen is maintained throughout the year on genotypes NHB 3 and 7042(S) in a field heavily infested with oospores (sexual spores of the pathogen). Five to 10 rows, each about 20-m long, are sown at monthly intervals depending on the need for inoculum. A high level of relative humidity (RH) is necessary for disease development and is developed by weekly furrow irrigation. Since sufficient oospore inoculum is present in the soil, artificial inoculation is not necessary. Disease-free plants and old diseased plants are cut back at 20-day intervals to promote the development of new tillers that are generally diseased. At maturity, the crop is plowed into the soil. This operation ensures that a sufficient number of oospores remain in the soil to infect each successive crop.

At ICRISAT the mean minimum and maximum temperatures (and their ranges) are 13°C (9-22°C) and 26°C (19-43°C). Over this wide range of temperatures, *S. graminicola* survives and could be similarly maintained in many other millet-growing locations in the world throughout the year.

On bright sunny days, systemically infected leaves are collected from the field and their old downy growth is removed with a wet cotton swab or camel-hair brush. The leaves are cut into small pieces and placed in humidity chambers prepared by lining the interior of petri dish lids or plastic boxes (46 x 30 x 10 cm) with a double layer of blotting paper.

For sporulation by the pathogen to occur at 20°C and >95% RH, the chambers are placed in an incubator for 6-6.5 h. The incubator is programmed to maintain a temperture of 5-6°C after this period. At this temperature, sporangia remain intact (they neither collapse nor germinate) and can be kept for at least 12 h. Sporangia produced on the leaves are washed off in cold water (5-6°C) into a beaker with a camel-hair brush or a wet cotton swab. The concentration of sporangia is adjusted using a hemacytometer to 1×10^6 sporangia mL^{-1}.

Leaves parasitized by a mycoparasite (*Fusarium longipes* Wollenw. and Reinking) that feeds on the mycelium of *S. graminicola,* or collected from plants grown in insufficient light (cloudy weather) do not sporulate well. To produce sporangial inoculum under such conditions, diseased pearl millet plants are grown in pots in a greenhouse to minimize the chances of infection. The potted plants are exposed to light in an incubator at 25-30°C and < 70% RH for about 16 h or overnight. The following day, the leaves are detached and used to produce sporangia as described above.

Healthy seedlings are needed for a good expression of disease reaction. It is advisable to test the soil or potting mixture for seedling establishment prior to screening because soil fertility levels vary among locations. Pearl millet seedlings do not establish well in soils with the high electrical conductivity that develops with the excessive use of farmyard manure. High soil fertility is not needed in greenhouse screening because seedlings are only needed for 15-20 days. At ICRISAT, a potting mixture (Alfisol, sand, and farmyard manure in a 2:1:1 ratio) with a small amount of diammonium phosphate (DAP) at 1 g kg^{-1} soil is used.

Laboratory screening technique

Laboratory screening techniques are needed for precise pathological studies (for example, host-pathogen interactions), for mass screening of germplasm and breeding material, and for detecting escapes from field screenings. For the results to be reliable, it is essential that a technique is simple, repeatable, allows inoculation in a natural fashion (without human interference), does not overemphasize the host or the pathogen, and exposes every plant to an equal amount of inoculum both by volume and spore number. It is also important to inoculate seedlings at the same growth stage. To achieve uniform emergence and growth of seedlings, pots are filled with the potting mixture, leaving the top 5 cm empty. Seeds are sown on the surface of the potting mixture and then covered with a 2-cm layer of potting mixture. The pots are irrigated daily and kept in the greenhouse until inoculation.

Potted seedlings at the coleoptile to one-leaf stage, or even later, are inoculated with a sporangial suspension using a pneumatic sprayer in a chamber maintained at 20°C and >95% RH. Inoculated seedlings are covered with a moist polythene sheet and retained under these conditions for 12-16 h. The pots are then transferred to greenhouse benches (25-30°C) for disease development.

This technique allows inoculation in a natural manner, at the desired stage of crop development, and with an appropriate inoculum concentration. The technique does not favor either the host or the pathogen. This is the most appropriate and economical method for mass inoculation of breeding material because it allows screening in a very small space (30-40 seedlings per 10-cm-diameter pot) and in a short time (about 20 days from sowing to evaluation) (Singh et al. 1993). There has been a good correlation between field results and this type of greenhouse screening. We screen about 10 000-15 000 breeding materials each year at ICRISAT in India, including materials from Indian NARS. Following the routine use of this technique for mass screening at ICRISAT, there has been a substantial increase in the levels of downy mildew resistance in breeding materials, and considerable decrease in the demand for screening in field disease nurseries, resulting in a substantial saving in running the field nursery. The technique is being used at the ICRISAT Sahelian Center in Niger and also at the Central Arid Zone Research Institute at Jodhpur in India.

Seedling age at inoculation and inoculum concentration greatly influence disease reaction — the younger the seedlings, the greater is their susceptibility to downy mildew. Certain genotypes show increased levels of susceptibility if inoculated at an early seedling stage. There are, however, genotypes that maintain their level of resistance irrespective of age at inoculation and/or inoculum concentration (Table 1).

Table 1. Percentage incidence of downy mildew in pearl millet after spray inoculation with sporangia of *Sclerospora graminicola* at different stages of growth in ICRISAT greenhouse, 1991.

	Age of seedlings (hr) after sowing				
Genotype[1]	24	48	72	96	120
700651	85	48	19	14	11
P 7-4	66	47	17	23	25
P 310-17	53	20	12	7	3
P 1449	17	17	3	4	2
7042 (DMR)	6	5	4	4	4
Susceptible checks					
7042 (S)	83	98	90	91	90
HB-3	92	99	92	94	93

1. Mean of two repetitions, each with two replications. In each replication, a treatment was repealed in 5 pots, each with 25-30 seedlings.

Disease record

Under optimum conditions (90-95% RH, 20-25°C), symptoms develop within 5-8 days of inoculation. Symptoms are seen as a distinct chlorosis of infected leaves. The fungus in the chlorotic areas of the leaves produces massive sporulation (sporangia). The presence of this downy growth is the sure symptom of the disease. Sometimes it is necessary to look for the downy growth because similar, but not identical, symptoms are also produced by nitrogen deficiency or viral infection. To avoid any such confusion, infected leaves should be kept in a humidity chamber at 18-22°C for 8-10 h to allow sporulation to occur. Almost all infected leaves/seedlings will sporulate under these conditions, provided they have been exposed to sufficient light prior to their humid incubation. However, plants whose growth is stunted may still not sporulate. Such plants generally show very poor asexual sporulation. Although, the symptoms appear within 8 days, records are usually taken 15-20 days after inoculation to allow expression of slow symptoms in some of the infected plants.

Field screening technique

Screening under field conditions is necessary to identify resistance that remains effective in the field. An ideal field screening technique should provide uniform distribution of inoculum, allow natural inoculation when the crop is at a susceptible stage, minimize escapes, and use both types of inocula (oospores and sporangia), while allowing breeding activities to be conducted in the same field. While these features are important for the repeatability of results, it is equally important that the technique should be cheap and simple. The infector-row technique, developed at ICRISAT and subsequently modified (Singh et al. 1993), meets all these criteria. It is advisable to use the same field each year to allow a build-up of oospore inoculum in the soil (as in the sick plot). This technique has three basic components.

Infector rows. These rows are the inoculum donors containing a mixture of 2-3 susceptible genotypes. They are sown at every fifth or ninth row at least 3 weeks prior to the test material. At the coleoptile to two-leaf stage, they are spray-inoculated with a viable sporangial suspension (10^6 sporangia mL^{-1}) during the late evening after irrigation. Frequent furrow irrigations are given during the first 15 days to promote high humidity to encourage the development of a high frequency of infected plants during early growth stages.

Test rows. These rows are materials to be tested. They are sown 2-3 weeks after infector rows in the intervening rows after the infector rows have developed 50-60% disease.

Indicator rows. These are the rows of known susceptible genotypes, sown with the test materials at regular intervals (after every 10-20 entries). They indicate the levels of disease pressure in the nursery.

This field-screening technique developed in 1981 has since been modified considerably. There are three major improvements:

- Inoculation of infector rows using infected potted plants (a massive operation involving huge amounts of money, time, and labor) was replaced by direct-spray inoculation with sporangia.
- Provision of humidity using a perfo-spray system was replaced by freqeunt furrow irrigation during the first 15-20 days after sowing, followed by normal irrigation. This change not only saves the money needed to buy, install, operate, and maintain the perfo-set, as well as its removal and reinstallation for each cultural operation, but also reduces much of the weed problem. However, the furrow irrigation method can not be used on sandy soils.
- Marking diseased plants with colored bamboo pegs was replaced by removing infected plants at the first count. However, some type of marking may be necessary if there is a need to distinguish resistant and susceptible test rows. This technique is used twice a year at ICRISAT and during the rainy season by NARS, both in India and in several African countries.

