Research Spillover Benefits and Experiences in Inter-Regional Technology Transfer

An Assessment and Synthesis

International Crops Research Institute for the Semi-Arid Tropics

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Abstract

The key role of international agricultural research is to develop technologies that will have wider impacts in certain niche ecoregions that often cross national boundaries. When the potential for inter-regional transfer of research results is high, it is often economical to develop more centralized research programs catering to the needs of the ecoregion. This is also the case when the national programs are small and lack the requisite capacity to develop viable research programs. There are three types of spillovers - inter-regional, cross-commodity and price spillovers. This assessment focuses on inter-regional spillovers - external benefits from research investments undertaken beyond the state (inter-state spillovers) and national (international spillovers) boundaries. Several studies have shown that spillovers make important contributions to agriculture; hence impact assessments that ignore such effects will underestimate R&D benefits.

This study is a first step towards providing a broader assessment and synthesis of inter-state and international technology transfers derived from ICRISAT's research. It brings together the available body of evidence and knowledge on technology spillovers from the major research areas - crop improvement, Natural Resources Management (NRM) and socioeconomics and policy. It provides a list of varieties and other innovations developed in one region that have been adapted in other regions or countries. Despite its limitations, the assessment identifies several instances of technology spillovers within Africa and Asia as well as a two-way transfer of germplasm and improved cultivars across the continents. With selected examples, the study tries to provide useful insights on the preferred characteristics of the technologies, the extent of spillovers, the enabling processes and constraints that limit wider adaptation.

Given its wider scope and interest to 'set the scene' (based on available information) for more in-depth future studies, a deliberate attempt has been made to focus on broader issues rather than details on specific innovations. This makes it difficult to draw very robust conclusions. However, the following generic lessons and recommendations can be made. The potential for future spillover of sorghum and millet technologies from Asia to Africa is limited. This implies the need to further strengthen sorghum and millet improvement work in WCA and ESA. Given the good potential for legume intensification in Africa, a stronger pigeonpea and chickpea improvement program is needed initially in the ESA region. A regional approach to breeding and genetic enhancement of groundnuts in Africa and Asia needs further analysis. The need for crop improvement research in all regions to account for changing market conditions, shifting consumer demand and farmer requirements may limit the potential for inter-regional spillovers. In addition to continuing the challenge of focusing NRM and socioeconomic and policy research on priority strategic areas that generate wider benefits, careful priority setting will be needed to exploit the existing opportunities from inter- and intra-regional transfer of technologies in all areas of research.

Résumé

La recherche agricole internationale a pour rôle principal de mettre au point des technologies qui auront des impacts plus importants dans des écorégions niches, souvent au-delà des frontières nationales. Lorsqu'il y a de grandes possibilités de transfert interrégional de résultats de recherche, il est souvent économique de développer des programmes de recherche plus centralisés qui prennent en compte les besoins de l'écorégion. C'est également le cas lorsque les programmes nationaux sont modestes et ne disposent pas des compétences nécessaires pour mettre en place des programmes de recherche viables. Il y a trois types retombés – les retombées interrégionales, les retombées entre produits et les retombées liées aux prix. La présente évaluation porte essentiellement sur les retombées interrégionales – les avantages externes des investissements faits dans la recherche et qui vont au-delà des frontières étatiques (retombées inter-états) et nationales (retombées internationales). Plusieurs études ont montré que les retombées contribuent de façon significative à l'agriculture; par conséquent, les évaluations d'impact qui n'en tiennent pas compte sous-estiment les avantages de la R&D.

Cette étude constitue une première étape vers une évaluation et une synthèse plus large des transferts de technologie inter-états et internationaux, résultant des travaux de recherche de l'ICRISAT. Elle réunit un ensemble de preuves et de connaissances sur les retombées technologiques se rapportant aux principaux domaines de recherche de l'ICRISAT – amélioration des cultures, gestion des ressources naturelles (GRN), socioéconomie et politiques. Elle présente une liste de variétés ainsi que d'autres innovations mises au point dans une région et adaptées dans d'autres régions ou pays. Malgré ses limites, l'évaluation identifie plusieurs cas de retombées technologiques en Afrique et en Asie ainsi que de transferts bilatéraux de ressources génétiques et de cultivars améliorés entre les continents. En s'appuyant sur des exemples choisis, l'étude essaie d'apporter des informations utiles sur les caractéristiques préférées en ce qui concerne les technologies, sur l'importance des retombées, sur les processus favorables et sur les contraintes qui limitent une plus grande adaptation.