Scoring methods. Material in the field disease nursery is scored twice, at the seedling and soft dough stages. Seedling stage evaluation is very critical, and its actual timing will depend on the appearance of the disease and on environmental conditions. If the disease appears within a week and there are continuous rains with an overcast sky, early-infected seedlings die and disappear, either as a result of heavy rain or during cultural operations. Under such conditions, the first incidence record should be made 10-15 days after sowing. Infected plants should be removed, otherwise they will die and disappear before the soft dough stage record. This might lead to an underestimation of the susceptibility level of the test materials.

The soft dough stage record is taken either as a measure of incidence or its severity. An incidence record is sufficient to assess resistance of any material. However, a severity record is an important way of estimating the disease yield-loss relationship. The severity record is taken on a 1-5 rating scale where 1 = no disease symptoms, 2 = disease only on the nodal tillers, 3 = less than 50% of the basal tillers of a plant infected, 4 = more than 50% of the basal tillers of a plant infected, and 5 = no productive panicle produced (Table 2).

Identification of resistance sources

Using the above screening techniques, a large number of resistance sources have been identified (Table 3), and these are being used in breeding programs (Singh et al. 1997). Many resistant cultivars have been produced that are being extensively grown by farmers (Table 4).

Sorghum midge

Sorghum midge *(S.sorghicola)* is probably the most damaging and widely distributed of all sorghum pests. It occurs in all sorghum-growing regions in Africa, the Americas, Asia,

Table 2. Scoring pearl millet for downy mildew at the soft dough stage.

	Number of plants with downy mildew reaction rated on a 1-5 scale of severity[1]					Incidence	Severity
Genotype	1	2	3	4	5	(percentage)	(percentage)[2]
1	30	17	2	0	0	39	11
2	31	6	10	15	4	53	33
3	6	41	16	0	0	91	29
4	5	4	17	37	7	93	63
5	53	0	0	0	0	0	0
6	0	0	0	0	60	100	100

1. Severity is rated on a 1-5 scale where 1 - no disease symptoms, 2 - disease only on the nodal tillers, 3 = less than 50% of the basal tillers of a plant infected, 4 - more than 50% of the basal tillers of a plant infected, and 5 ■ no productive panicle produced.

2. Disease severity (percentage infection index) - $\dfrac{Y(1\text{-}1)+Y(2\text{-}1)+Y(3\text{-}1)+Y(4\text{-}1)+Y(5\text{-}1)}{N \times 4} \times 100$

where Y - the number of plants in each disease category (severity rating) and N - the total number of plants in the genotype that is being tested.

Table 3. Total accessions of *Pennisetum* spp., their distribution in downy mildew categories, and minimum and maximum incidence values recorded in field disease nurseries or in greenhouses, 1976-94, at ICRISAT, Patancheru, India.

Accession	Accessions tested	Downy mildew score[1]				Minimum incidence[2]	Maximum incidence[3]
		0	1-5	6-10	>10		
Normal flowering[4]	2 800	1 090	742	324	644	0	100
Photoperiod sensitive[5]	1 030	50	301	307	372	0	90
Genetic stocks[5]	237	48	56	29	104	0	100
Dwarfs[5]	70	3	4	6	57	0	98
Sweet stalks[5]	50	0	2	1	47	5	79
Intermediate weedy forms[5]	50	0	0	6	44	6	91
Wild relatives[5]	534	239	13	37	265	0	95

1. Mean of two repetitions, each with two replications.
2. Minimum downy mildew incidence.
3. Maximum downy mildew incidence.
4. Tested in field downy mildew nursery.
5. Tested under greenhouse conditions.

Australia, and Europe. Damage is caused by the larvae, which feed on the ovary inside the glumes. This results in chaffy (empty) florets, and the panicles present a blasted appearance. Egg laying occurs in the morning when the female lays 75-100 eggs in florets at anthesis. Eggs hatch in 2-3 days. Larvae are orange-red and feed on the developing grain inside the glumes. Larval development is completed in 9-12 days, and pupation occurs beneath the glumes. The pupal period lasts for 3-4 days, after which the pupa wriggles its way to the tip of glumes, and the adult emerges from the pupal case leaving the characteristic white pupal skin attached to the glumes. Larvae may also diapause inside the glumes, and the diapause may last for 1 to several years.

Screening techniques

The major difficulties in identifying stable sources of resistance to sorghum midge include:

- variation in the flowering of sorghum cultivars in relation to midge incidence;
- day-to-day variation in midge populations;
- competition with other insects such as head bugs;
- parasitization and predation by natural enemies; and
- sensitivity of midge flies to temperature and RH.

A large proportion of lines selected as less susceptible under natural conditions includes early and late escapes. Because of these problems, genotypes rated as resist-

Table 4. Commercial varieties, hybrids, and male-sterile lines in which downy mildew resistance sources were used or their resistance was tested/developed using the field and/or greenhouse screening techniques at ICRISAT and/or NARS locations in India and Africa.

Name	Type of material	Pedigree	Year of release	Country of release
WC-C75	Variety	7 full sib progenies of WC	1982	India
ICMV 2	Variety	IB V 8001	1975	Senegal
ICMV 3	Variety	IBV 8004	1985	Senegal
ICMV 7703	Variety	7 inbred lines	1985	India
ICMV 5	Variety	ITMV 8001	1985	Niger
ICMV 6	Variety	ITMV 8002	1985	Niger
ICMH 451	F_1 hybrid	81A x ICMP 451	1986	India
ICMH 501	F_1 hybrid	83A x ICMP 501	1986	India
ICMH 423	F_1 hybrid	841A x ICMP 423	1986	India
Pusa 23	F_1 hybrid	841A x D23	1986	India
ICMA 81	Male sterile	23D2A	1986	India
ICMB 81	Maintainer	23D2A	1986	India
ICMA 4	Male sterile	834A	1986	India
ICMB 4	Maintainer	834B	1986	India
ICMA 841	Male sterile	5141 A	1986	India
ICMB 841	Maintainer	5141 B	1986	India
ICTP 8203	Variety	5 S, progenies of selected from a landrace from Togo	1988	India
Okashana 1	Variety	ICMV 88908	1989	Namibia
PCB 138	Variety	ICTP 8203 selection	1989	India
Kaufela	Variety	ICMV 82132	1989	Zambia
IKMV 8261	Variety	ICMV 84400	1989	Burkina Faso
ICMV 155	Variety		1991	India
Pusa 322	F_1 hybrid	841A x PPM 1301	1993	India
ICMH 356	F_1 hybrid	88004A x ICMR356	1993	India

ant under natural infestation often become susceptible in the following seasons, or at other locations. The following techniques have been standardized to screen for resistance to sorghum midge (Sharma et al. 1992). There are several techniques to screen for midge resistance, however, at ICRISAT in India, only the head cage technique is being used.

Field screening (multichoice conditions)

Sowing date. For successful screening of test material for midge resistance under natural conditions, it is important to determine the periods of maximum midge density through fortnightly sowings of a susceptible cultivar. Sowing dates should be adjusted so that the most susceptible stage of the crop (flowering) coincides with greatest insect density. At ICRISAT, maximum midge density and damage have been observed in the crop sown during the 3rd week of July. The peak in midge density occurs during October. A second but smaller peak has been observed during March in the postrainy season, for which the optimum planting date is mid-December. In the Dharwad region in Karnataka state in India, the peak in midge numbers occurs during October. The optimum time for sowing test materials is 20 Jul-5 Aug.

Augmentation of midge density. Midge populations can be augmented through infester rows and sorghum panicles containing diapausing midge larvae.

- Sow infester rows of CSH 1 and CSH 5(1:1 mixture) 20 days before the test material. Alternatively, early flowering (40-45 days) lines (IS 802, IS 13249, and IS 24439) can be sown along with the test material to avoid problems in field management.
- Sow four infester rows after every 16 rows of the test cultivars.
- Spread midge-infested sorghum panicles containing diapausing larvae at the flag leaf stage of the infester rows. Moisten the panicles for 10-15 days to stimulate the termination of larval diapause for pupation and adult emergence. Adults emerging from diapausing larvae serve as a starter infestation in infester rows to supplement the natural population. The midge population multiplies for one to two generations on the infester rows before infesting the test material. A combination of infester rows and spreading sorghum panicles containing diapausing larvae increases midge damage 3-5 times. Infester rows alone also increase midge damage.