Etant donné sa plus grande portée et son désir de "planter le décor" (à partir des informations disponibles) pour des études futures plus approfondies, l'étude a tenté à dessein de mettre l'accent sur des questions plus larges plutôt que sur des détails concernant des innovations spécifiques. De ce fait, il a été difficile de tirer des conclusions définitives. Toutefois, il est possible de tirer les leçons et de faire les recommandations ci-après. Il y a, en Afrique, peu de possibilités de retombées des technologies du mil et de sorgho mises au point en Asie. Cela suppose qu'il faut renforcer davantage les travaux d'amélioration du sorgho et du mil en Afrique de l'ouest et de centre et en Afrique du est-sud. Etant donné les perspectives prometteuses concernant l'intensification des légumineuses en Afrique, un programme de pois d'angole et de pois chiche plus solide a été lancé dans la région de l'Afrique du est-sud. Il convient d'étudier davantage une approche régionale en matière de sélection et d'amélioration génétique de l'arachide en Afrique. La nécessité de mener des recherches sur l'amélioration des cultures dans toutes les régions pour expliquer l'évolution des conditions du marché, le changement de la demande des consommateurs et les besoins des paysans, peut limiter les possibilités de retombées interrégionales. Outre le fait de continuer à focaliser les recherches relatives à la GRN, à la socioéconomie et aux politiques, sur les domaines stratégiques prioritaires se traduisant par des avantages plus larges, il faudra soigneusement définir les priorités pour exploiter les possibilités qu'offrent actuellement les transferts de technologies inter et intra régionaux dans tous les domaines de la recherche.

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With contributions from several scientists

ICRISAT

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Acknowledgments

Documenting inter-regional spillovers resulting from decades of research and development efforts of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) across disciplines and technologies is no easy task. However, a first attempt is made here to highlight the spillovers from the international public goods (research products) generated from the Institute's different mandate crops, Natural Resources Management (NRM) and socioeconomics and policy research. We gratefully acknowledge the contribution of current and former ICRISAT scientists who provided the much needed information to better understand the process and extent of spillovers across regions, which played a crucial role in completing this preliminary study. A partial list of the scientists who responded to our electronic survey, participated in consultations and contributed useful information is given below. The Director General, Dr William Dar, not only initiated this study but also provided useful guidance since its inception. We hope the study will serve as a useful reference for future in-depth assessments in this important area. We are also thankful to PN Jayakumar for his contribution in editing the material and compiling and analyzing the data. The usual disclaimer applies.

Scientists who provided useful information and contributed to the study.

Sorghum	Millets	Groundnuts	Pigeonpea	Chickpea	NRM	Socio-economics and policy	Capacity building
BVS Reddy	KN Rai	SN Nigam	KB Saxena	PM Gaur	*SP* Wam	D Rohrbach	CLL Gowda
AB Obilana	ES Monyo	F Waliyar	SN Silim	CLL Gowda	S Twornlow	HA Freeman	S Koala
DS Murthy	CT Hash	BR Ntare	HA Freeman	J Kumar	P Pathak	PP Rao	D Fatondji
HC Sharma	D Rohrbach	GV Ranga Rao	R Myers	GV Ranga Rao	TJ Rego	KPC Rao	E Weltzien
D Rohrbach	RP Thakur	JH Crouch	GV Ranga Rao	YS Chauhan	J Dimes	J Ndjeunga	KPC Rao (Kenya)
E Weltzien	R Myers	AJ Chiyembekeza	J Adu Gyamfi	S Pande	J Adu Gyamfi		R Navarro
RP Thakur	B Ouendeba	M Siambi	YS Chauhan	JH Crouch	RTabo		S Chandra
JH Crouch		HD Upadhyaya	S Twomlow		A Ramakrishna		
CT Hash					B Shapiro		
					S Snapp		

Acronyms

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
ADP	Agricultural Development Projects
AICF	Action Internationale Contre la Faim
AICMIP	All India Coordinated Millet Improvement Project
AICORPO	All India Coordinated Research Project on Oilseeds
AICSIP	All India Coordinated Sorghum Improvement Project
ANGRAU	Acharya NG Ranga Agricultural University
APAARI	Asia-Pacific Association of Agricultural Research Institutions
APSIM	Agricultural Production Simulator
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
BARC	Bhabha Atomic Research Center
BARI	Bangladesh Agricultural Research Institute
BBF	broadbed and furrows
BBM	broadbed maker
BGM	Botrytis Gray Mold
BND	Bud Necrosis Disease
BSEC	Bold Seeded Early Composite
CERES	Crop Estimation through Resource Environment Synthesis
CFTRI	Central Food Technological Research Institute
CGIAR	Consultative Group on International Agricultural Research
CIDA	Canadian International Development Agency
CILLS	Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel
CIMMYT	Centra International de Mejoramiento de Maiz y del Trigo
CLAN	Cereals and Legumes Asia Network
CMS	cytoplasmic male sterility
CORAF	Conseil Ouest et Centre Africain pour la Recherche et le Developpement Agricoles
CRIDA	Central Research Institute for Dryland Agriculture
CSWCRTI	Central Soil and Water Conservation Research and Training Institute
CWANA	Central and West Asia and North Africa
DANIDA	Danish International Development Agency
DDSAT	Decision Support System for Agrotechnology Transfer
DFID	Department for International Development, UK
DR&SS	Department of Research & Specialist Services, Zimbabwe
EARCAL	Eastern Africa Regional Cereals and Legumes Program
ECARSAMN	East and Central Africa Regional Sorghum and Millet Network
ECOWAS	Communaute economique des etats de l'Afrique de l'Ouest
ELS	Early Leaf Spot
EPR	External Panel Review
ESA	Eastern and Southern Africa
ESDP	extra-short-duration pigeonpea
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GITAs	Global Impact Target Areas
GMS	Gridded Mass Selection
GT	Global Theme
HK	Heine Keiri
HPLC	high performance liquid chromatography
IAR	Institute of Agricultural Research
IARCs	International agricultural research centers
IBPGR	International Board for Plant Genetic Resources
ICAR	Indian Council for Agricultural Research

ICARDA	International Center for Agricultural Research in the Dry Areas
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IITA	International Institute for Tropical Agriculture
INSAH	Institute of Sahel
INTSORMIL	International Sorghum/Millet Collaborative Research Support Program
IPG	international public good
IRA	Institut de la Recherche Agronomique
IRR	internal rate of return
IWMI	International Water Management Institute
JVP	Joint Vertisol Project
KARI	Kenya Agricultural Research Institute
LBC	Late Backup Composite
LCRI	Lake Chad Research Institute
LEGOFTEN	Legumes On-farm Testing and Evaluation Nursery
LLS	Late Leaf Spot
MDG	Millennium Development Goals
NARES	national agricultural research and extension systems
NARS	national agricultural research systems
NCRE	National Cereals Research and Extension Project
NGOs	non-governmental organizations
NPV	nuclear polyhedrosis virus
ONDR	Office Nationale de Developpement Rurale
OPV	open-pollinated varieties
ORSTOM	French Institute of Scientific Research for Development through Cooperation
PERFECT	Productivity, Erosion, Runoff Functions to Evaluate Conservation Technologies
QDPI	Queensland Department of Primary Industries
R&D	research & development
REIA	Research Evaluation and Impact Assessment
SACCAR	Southern African Centre for Cooperation in Agricultural and Natural Resources
SADC	Southern African Development Community
SAFGRAD	Semi-Arid Food Grain Research and Development
SAT	semi-arid tropics
SDC	Swiss Development Corporation
SDP	short-duration pigconpea
SEA	Southern and Eastern Africa
SEPON	Sorghum Elite Progeny Observation Nursery
SMINET	Sorghum and Millet Improvement Network
SMIP	Sorghum and Millet Improvement Program
SPAAR	Special Program on African Agricultural Research
SSC	Super Serere Composite
SWMnet	Soil and Water Management Research Network for Eastern and Central Africa
TLC	thin layer chromatography
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
VAM	vesicular arbuscular mycorrhiza
VLS	Village-Level Studies
WANA	West Asia and North Africa
WCA	West and Central Africa
WCAMRN	West and Central Africa Millet Research Network
WCASRN	West and Central Africa Sorghum Research Network
WMO	World Meteorological Organization