Sprinkler irrigation. High relative humidity is important for midge activity, adult emergence, and subsequent damage. Overhead sprinkler irrigation should be used to increase RH in the midge-screening trials during the postrainy season or periods of low RH daily (15:00-16:00) from panicle emergence to the grain-filling stage of the crop. Midge damage increases significantly with the use of sprinkler irrigation. Use of sprinkler irrigation over the crop canopy between 15:00 and 16:00 does not affect oviposition because the peak midge abundance and oviposition occurs between 07:30 to 10:00. Selective use of insecticides to control *Calocoris angustatus,* (head bug) and *Tetrastichus diplosidis* (parasite) are the two major biotic factors limiting midge abundance in trials of screening for midge resistance. Head bugs damage the sorghum panicles from emergence to hard-dough stage and compete for food with sorghum midge. Also, adult head bugs prey on ovipositing midges at flowering. At some locations *T. diplosidis* is an efficient parasite of sorghum midge.

Sprays of less persistent and contact insecticides such as carbaryl and malathion will control head bugs at complete-anthesis to milk stages. The midge larvae feeding inside the glumes are not affected by the contact insecticides. Parasitism by *T. diplosidis* is also reduced in panicles sprayed at the complete-anthesis to milk stage.

Split sowing. Sow the test material twice with a 15-day interval to minimize the chances of escape from midge damage in early- and late-flowering lines. This method of sowing increases the efficiency of selection for midge resistance.

Plant density. Plant population affects the insect density/unit area, and in some cases, influences the incidence and survival rate of insects. The level of midge damage has been observed to be higher at a lower sowing density.

Under field conditions, midge damage and efficiency of screening for midge resistance can be substantially increased by using a combination of timely sowing, spreading midge-damaged sorghum panicles containing diapausing larvae in the infester rows, split sowings, and selective use of contact insecticides to control head bugs and midge parasites. These techniques are useful in the initial large-scale screening of germplasm and breeding materials for resistance to sorghum midge.

Headcage technique (no-choice technique). Caging midge flies with sorghum panicles is an important method of avoiding escape and allows screening for midge resistance under uniform insect pressure. A head cage technique developed and standardized at ICRISAT consists of a cylindrical wire frame made of 1.5-mm diameter galvanized iron wire. The loop attached to the top ring rests around the tip of the panicle, and the extensions of the vertical bars at the lower ring are tied around the peduncle with a piece of galvanised iron wire or electric wiring clips. These prevent the cage from slipping when disturbed by wind or other factors. The screening is done as follows:

- Select sorghum panicles at the 25-50% anthesis stage. Remove florets with dried anthers at the top and immature ones at bottom of the panicle with scissors so that only the florets at anthesis in the middle of the panicle are exposed to the midge flies.
- Place the wire-framed cage around the sorghum panicle and cover it with a muslin or any similar thin blue cloth bag (20-cm in diameter, 30-cm long). The top of the cloth bag should have an extension (5-cm in diameter, 10-cm long) through which to introduce the midges.
- Collect 20 adult female midges in a plastic bottle (200 mL) aspirator between 08:00 and 11:00 from flowering sorghum panicles (only female midges visit the flowering sorghum panicles and these are •collected for infestation).
- Release 40 midges into each cage and tie up the opening. Repeat the operation the next day. Infest 5-10 panicles of each genotype, depending upon the stage of material and resources available.

- Examine the cages 5-7 days after infestation and remove any other insects such as head bugs, head caterpillars, and predatory spiders.
- Remove the cages 15 days after infestation and evaluate midge damage as described below.

Florets with midge larvae and midge-damaged chaffy florets are greatest in panicles infested with 40 midges for 2 consecutive days. There is some variation in midge damage over seasons because of temperature, rainfall, and RH that influence both oviposition and damage. Midge damage decreases as the time of collection and release advances from 08:30 to 14:30 (Table 5). Other factors that account for decrease in midge damage over time are natural death of adults (midges die after 4-24 h), reduced fecundity, and oviposition because of increasing temperatures and decreasing RH. Panicles infested at the top- and at half-anthesis stages generally suffer greater damage than those infested at the pre- and complete-anthesis stages. Sorghum midge behavior is influenced by different colors. Maximum midge damage has been recorded in panicles covered with blue and black bags (Table 6). Blue bags are used to cover the cages because black bags may cause very high temperatures inside the cage during the hot and dry season in the semi-arid tropics.

The headcage technique is quite simple, easy to operate, and can be used on a fairly large scale to confirm

Table 5. Effect of collection time and infestation on percentage of florets with midge larvae and chaffy florets.

Sample	Time of collection	Growing season and number of florets with midge larvae (percentage)[1]			Growing season and number of chaffy florets (percentage)[1]		
		1980/81 P[2]	1982 R[3]	1982/83 P[3]	1980/81 P[3]	1982 R[3]	1982/83 P[3]
1	0830	11.0(3.4)	47.8(43.7)	81.6(64.6)	39.8 (39.1)	67.0 (55.2)	87.8 (69.7)
2	1030	8.0 (3.0)	36.2(36.9)	44.0(41.5)	34.2 (35.7)	58.4 (49.9)	53.2 (46.9)
3	1230	7.0 (2.8)	37.2(37.4)	10.0(18.0)	29.8(32.9)	74.0(59.8)	27.6(31.7)
4	1430	0.8(1.3)	17.4(23.9)	7.4(15.4)	21.8(27.6)	66.4(55.2)	39.4(38.9)
SEM[4]		(±0.28)	(±2.89)	(±1.67)	(±2.32)	(±3.67)	(±1.14)
LSD[5]		(0.85)	(8.9)	(5.14)	(7.16)	Not significant	(3.51)
CV[6]		(23.74)	(18.21)	(10.69)	(15.38)	(14.93)	(5.45)

1. R = rainy season; P = postrainy season.
2. First number is theoriginal value. Number in parentheses is the transformed value ($\sqrt{n+1}$), which generally reduces the heterogeneity of the sample.
3. First number is the original value. Number in parentheses is the transformed (arc sine) value ($\sqrt{\%}$),which generally reduces the heterogeneity of the sample.
4. SEM = standard error of the mean.
5. LSD = least significant difference *(P<0.05)* for comparing treatment means of transformed values.
6. CV = coefficient of variance (%).

Table 6. Effect of muslin bag color on midge damage in headcage test in sorghum CSH 1, ICRISAT, Patancheru, India, 1989.

Bag color	Midge damage (percentage)[1]
Black	77 (61.4)c
Blue	76 (60.1)bc
White	66 (54.7)ab
Red	61 (51.6)a
Yellow	63 (52.7)a
LSD[2]	-6.3
DP	16

1. Figures in parentheses are arc sine values.
2. LSD = least significant difference.
3. Degrees of freedom

Figures followed by the same letter in a column were not significantly different at *P<0.05*

the resistance of field-selected cultivars. Although changing weather conditions influence midge activity and can affect midge damage under the headcage, it is a thorough test for the identification of genetic resistance. Test material should be screened under the headcage and over several testing environments to identify lines with stable resistance.

Damage evaluation for resistance screening. Feeding by the midge larvae on a developing grain inside the glumes leads to sterile or chaffy spikelets. Chaffiness due to natural sterility and extensive grain damage by sucking insects also look similar to midge damage. However, the midge-infested panicles have either small white pupal cases hanging to the tip of spikelets or small parasite exit holes in the glumes.

Two methods are suggested for damage evaluation.

- **Chaffy spikelets.** This is the most appropriate critefion by which to evaluate sorghum lines for midge resistance. Tag five panicles in each genotype at half-anthesis. Record midge incidence in the florets 15 days after flowering as follows:
  - Collect five primary branches each from the top, middle, and bottom portions of the panicle.
  - Bulk the samples from all the five tagged panicles from a genotype.
  - Remove secondary branches from the primary branches and mix the sample thoroughly.
  - Pick up the secondary branches at random and count the number of chaffy spikelets in a sample of 500 spikelets.
  - Squeeze the chaffy spikelets between the thumb and first finger with forceps. Record the number of spikelets producing a red ooze (this indicates midge-damaged florets).
  - Express the data as the percentage of chaffy or midge-damaged spikelets. Midge-damaged chaffy spikelets can also be recorded at harvest by adopting the procedure described above.
- **Visual damage rating.** At crop maturity, midge damage is evaluated on a 1-9 scale, where 1 = <10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, and 9 = >80% midge-damaged spikelets.

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Assessing the Impact of CLAN

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Networks help improve interaction among scientists in national research programs, and between national research programs and international agricultural research institutions. These networks enhance the effectiveness of collaborative research. They facilitate organization of regional meetings, surveys, monitoring tours, workshops, and technical working groups to help identify research needs and opportunities, and assess comparative advantages in specific research areas.