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Foreword

The major contribution of international agricultural research in the CGIAR is to develop new technologies that generate international public goods for enhancing food security and protecting the productive resource base in the poorest countries of the world. ICR1SAT has been at the forefront of developing various seed-based and natural resource management technologies and other useful innovations suitable for diverse niches in the dry tropics. These innovations were designed and developed in several regional hubs of ICRISAT in close *partnership with* NARS, NCOs*, governments and farmer organizations in Africa, Asia and Latin* America. It is very important to ensure that technologies developed in certain regions will be useful for other areas and eco-regions sharing similar biophysical and socioeconomic conditions. Many small countries without strong national research systems have benefited from inter-regional and cross-boundary transfer and adaptation of new technologies developed elsewhere.

As an international research institution in the public sector driven by non-profit objectives, ICRISAT is keen to maximize benefits from its research and development investments through facilitating wider adaptation and use of its valuable technologies to achieve its noble mandate. One of the major problems for technology exchange has been the lack of capacity for enhanced utilization of available technological options within the national programs. We have used various approaches and strategies for tackling these problems and enhancing spillover of germplasm, improved vanities and other innovations across regions. Capacity building through sustained training programs and south-south collaboration among scientists in the developing countries played a critical role in this process. In addition, workshops, symposia, policy dialogues and networking among like-minded scientists have contributed to the exchange of knowledge and technologies and for wider utilization of innovations.

This book has made an initial but systematic attempt to provide a broader assessment and synthesis of ICRISAT's experience in inter-regional and international technology exchange and adaptation over the years. It brings together the broad literature and summarizes the available evidence and knowledge on technology spillovers from our diverse areas of research endeavors. With selected spillover examples across continents, the book brings much needed knowledge on the status of technology exchange and factors that deter or facilitate this process. The lessons and insights derived from this work will guide our future effort and play an important role in our continued stride to enhance the impact of research on poverty and for the betterment of the living conditions of millions of poor families in the semi-arid tropics worldwide.

William D Dar
Director General

Executive Summary

Research products aimed at a given location may spill across regions, nations, or even across traditional agroecological zones. The potential for such spillovers depends on several factors like biophysical and socioeconomic similarities between locations. Agricultural research and development investments (eg, on roads and irrigation) have contributed to the creation of new niches and the expansion of crops into new areas. Agroecological similarities are essential for agrobiological technology spillovers across countries or regioas, but they are by no means sufficient. The potential for spillover of research products also determines the size and scale of new research programs in a given country or region. The potential for spill-out and spill-in of agricultural technologies across geopolitical boundaries could also be disincentives for national programs to invest in agricultural research. Recent studies on inter-regional spillovers have shown that such benefits often account for up to half the measured growth in crop productivity in many countries.

Given such intended and unintended research benefits (spillovers), regional and international cooperation is required to share the costs and benefits of research investments. Such effective cooperation may not always be forthcoming because of many reasons, including political constraints and the inherent lack of institutional capacity within the national programs in poor countries. International agricultural research centers (IARCs) like ICRISAT were established to address this problem and to develop knowledge and technologies that generate international public goods (IPGs) benefits in the poor regions of the world. Facilitating inter-regional research spillovers is therefore one of the vital contributions of international agricultural research institutes worldwide.

ICRISAT currently conducts its research through three regional hubs in sub-Saharan Africa - Nairobi in the Eastern region, Bulawayo in the Southern region and Niamey in the Western and Central region - and a regional hub for Asia based at its headquarters at Patancheru near Hyderabad in India. The hubs represent broad ecoregions covering a number of countries in the Semi-Arid Tropics (SAT) of Africa and Asia. New research products from any of these regional hubs are expected to have a high potential for spillover within the region and sometimes across regions, including a two-way transfer of technologies between Africa and Asia. Between 1976 and 1985, ICRISAT stationed scientists in six African countries (Burkina Faso, Mali, Niger, Nigeria, Senegal and Sudan) to improve the productivity of sorghum and pearl millet. Gradually, these country-based programs were replaced with three regional programs. ICRISAT also had a sorghum improvement program in Latin America from 1978 to 1993.