The Cereals and Legumes Asia Network (CLAN) is a collaborative research and technology exchange network. It was formed by merging the former Asian Grain Legumes Network (AGLN) and the Asian component of the Cooperative Cereals Research Network (CCRN). AGLN was established in 1986 to facilitate technology exchange in chickpea, pigeonpea, and groundnut in Asia, while CCRN began in 1988 and operated globally for the exchange of genetic material and information. The scientists and research administrators in the member countries, however, wanted a single network for collaborative research and technology exchange activities for both cereals (sorghum and millets) and legumes (chickpea, pigeonpea, and groundnut). To meet this demand, CLAN was formally launched in April 1992. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) provides the coordination unit, and the technical and backup support for ICRISAT mandate crops — sorghum, pearl millet, chickpea, pigeonpea, and groundnut, and their natural resource management.

CLAN activities are currently concentrated in Bangladesh, China, Iran, India, Indonesia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam. CLAN works closely with scientists in the national programs and ICRISAT as

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

equal partners in planning, conducting, monitoring, and evaluating approved collaborative research endeavors. The specific objectives of CLAN are to:

- strengthen links and enhance the exchange of germplasm, breeding material, information, and technology options among members;
- facilitate collaborative research among the members to address and solve high priority production constraints, giving attention to poverty and equity issues according to the needs and priorities of member countries;
- help improve the research and extension capabilities of member countries through human resource development;
- enhance coordination of regional research on sorghum, pearl millet, chickpea, pigeonpea, and groundnut; and
- contribute to the development of stable and sustainable production systems through a responsive research capability in member countries.

CLAN (and the former AGLN) has operated in member countries for the past 10 years, and an assessment of the value of the network and feedback from members was considered essential. The objective of this initiative was to assess the value, usefulness, and impact of the collaborative research activities undertaken by CLAN in the member countries.

Methodology

The assessment was designed to evaluate the benefits of the collaborative research and technology exchange undertaken in member countries by AGLN/CLAN during the last decade. A benchmark survey was conducted in 1989 to collect basic and descriptive information about the participating national agricultural research systems (NARS). The second was a detailed survey undertaken in 1993 to assess the response and feedback from CLAN country coordinators about the usefulness of network activities. A follow-up survey in 1995 obtained feedback from country coordinators on the value of CLAN to member countries, and measured changes in yield levels due to technology generation, expected adoption ceiling levels, and adoption of improved technologies.

A questionnaire, designed to elicit information about how CLAN helped to facilitate collaborative research in the Asia region, was developed and sent to all country coordinators. Responses were documented on the following qualitative and quantitative aspects of the network's contributions.

Qualitative information. The extent of involvement by network member countries and contributions from the network were solicited for each of the following activities:

- germplasm and breeding materials;
- training and human resource development activities;
- information exchange and related activities;

- network support to national research programs;
- increasing links and contacts among scientists; and
- coordination of regional research on legumes in Asia.

Quantitative information. This part of the questionnaire collected data on:

- volume of germplasm and breeding material received and number of varieties released;
- technology adoption by farmers (rate of adoption and expected ceiling level of technology adoption);
- measures taken to spread or disseminate the technologies; and
- research costs incurred by the national program for each crop.

Finally, the country coordinators were asked to provide comments on the value of CLAN, and suggestions for future activities.

Preliminary results and analysis

Responses were received from all 11 member countries participating in the network. Respondents provided valuable qualitative information, but the responses on quantitative data were incomplete. Many country coordinators expressed difficulty in completing the questionnaire because it required data that were not readily available. This report analyzes and interprets the available information.

Qualitative measures

Exchange of germplasm and breeding materials

Exchange of germplasm was rated as very significant and exchange of breeding material as significant by most countries for groundnut and sorghum, the important crops in many countries (Fig. 1). Use of germplasm and breeding materials has been minimal for pearl millet, chickpea, and pigeonpea because these crops are not grown in some Southeast Asian countries.

CLAN contribution to NARS Figure 2 presents the different dimensions of CLAN contributions and

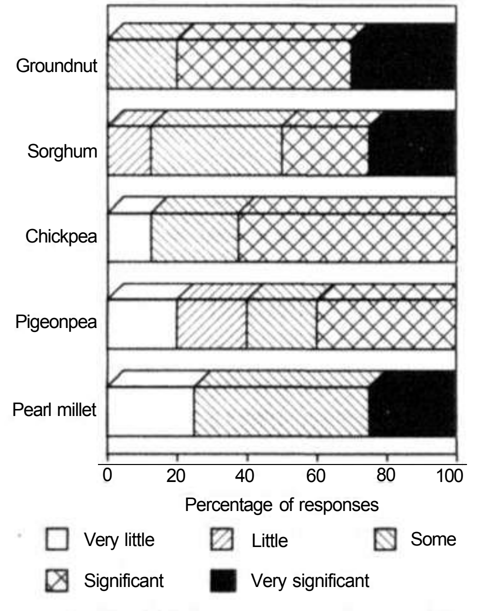

Figure 1. Significance of germplasm and breeding materials exchanged through CLAN as rated by country coordinators.

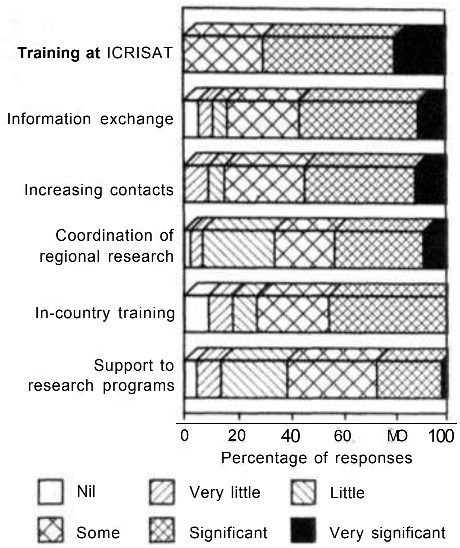

Figure 2. CLAN contributions to NARS as rated by country coordinators.

responses from NARS through the country coordinators. These include training and human resource development, information exchange, network support to national research programs, increasing contacts among scientists, and coordination of regional research in Asia.

Training and human resource development. About 78% of the country coordinators reported that significant to very significant training activities were provided to NARS scientists at ICRISAT. While about 50% of the country coordinators indicated that significant in-country training activities were conducted, some countries reported a need to organize in-country training activities in the future (Fig. 2). Suggestions were solicited from country coordinators on specific needs and requirements to organize training programs, both in-country and special regional courses.

Information exchange and related activities. Visits of NARS scientists to ICRISAT were assessed as average to very significant. The interaction among scientists and information exchange in most countries is reported to be satisfactory (Fig. 2). Similarly, study tours and meetings were rated as significant to very significant by many, Exchange of literature was rated excellent by all countries. Although some countries have benefitted by co-publishing (in local languages), required input by the network has not been received by many other country programs (Fig. 3).

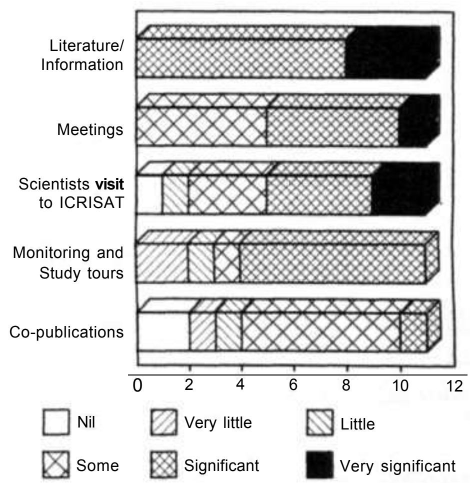

Figure 3. Usefulness of information exchange activities as rated by responses from CLAN country coordinators.

Network support to NARS. About 50% of the country coordinators reported they received significant support for organizing national meetings, while the others mentioned that support was less than desired (Fig. 4). Support to experimentation ranged from little to significant levels, while the assessment of support for supplies and equipment varied. Support provided by ICRISAT scientists was considered adequate by 80% of national programs. Some of these issues need to be discussed with individual country coordinators to assess and improve the situation.

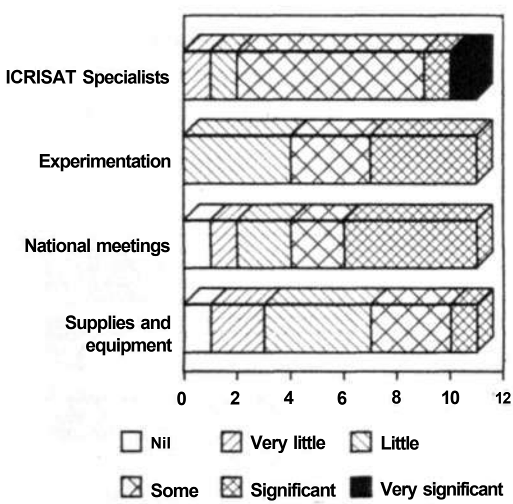

Figure 4. Significance of CLAN support to NARS as rated by responses from country coordinators.

Increasing contacts among scientists. Almost all national programs felt that increased contacts among scientists within the country has been greatly facilitated by the network (Fig. 5).

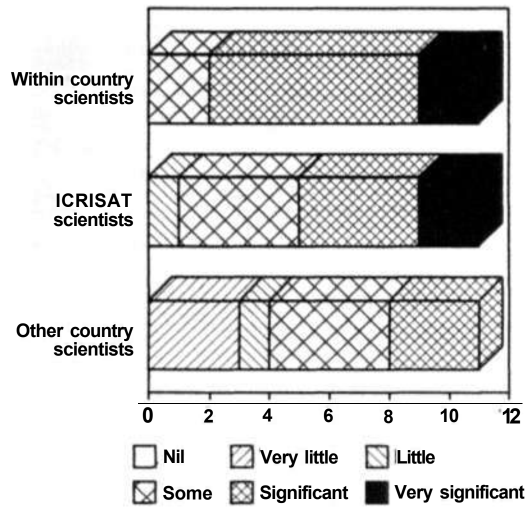

Figure 5. CLAN's role in increasing contacts among scientists in member countries, as rated by responses from country coordinators.

About 90% reported that the network helped develop and increase links between NARS and ICRISAT scientists. Increased contacts with scientists from other countries was found to be adequate only by 70% of the countries.

Coordination of regional research in Asia. Network support to regional meetings and working groups was reported to be adequate to very significant by more than 70% of the member countries. Assistance to study tours and to establish links with other institutions was found to be good to very significant only by 30% of NARS, and needs to be improved in the future (Fig. 6).

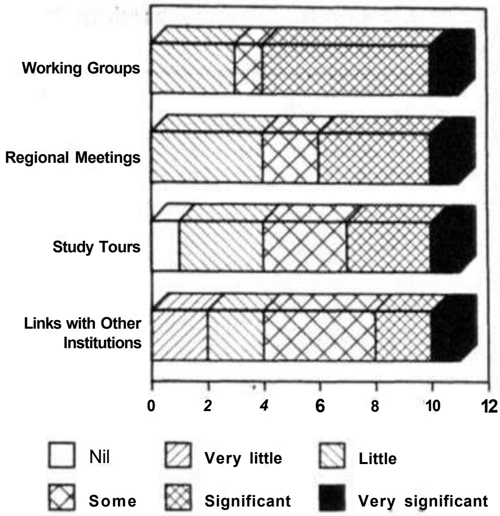

Figure 6. Assessment of CLAN's role in coordination of regional research on legumes, as rated by responses from country coordinators.

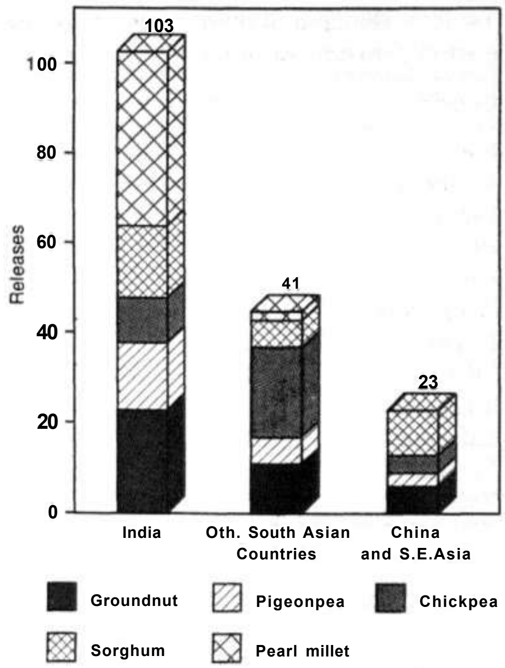

Figure 7. Number of releases in Asia of ICRISAT/NARS cultivars using ICRISAT germplasm

Quantitative measures

Releases of cultivars using ICRISAT materials

ICRISAT supplied germplasm and breeding materials for 167 cultivars that have been released by 11 member countries (Fig. 7 and Table 1). Tables 2-6 give details of cultivars released in each crop by different countries. Overall, these tables and Figure 7 show the volume of cultivars released, and thus indicate the value to the agriculture of individual countries.

Reduction in R&D lag due to CLAN

The reduction in time for development of technologies (variety, agronomic management, etc.) due to CLAN ranged between 3.6 and 6 years (Table 7). The average reduction in lag was 5 years across crops and countries. CLAN member countries were able to reduce the time for research to develop a variety or technology, and NARS scientists were able to deliver technology to farmers earlier, thus saving the scarce research resources of NARS.

We have not received complete data from the country coordinators for the following:

- present area under improved cultivars or practices;
- crop area in the recommendation domain, present area covered, and

Table 1. Release of plant materials in Asia by CLAN member countries using germplasm conserved in ICRISAT genebank.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Total
India	16	39	10	15	23	103
Myanmar	4	0	5	1	4	14
China	7	0	4	0	0	11
Pakistan	2	2	4	0	3	11
Nepal	0	0	4	2	2	8
Bangladesh	0	0	7	0	0	7
Philippines	2	0	0	2	1	5
Sri Lanka	0	0	0	3	2	5
Thailand	1	0	0	0	0	1
Indonesia	0	0	0	1	0	1
Vietnam	0	0	0	0	1	1
Total	32	41	34	24	36	167

expected maximum adoption;

- yield gain (both on-station and on-farm) due to improved varieties and/or practices;
- implicit unit cost reduction due to improved technology;
- welfare gains due to adoption of improved technology and distribution of welfare gains; and
- perception of benefits.

Many country coordinators indicated that they do not have access to such information or the information is not available in the country. We are now planning some joint studies to elicit such information and to gather data to assess the impact of improved technologies.

Value of CLAN and suggestions for improvement

CLAN member countries have benefited from network activities in the region, although the degree of benefit to individual countries varies (Table 8). The greatest benefit has been in development and release of cultivars and improved management practices. The research process was accelerated by reducing the average R&D time lag by 5 years, thus reducing research costs and making technology available to farmers sooner. The network helped to increase contacts and information among scientists, both within and among countries. Development and training of NARS scientists and general improvements in the R&D infrastructure were also indicated as benefits from the network. Many country coordinators also appreciated the usefulness of research collaboration through working groups that has led to coordination of regional research. There are, however, a few more areas that need to be addressed to enhance the network's usefulness to member countries (Table 9).

Table 2. Sorghum releases by CLAN member countries using germplasm conserved in ICRISAT genebank.

Country	Releases	ICRISAT name	Release name	Year of release
China	7	A 3681	Yuan 1-98	1982
		A 3872	Yuan 1-28	1982
		A 3895	Yuan 1-505	1982
		A 6072	Yuan 1-54	1982
			Liao 4	1988
			Liaoza 4	1995
			Liao 5	1996
India	16	E 1966	NTJ 2 (IS 30468)	1980
		ICSV 112	CSV 13	1982
		ICSV 1	CSV 11 (SPV 351)	1984
		ICSH 153	CSH 11	1986
		ICSV 145	SAR 1	1988
		SPH 468	CSH 14	1993
		ICSV 745	DSV 3	1993
			JKSH 22	1993
			PJH 55	1993
			PJH 58	1993
			PKH 400	1993
		ICSV 197	ICSV 197	1993
			PSH 8340	1993
			JKSH 27	1993
			JKSH 45	1994
			MLSH 36	1994
Myanmar	4	M 36248	Yezin 2 (Schwe phyu 2)	1984
		M 36335	Yezin 3 (Schwe phyu 3)	1984
		M 90906	Yezin 1 (Schwe phyu 1)	1984
		M 36172	Yezin 4 (Schwe phyu 4)	1984
Pakistan	2	ICSV 107	PARC-SS 1	1991
		IRAT 408	PARC-SS 2	1991
Philippines	2		IES Sor 1 (PSB Sg 93-02)	1993
			IES Sor 4 (PSB Sg 94-02)	1994
Thailand	1		Suphan Buri 1	1993

Table 3. Pearl millet releases in India and Pakistan using germplasm conserved in ICRISAT genebank.