In addition to enhancing the capacity of the national programs across the SAT of Asia and sub-Saharan Africa, ICRISAT and its diverse partners have developed new technologies, methods and innovations that generate regional and global spillovers. To date, about 130 sorghum, 76 pearl millet, 42 chickpea, 26 pigeonpea and 45 groundnut varieties have been released across countries. A number of these products have good potential for spillover across ecoregional and political boundaries. Among the varieties developed through partnerships between ICRISAT and the national agricultural research systems (NARS), about 73% of sorghum, 37% of pearl millet, 80% of groundnut, 62% of pigeonpea and 52% of chickpea varieties have generated important spillover benefits.

To attain its goals of improving food security and ensuring more sustainable management of natural resources in the dryland tropics, ICRISAT needs to promote the sharing and spillover of finished products (such as new varieties), germplasm, knowledge, methods, tools, etc, across national and regional borders. Acting as a bridge, broker and catalyst, ICRISAT has facilitated south-south collaboration among developing countries in the transfer, utilization and adoption of research products, skills and materials. This has taken several forms ranging from the exchange of information to the acquisition of germplasm and advanced breeding materials from other countries via ICRISAT.

Research networks, training programs, workshops and symposia undertaken across regions have also contributed to capacity building and inter-regional spillover of research products. ICRISAT also encourages, facilitates and supports the integration of scientists from national programs in the south into the global scientific community. Such integration is very useful for sustained development and for effective utilization of existing spillover potential globally.

Although international agricultural research institutes worldwide have made vital contributions towards achieving inter-regional research Spillover benefits, very little has been done so far in terms of assessing and systematically quantifying the potential and actual inter-regional spillovers from ICRISAT's own Research & Development (R&D) efforts. This document analyzes and summarizes the limited Studies available and information gathered through discussions and consultations with relevant scientists in different regions. Therefore, it is not exhaustive; it only presents broad results from cases with useful summarizable information. More case studies are needed to understand the spillover process and identify key constraints to and facilitating mechanisms for technology transfer across regions. This will inform organization and management of research at ICRISAT and help design policy instruments that facilitate inter-regional collaboration in technology transfer.

In order to provide brief highlights about the state of inter-regional technology transfer, we briefly summarize the extent of technology spillovers and contributing factors for the inter-regional technology transfer from research endeavors at ICRISAT: crop improvement, natural resource management and socioeconomics and policy research.

Sorghum. Twelve sorghum varieties and 13 germplasm accessions from ICRISAT-Patancheru have been released in African countries. The national programs in African countries have also developed and released at least four varieties using ICRISAT lines. Twenty-three sorghum varieties bred at ICRISAT-Patancheru have been released in Asia (excluding 21 in India) and 13 in Latin American countries. In addition, at least 19 varieties developed by the African national programs together with ICRISAT or using ICRISAT-Patancheru bred lines, have been released in Africa. A number of germpiasm accessions from Africa have also been identified as sources of resistance for abiotic and biotic stresses.

In terms of cross-regional spillovers, the findings indicate that large-scale adoption of varieties introduced from ICRISAT-Patancheru into Africa has occurred mainly for S 35 (Cameroon and Chad), ICSV 111 (Nigeria and Ghana) and SV 2 (Zimbabwe).

Sorghum variety S 35 was introduced from ICRISAT-Patancheru to ICRISAT-Zaria (Nigeria) and then to Cameroon and Chad. It was released in 1986 in Cameroon and in 1989 in Chad. ICRISAT conducted on-farm surveys in 1995 in Cameroon and Chad to assess farmer perceptions and to track its spread in drought-prone areas. The study showed that farmers were substituting S 35 for traditional varieties in these areas. Ten years after its release in some parts of northern Cameroon, S 35 occupies about 33% of the rainfed sorghum area in the region. In Chad, it occupied about 27% of the rainfed sorghum area in 1995 in the three southern provinces where it was tested and initially promoted. The uptake of S 35 was motivated by its higher yields and earliness compared to local varieties and the availability of small seed packs.

Sorghum variety ICSV 111 was introduced to ICRISAT-Nigeria for evaluation in 1988 from ICRISAT-Patancheru and released in Nigeria and Ghana in 1996 and in Benin in 1999. The variety has found a niche in the semi-arid areas, and an estimated 100,000 ha are grown with this variety in Nigeria. Farmers adopted this variety because of traits such as earliness, white grain color and good food quality. Strong partnerships with JocaJ partners and the availability of seed through the extension system facilitated spillovers and local adoption.

The variety SV 2 is a good example of inter-regional spillover benefits facilitated by a visiting scientist (from Zimbabwe in 1980) who introduced the breeding line from Patancheru. While it was released in 1987 lor its earliness and higher grain productivity, significant diffusion did not occur until 1992 due to the lack of seeds. Within three years of ICRISAT's emergency seed production program in 1992, the area covered by SV 2 grew quite significantly.

The best example of inter-regional spillovers within Africa is that of the sorghum variety popularly known as Maria (SDS 3220), developed by ICRISAT-Bulawayo. This variety was released in Botswana, Mozambique, Namibia, Tanzania and Zimbabwe and pre-released in Eritrea and Kenya. Farmers prefer this variety because of its early maturity, better yields, large heads and good grain quality. Macia's stay-green trait with broad leaves and a juicy thick stem also makes it a valuable fodder for livestock.

There are also a few sorghum varieties from the African national programs, introduced to ICRISAT-Patancheru and released in India and Pakistan. However, most significant in terms of intercontinental spillovers is the exchange of germpiasm between Africa and Asia. Sources of resistance to diseases identified from several germpiasm accessions of African origin are widely used in sorghum research in Asia and other regions. ICRISAT's germpiasm collections are IPGs widely utilized in crop improvement and as sources of resistance against biotic stresses worldwide.

Pearl millet. In addition to Indian germpiasm, ICRISAT-Patancheru's breeding program has used pearl millet germpiasm accessions from several African countries such as Togo, Nigeria and Uganda. Indian landraces and breeding lines generally provide excellent sources of desirable traits like resistance to diseases (downy mildew and smut), large panicle size and bold grains. West African germpiasm improved at Patancheru has been found well adapted in Eastern and Southern Africa (ESA). ICRISAT-Patancheru bred pearl millet varieties have not been adopted by farmers in West and Central Africa (WCA) mainly due to disease susceptibility. Six Patancheru-bred varieties have been released in ESA and one in WCA. About 17 varieties bred within Africa are also grown in other African countries. About 42 varieties developed at ICRISAT-Patancheru with Indian NARS have been released in India. The Consultative Group on International Agricultural Research (CGIAR) recognized ICRISAT's outstanding contribution to the improvement of this sturdy crop of the poor in marginal environments with the King Baudouin Award for 1996.

The major impact of Patancheru-bred varieties has been seen in Namibia from Okashana 1, primarily constituted from germplasm accessions from Togo. In 1986, ICTP 8203 was introduced from ICRISAT-Bulawayo to Namibia and released as Okashana 1 in 1989. this variety was replaced in 1990 with ICMV 88908, another higher-yielding variety with a similar morphology. Later, ICMV 88908 was released in Malawi and Botswana.

A recent impact study has shown that in 1996-97, about half of the total pearl millet area in Namibia was under Okashana 1. This was possible because of the strong commitment from the national programs, timely donor support and farmers' preference for the variety for its earliness and large seed size. With technical support from ICRISAT, the government made seed available to farmers at affordable prices and conducted several demonstrations across the country to enhance farmer awareness.

Several breeding populations, accessions and sources of resistance to diseases introduced from Africa have been utilized in breeding programs at Patancheru. The variety WC-C75 was developed in the 1980s from a composite population introduced from the Nigerian national program in 1973. This variety was grown over a million ha in India for 12 years. It is now grown in Gujarat and Rajasthan mainly for fodder. It has also been released in Zambia. The second example is the Iniadi germplasm from Togo and Ghana from which several varieties were-developed at Patancheni, three of which are cultivated by farmers in India.

In WCA, two pearl millet varieties are being widely adopted by farmers. The variety SOSAT-C88 was developed by the Malian national program in collaboration with ICRISAT-Niamey at Cinzana (Mali). This variety was released in Burkina Faso, Cameroon, Chad, Mali, Mauritania and Nigeria, and is widely grown in Nigeria and other countries. It is highly resistant to downy mildew. Variety GB 8735 developed at ICRISAT-Niamey has been adopted in several countries, including Benin, Chad, Mauritania and Nigeria.