Country	Releases	ICRISAT name	Release name	Year of release
India	39	ICMV 1	MHB 110	1981
			WC-C75	1982
			HB 45	1984
			X5	1984
		ICMV 4	ICMS 7703 (MP 15)	1985
			HC 4	1985
		ICMH 451	ICMH 451 (MH 179)	1986
		ICMH 501	ICMH 501 (MH 180)	1986
			MH 182	1986
			Pusa 23 (MH 169)	1987
		ICTP 8203	ICTP 8203 (MP 124) (PCB 138)	1988
		ICMH 423	ICMH 423 (MH 423)	1988
			HHB 50	1988
			HHB 60	1988
		RCB-IC 9	Raj 171	1990
			HHB 67	1990
			VBH 4	1990
		ICMV 155	ICMV 155 (MP 55) (ICMV 84400)	1991
			GHB 181	1990
			GHB 235	1990
			RHB 58	1990
			MLBH 104	1991
			RHB 30	1991
			Eknath 301	1991
			ICMH 356	1993
		ICMH 88088	ICMH 312 (Pooja)	1993[2]
		ICMV 88904	ICMV 221	1993
			PCB 141	1993
			Pusa 322	1993
			HHB 68	1993
			Pusa 444	1994
		CZP-IC 923		1995[3]
			RCB-IC 911[1]	1996
		GICH 91834	JBH 1	1996[3]
			C2-IC 923	1996
		MLBH 267		1995
		HHB 94		1995
		Pusa 325		1995
Pakistan	2	Pusa 44		1995
		Ugandi	PARC-MS 1	1991
		ICMS 7704	PARC-MS 2	1991

1. Diffused to farmers in 1993, possible release in 1996.
2. Not officially released, but privately marketed.
3. Notifications pending.

Table 4. Chickpea releases by CLAN member countries using germplasm conserved in ICRISAT genebank.

Country	Releases	ICRISAT name	Release name	Year of release
Bangladesh	7	ICCV 81248	Nabin,	1987
		(ICCL 83228) ICCV 10	Barichhola 2	1993
		ICCL 83105	Barichhola 3	1993
		ICC 4998	Bina Sola 2	1994
		ICCL 85222	Barichola 4	1995
		RBH~228(a)	Barichola 5	1995
		ICCL-83149	Barichola 6	1995
China	4	ILC 202	ILC 202	1988
		ILC 411	ILC 411	1988
			Chickpea 4	1991
			Chickpea 18	1991
India	10	ICCV 1	ICCC 4	1983
		JG 62 x F496	RSG 44	1984
		L550 x L2	GNG 149	1985
		F 378 x F 404	Anupam	1988
		ICCL 80074	ICCC 37 (Kranti)	1989
		ICCL 82001	ICCV 2 (Sweta)	1989
		ICCV 6	ICCV 6	1990
		ICCV 10	Bharati	1992
		ICCV 88202		1994[1]
		ICCC 42		1995[1]
Myanmar	5	Sel. from (K 850 x F378)	Schwe Kyhemon	1986
		ICC 552	Yezin 1	1986
		ICCC 42	ICCV 42	1994
		ICCV 82001	ICCV 2	1994
		ICCV 4958	ICCV 4958	1993
Nepal	4	ICCC 4	Sita	1987
		JG 74	Radha	1988
		ICCV 6	Kosheli	1991
		ICCL 82108	Kalika	1991
Pakistan	4	FLIP 81-293C	Noor 91	1992
		FLIP 83-48C	Rizki	1992
		Sel. from (L 550 x F 496)	DG 92	1993
		FLIP 84-92C	Douyet	

1. Not officially released, but adopted by farmers.

Table 5. Pigeonpea releases by CLAN member countries using germplasm conserved in ICRISAT genebank.

Country	Releases	ICRISAT name	Release name	Year of release
India	15	ICPV 1	ICP 8863 (Maruti)	1986
		ICPL 87	Pragati	1986
		ICPL 151	Jagriti	1987
		ICPL 332	Abhaya	1989
		ICPH 82008	ICPH 8	1991
		(Prabhat x HY3C) x (T21 x ICP 102)	Vamban 1	1992
		ICP x 78120 - WB x-WB-WB	Birsa Arhar-1	1992
		ICPL 87119	Asha	1993
		IPH 732	Hybrid CoH 1	1994
		PPH 4	PPH 4	1994
		ICPL 84031	Durga	1995
		ICPL 85063		1996
		ICPL 85010	ICPL 85010	1996
		AKG 46	Akola	1990[1]
		ICPL 87091		1990[1]
Indonesia	1		Megha	1987
Myanmar	1	ICPL 87	ICPL 87	1990
Nepal	2	ICP 11384	Bageswari	1990
		ICP 6997	Rampur rhar	1991
Philippines	2	ICPL 85015		1991
		ICPL 295		1990[1]
Sri Lanka	3	ICPL 84045		1990[1]
		ICPL 87		1990[1]
		ICPL 02		1990[1]

1. Not officially released, but made available to farmers from 1990.

Table 6. Groundnut releases by CLAN member countries using germplasm conserved in ICRISAT genebank.

Country	Releases	ICRISAT name	Release name	Year of release
India	23	ICGS 1	Spring Groundnut '84	1984
			Konkan Gaurav	1984
		ICG 2974	Robut 33-1	1985
		ICGV 87123	ICGS 11	1986
		TMV 7 x FSB 7-2	VRI 1	1986
			ALR 1	1987
		ICGV 87128	ICGS 44	1988
		ICGV 87141	ICGS 76	1989
		ICGV 87121	ICGS 5	1989
			Girnar 1	1989
			RG 141	1989
		ICGV 87119	ICGS 1	1990
		ICGV 87187	ICGS 37	1990
		ICGV 87160	Sinpadetha 5 (ICG[FDRS)] 10)	1990
		ICGV 86950	ICGV 86590	1991
		ICG 86011	ALR 2	1994
		ICGV 86143	BSR-1	1994
		ICGV 86325	ICGV 86325	1994
		ICGV 86011	ALG 2	1994
		ICGS 87157	—[1]	
		ICGS 21	ICGS 21	—[1]
		ICGV 86564	ICGS 49	—[1]
		ICG (FDRS) F	ICG (FRDS) 4	—[1]
Myanmar	4	JL 24	Sinpadetha 2	1982
		Robut 33-1	Sinpadetha 3	1984
		ICGV 87160	Sinpadetha 5	1993
		ICGV 87160	Yezin 5	1993
Nepal	2	—[2]	B-4	1980
		—[2]	Janak	1989
Pakistan	3	(ICGS 44 + ICGS 37)	BARD 699	1989
		ICGV 4989	BARD 479	1993
		ICGS(E) 56	ICGV 86015 (BARD 92)	1994
Philippines	1	JL 24	UPL Pn 10	1992
Srilanka	2	ICGV 86564	Walawe	1994
		ICGV 87123	ICGS 11	1994
Vietnam	1	ICGS (E) 56	HL-25	—[1]

1. Not officially released, but adopted by farmers. 2. Not ICRISAT releases.

Table 7. Reduction in R&D lag due to participation in CLAN.

Crop	Countries	Number of varieties (technology)	Reduction in lag due to CLAN (years)
Sorghum	Myanmar Philippines	5	3.6
Chickpea	Bangladesh Myanmar	9	5.5
Pigeonpea	Myanmar Sri Lanka	5	6
Groundnut	Myanmar Philippines Sri Lanka Vietnam	11	5
Mean R&D lag			5

Table 8. Value of CLAN to individual countries.

CLAN activity	Country	Value to country R&D
Germplasm and breeding material	Bangladesh	Flow of chickpea germplasm and breeding lines
	India	Greatly benefited Indian scientists by providing relevant germplasm
	Nepal	Assistance in collection of indigenous germplasm in mandated crops
	Pakistan	Supply of breeding material was a great help to national groundnut, chickpea, sorghum, and pearl millet programs
	Philippines	Mechanism for continuous provision of germplasm materials/improved varieties
	Thailand	Useful source of germplasm; ICRISAT germplasm increasingly used in many breeding programs
Network to NARS	Indonesia	Increased intensity of research on crops neglected by national program: groundnut, pigeonpea, and sorghum
	Myanmar	Upgrading research activities; improved crop production systems
	Nepal	Strengthening breeding program on grain legumes and oilseeds; lab facilities for soil testing, especially micronutrients
	Pakistan	Provided reasonable support to national program activities

Continued

Table 8. *Continued*

CLAN activity	Country	Value to country R&D
	Philippines	Enhanced development of R&D program on groundnut, pigeonpea, and chickpea; contributed to improved production and expansion of groundnut, pigeonpea, and chickpea
	Vietnam	Significantly contributed to improved groundnut production in Vietnam
Increasing linkage and contacts among scientists	India	Exposure to international working system; opportunities to visit ICRISAT
	Indonesia	Research partnership in groundnut serves as model for research-extension link
	Nepal	Visit of scientists to ICRISAT
	Philippines	Involvement in the mainstream of international R&D developments; enhanced interaction with other NARS
Training and human respurce development activities	Nepal	Special training at ICRISAT for manpower development of scientists and technicians
	Pakistan	Provided reasonable support to train scientists
	Philippines	Training/fellowship programs to upgrade skills
	Thailand	ICRISAT is a huge knowledge center
Information exchange and related activities	Myanmar	Update agriculture research literature
	Philippines	Upgrade technical information/publication skills

Table 9. Suggestions to increase the value of CLAN.		
CLAN activity	Country	Action plan to increase value to NARS R&D
Germplasm and breeding material	India	Emphasis on flow of germplasm and sources of resistance
	Myanmar	Assist in exchange of germplasm
	Sri Lanka	Exchange of advanced generation breeding materials among member countries
Increasing linkage and contacts among scientists	Bangladesh	Working group meetings to strengthen research linkages; involve working scientists in CLAN activities/seminars
	India	More opportunities for interaction with international scientists: meetings, conferences, field trips
	Sri Lanka	Exchange of scientists/information among countries
	Thailand	Working groups to to solve common problems faced in crop production and to facilitate exchange of technical information/breeding materials/germplasm; progress meetings every 1-2 years to activate interest of researchers
Information exchange and related activities	Bangladesh	Regular circulation of publications on legume and cereal research
	Myanmar	Establish database and information exhange system with member countries
Training and human resource development activities	Myanmar	Assignment of ICRISAT resident scientist will improve research and technology transfer; assist in exchange of expertise; in-country training for research and extension workers
	Philippines	Training on new technologies: IPM, seed technology, seed storage, processing, and use of CLAN crops
Network support to national research programs	Bangladesh	Continuation of support for groundnut and pigeonpea
	India	Jointly structured programs to address issues relevant to Indian context
	Pakistan	Provide more funds, training, and exchange visits
Coordination of regional research on legumes in Asia	Thailand	Closer interaction in collaborative research

Conclusion

Workshop Synthesis

M C S Bantilan[1]

This workshop was organized to enable Research Evaluation and Impact Assessment (REIA) team members from various disciplines within ICRISAT and different national agricultural research systems (NARS) to report on results of studies documenting the joint impact of our research partnership in the semi-arid tropics (SAT). The workshop also aimed to provide a forum for peer review of the various studies and to set priorities for future work on the REIA agenda.

To give some historical perspective, 3 years ago we initiated a series of activities that began with an awareness workshop on impact assessment. This was followed a year later by an international conference on research evaluation methodologies. It was during this conference that we drew our workplan to integrate research evaluation efforts of ICRISAT and the national programs and other international agricultural research centers (IARCs). Implementation of the joint impact assessments was pursued more extensively with the beginning of a global project on research evaluation and impact assessment in 1995 at ICRISAT. A series of training workshops and on-the-job training/field work were conducted both in Asia and Africa. The present workshop, after almost two years of project implementation, serves as a venue to share the results of completed assessments, as well as progress with ongoing work for an audience with multidisciplinary backgrounds from the biological and social sciences. We invited a panel of experts on economic evaluation to serve as peer reviewers, and they provided constructive criticisms and suggestions for the direction of our future work.

ICRISAT's Director General, J G Ryan, inspired us during the opening session with his message that our pursuit of a joint approach to the

Bantilan, M.C.S. 1998. Workshop synthesis. Pages 271-276 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

ICRISAT Conference Paper No. 1349

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

assessment of research impact is crucial for the continuing viability of the IARCs and the global agricultural R&D system. The first session of the workshop gave an overview of available NARS/ICRISAT technologies for the SAT that represent the population of technologies from which we selected a sample for ex-post assessments. It also included a discussion of research evaluation methodology based on the principle of economic surplus, and measurements of other dimensions of research impacts. The theoretical underpinning for research evaluation uses the research-adoption-impact framework, where research investments result in research products that may take the form of new knowledge, information, or technologies that will ultimately contribute to improving crop productivity and farm profitability by the adoption of innovations in farmers* fields.

That adoption is a condition of impact was noted. As introduction of new technologies may result in either success (adoption and benefits to target clientele) or failure (non-adoption due to limitations of the technology or factors constraining adoption), methodologies involving rapid rural appraisal and focus group surveys were covered. Three broad topics were discussed — primary and secondary sources of data that support the minimum data set for research evaluation; development of a sampling scheme that will ensure we collect information from a sample that is representative of the target environment; and survey instruments of the various modules essential in the generation of the minimum data set in the target and diffusion zones.

The efficiency dimension of impact served as a starting point in most analyses. Other dimensions of impact include food security, gender equity, sustainability, human nutrition, employment, and spillover effects. The integration of some of these dimensions in the research evaluation theoretical framework is in progress.

The presentation of case studies in the three workshop sessions featured research impact case studies in four areas — genetic enhancement research in cereals (pearl millet and sorghum) and legumes (chickpea, pigeonpea, and groundnut); resource management options (groundnut production technology and Vertisol technology); intermediate products of research (germplasm, screening techniques for resistance breeding, models); and impact of networks.

The economic evaluation of genetic enhancement research involved assessment of single cultivar and generations of cultivars. Productivity gains and reductions in the unit cost of production as a result of improved varieties and hybrids were featured in the assessment of the impact of improved cultivars of chickpea, pigeonpea, sorghum, and pearl millet. Studies in drought-prone regions of Africa and India demonstrated the food security dimension of research impact, including sorghum S 35 in Chad and Cameroon, and improved pearl millet varieties in Mali, India, and Zimbabwe.

The significant yield gain of short-duration cultivars during years of drought was presented as one measure of gains in food security. Contributions to sustainability of natural resources was tackled in the assessment of short-duration pigeonpea and in the study of the sustainability consequences of land, nutrients, and water management in Vertisols and watershed technology.

Indicators of gender-related impacts identified from case studies in two states of central India were used in analyzing the effects of adoption of various groundnut technology options. The integration of a gender variable in the research evaluation framework was also discussed.

The presentation related to the impact assessment of intermediate products of research (for example, screening techniques) was confined to a background technical paper reflecting the process involved in this research phase. The workplan to assess the impact of screening techniques and the survey instrument was presented.

A peer review and discussion followed each paper presentation. The last session of the workshop was a formal presentation by each team of peer reviewers, feedback, and suggestions. This peer review served as a basis for the discussions on priorities for the future research agenda on impact assessment.

Peer review comments

The summary of the peer reviews is presented as three issues — concepts, methods, and estimates.

Concepts

Direct and indirect impacts. On one hand, aspects of direct impact take the form of effects that can be measured directly as a consequence of the technology change or technology adoption. Examples are measures of efficiency, poverty, and equity (for example, Gini ratio), improved human nutrition, employment effects, and sustainability. On the other hand, examples of indirect impact are the release of area to other income-generating crops due to improved productivity of staple crops, the enhanced opportunity cost of lands that are released for other uses with increases in crop yield, and the indirect industrial links that may result in improved income and employment opportunities for other crops.

Impacts on the poor. Participants asked if sorghum and millet are still the poor man's crop in India? Policy interventions favoring other cereal grains such as rice and wheat may have created a situation where sorghum and millet are no longer the poor man's staple food, thus research in these two crops may no longer benefit the poor sector. A series of questions were raised, including 'Where are the poor in India?'; 'What crops are they raising?'; and 'What crops (staple foods) are they eating?' One observation noted that while research on coarse cereals may significantly benefit Africa, there is a need to reassess these questions in the Indian context.

General equilibrium framework. The concept of general equilibrium was suggested to emphasize that agricultural research technology innovations can affect the consumption, production, and labor supply of both men and women. Two case studies were noted to show that adoption of better technology options is a joint decision of both male and female members of the household. Integration of a gender variable in the research evaluation framework should then take into account this type of household decision process, particularly relating to labor supply and production decisions.

Methods

Economic surplus principle. Impact measures underpinned by the principle of economic surplus are net present value of research benefits, distribution of benefits among sectors or target clientele, internal rate of return of research investments, and benefit-cost ratio.

Additional measures. Suggested additional measures are based on macro- and micro-level analyses. For macro-level analysis, a peer reviewer noted the usefulness of total-factor productivity and sources of growth as indicators of R&D impact. In this context, productivity effects are studied analytically through aggregate production and cost functions, meta-production density function, and the input-output market interface within a general equilibrium framework. Micro-level analysis considers such aspects as input saving, consumer preferences for feedback to plant breeders (cooking quality, shape, color, stem thickness), and inclusion of post-harvest related technologies (storage, keeping quality).

Estimates

Demand-supply issues. Consumer preferences have moved away from coarse cereal grains as a result of policy interventions such as price subsidies in rice and wheat. Related issues are competition with other crops and value added via alternative uses.

Supply elasticity estimates. The studies generally used published elasticity estimates and recent updates. A sensivity analysis using a range of reasonable elasticity values was reported. One suggestion was to consider sole crop and intercrop differences in elasticities, noting that elasticity for sole/commercial crops tends to be higher.

Research lag. Considering that agricultural research to enhance crop productivity in risky environments such as the SAT is more difficult than research in more favorable environments, one peer reviewer suggested the classification of research by its innate difficulty and target environment. In other words, research lag depends on the types of constraints and difficulty of achieving a research breakthrough.

Research costs. Participants questioned how far they should go in estimating research costs. This is especially relevant for research that is based on a stock of knowledge developed much earlier, including germplasm evaluation and chemical fertilizers. Studies should ensure careful documentation of the research process in order to properly determine the start of investments in a specific research effort.

Genetic resources research

Returns to genetic resources research derive from the added value of information on germplasm materials that are collected, characterized, evaluated, and conserved for distribution. Value added may be measured as cost savings due to reduction in the research lag. A careful costing of these activities is required in research evaluation so that we can properly attribute the benefits derived from the final product.

Genetic enhancement research

Several observations about genetic enhancement research were offered, including:

- What are the effects of prices on adoption? Prices that vary across regions serve as an incentive for production and therefore serve as an incentive for adoption. It was suggested that prices should be considered as a determining variable in adoption.
- There should be a zonal basis for establishing research targets.
- Consideration of alternative uses for sorghum in economic evaluation of sorghum research was suggested. Important opportunities for sorghum research featured in the discussions included lack of an effective seed sector system, grain mold or lack of good grain quality, sorghum biotechnology; dual purpose sorghum, and *Striga.*
- The highlight from the pigeonpea research impact assessment was the confirmation of high adoption in target zones. The next challenge is how to accelerate adoption in other zones.
- Estimated NARS research costs seems high, so there is a need to check sources of data.
- The reduction in costs due to farmyard manure requires information on the residual effects in subsequent years.
- The reports on chickpea raised questions on the sampling procedure. The sample sizes were too small for an economic evaluation in Nepal and Bangladesh.

Resource management research

Evaluation of groundnut production technology featured gender-related issues, including the balance of increased employment and drudgery. In particular, while increased employment brings higher household income, women may suffer drudgery given all household and non-household tasks.

An issue that was raised for consideration, particularly in Africa, was soil fertility management in terms of crop residues and benefits of legumes in the cropping system.

Reviews noted several additional factors to be considered when evaluating the impact of Vertisol technology:

- benchmarks;
- positive and negative impacts on the resource base and associated costs;
- short- and long-term gains;
- transaction costs;
- institutional changes; and
- people's participation.

Conclusion

I would like to take this opportunity to thank all our peer reviewers and the participants for your active participation throughout the workshop. Thank you.

Closing Remarks

Y L Nene[1]

There is an anecdote which I could tell, perhaps because 1 will be retiring in a few days. I did not choose economics as a field of study because when I studied economics in the twelfth grade, I had difficulty in memorizing the law of diminishing returns. And I memorized it so well then that even today if you want I can repeat it. But then that was the end of my interest in economics. I wish I had a teacher like Cynthia, who speaks so well, explains so well. You might have had an economist, Cynthia, if you had been my teacher. Thank you indeed.

I would like to make a few remarks very quickly. When I saw the program, I was very happy with the title itself, that it is a joint impact assessment of NARS and ICRISAT. If questions were asked about ICRISAT's impact, I have always said in such meetings there is very little that we can claim as our impact, as an institutional impact, it is always a joint impact, always in cooperation with NARS or similar partners that impact can be measured, assessed, and claimed. We can't claim that this is ICRISAT's impact alone. And therefore, I was delighted to see the theme of this particular workshop.

I see from the peer review that this was the spirit in which the discussions took place. I did sense a little bit difficulty in understanding the impact of germplasm and enhanced germplasm, and I had an uncomfortable feeling that we are confusing issues, that we are measuring impact of the materials and technologies, and not measuring impacts of the work of breeders and genetic resources scientists or pathologists. And that's where I find a little bit of emotion coming in. Let me remind breeders that often they remind me of the books written by many authors, and they are the editors. The editors get their names in all the book listings, but inside the book are the authors of the chapters who have contributed to that book. That does not reduce the contribution of the breeder in putting things together, but it should not also be claimed completely as the

Nene, Y.L. 1998. Closing remarks. Pages 277-278 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, 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.

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breeders' work because so many people have contributed.

And I think if we remember this, then there will not be such emotion arising as to whether the impact is due to germplasm or enhanced germplasm, and I hope the disciplines I mentioned do not mind my saying so. I also got a feeling from the presentations that Cynthia has too much on her plate. So many things were suggested, and I am sure you will have to identify a few that you can manage. Maybe I am wrong, but that's the impression I got from the four presentations and the last External Program and Management Review (EPMR) that also told us to identify a few examples where we can demonstrate measurable impact. Those are my brief comments friends.

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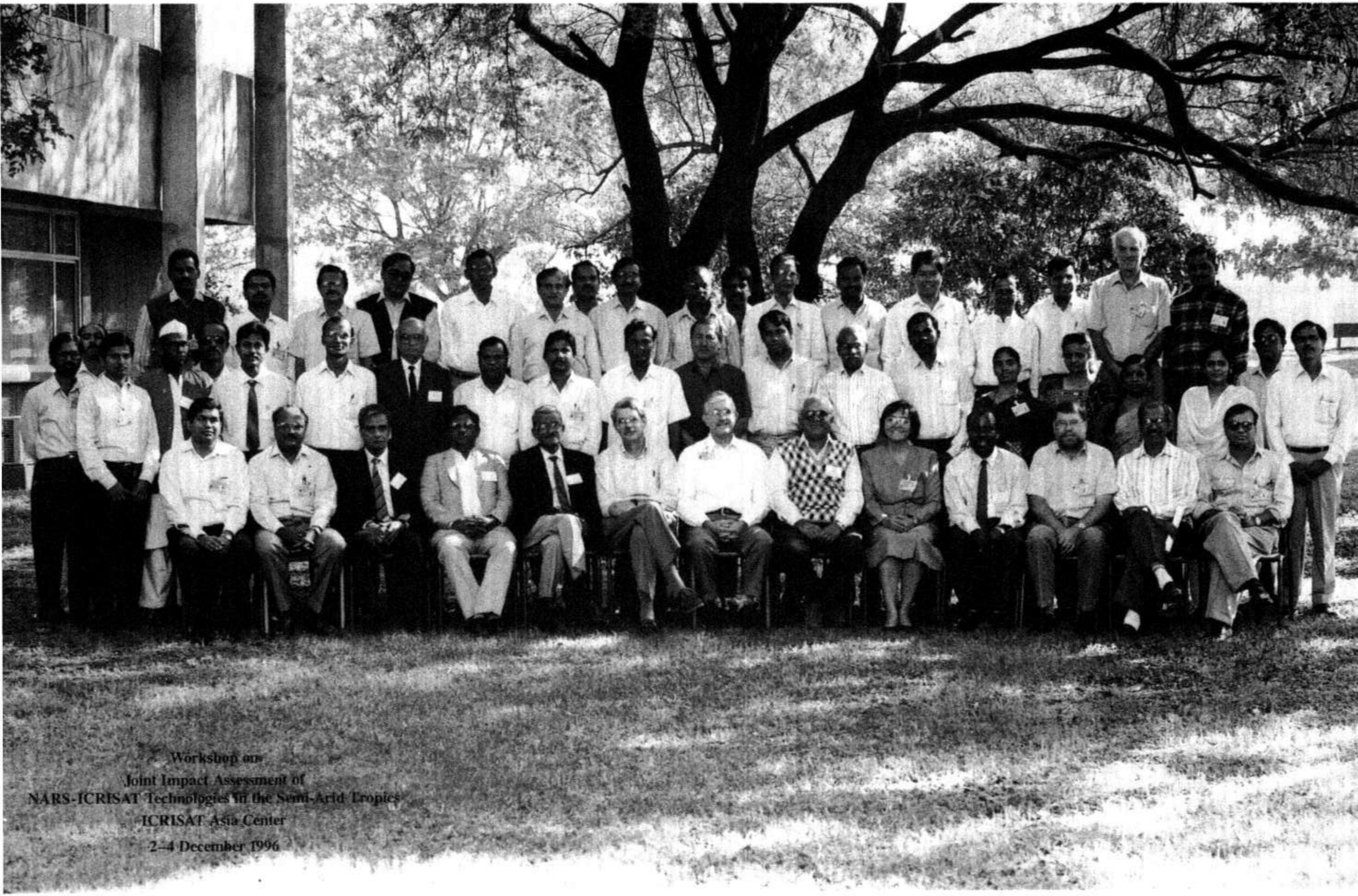
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About ICRISAT

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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