Finger millet. Two finger millet varieties (FMV 1 and FMV 2) bred by ICRISAT-Bulawayo and its partners were released in Zimbabwe in 1992. There was no spillover to other countries as there was no follow up from the regional program; the activity lasted from 1986 to 1992 due to budget constraints. Since then, work on finger millet has been discontinued.

Groundnut. ICRISAT-Patancheru-bred groundnut varieties have been released in ESA (6), WCA (8), Cyprus (3), and within India (11) and other Asian countries (13). Six out of seven varieties developed at ICRISAT-Malawi have been released in ESA countries other than Malawi. There has been no direct spillover of any groundnut variety developed in Africa and released in Asian countries. However, some germplasm accessions introduced from Africa to Patancheni have been identified as sources of resistance to aflatoxin and late leaf spot.

Groundnut variety CG 7 (ICGMS 42) was bred at Patancheni and was released in Malawi, Zambia and Uganda for its higher productivity. Another variety (ICGV-SM 90704) was developed by ICRISAT-Malawi and its partners primarily for rosette resistance and high yield. A study conducted on the adoption potential of these two varieties in Malawi suggested a high level of acceptability by participating farmers.

Variety ICGV 87157 was bred at Patancheru in 1981, introduced to ICRISAT-Bamako and released to farmers in Mali in 2001 for its high yield and resistance to diseases and pests. The variety is gaining popularity among farmers in Kolakani region of Mali because of its high pod yield, resistance to foliar diseases, large seed size and preferred taste by farmers.

Along with its partners, ICRISAT-Patancheru developed a simple, low-cost and robust testing method (ELISA) to facilitate the detection and estimation of aflatoxin contamination in food and feed products, particularly in groundnuts. The technology is being adopted in Burkina Faso, India (including the private sector), Mali, Niger and Nigeria.

Pigeonpea. About 12 pigeonpea varieties developed at ICRISAT-Patancheru with its partners have been released in India and about 5 in other Asian countries. At least two varieties developed at Patancheru have been adopted in five countries of ESA. Pigeonpea research has been concentrated at Patancheru, but it has recently been expanded to Eastern Africa (ICRISAT-Nairobi), where three varieties have been developed and released. In recognition of the groundbreaking work on this less-known crop, the CGIAR's King Baudouin Award was bestowed on ICRISAT in 1998.

Pigeonpea variety ICPL 88039, a short-duration and high-yielding type, stimulated large productivity gains in the rice-wheat system in South Asia. The variety enabled diversification of cereal-dominated cropping systems by inserting a legume component. This triggered a major geographic extension of the crop.

Another short-duration variety, ICPL 87, which became popular in Central and Southern India, also spread to Sri Lanka encompassing the tropical rice belt of South/Southeast Asia.

Other pigeonpea varieties such as ICPL 87091, ICPL 87119 and ICP 7035 are also spreading in the hilly rainfed areas of China, preferred by fanners lor soil conservation and as fodder for cattle, goats and rabbits.

A short-duration pigeonpea line, ICPL 87091, developed at Patancheni to meet vegetable pigeonpea needs, has found home in Kenya, Malawi, Mozambique, Tanzania and Uganda. It has been officially released for cultivation in Kenya.

Fusarium wilt is one of the most widespread and destructive diseases of pigeonpea in Asia and Africa. An effective screening technique has been developed by ICRISAT to identify resistance sources. This innovation is being used by NARS in many pigeonpea-growing countries. The diffusion of wilt-resistant varieties ICP 8863 in India and ICP 9145 in Africa (Malawi and Tanzania) exemplify the successful application of this technology.

Chickpea. ICRISAT and the International Center for Agricultural Research in the Dry Areas (ICARDA) share the global research mandate *for* the improvement of this crop in the SAT (for Desi types) and dry temperate regions (for Kabuli types), respectively. ICRISAT's chickpea research team is based in Patancheru, but the research activities are conducted throughout the chickpea-growing regions of the world in collaboration with the NARS. ICRISAT research conducted with partners around the world has generated over 40 improved varieties released in several countries, This does not include the varieties ICARDA had developed for the dry temperate regions. As a result, chickpea area and productivity have increased dramatically in the tropics, as the crops found new niches in nontraditional areas. For example, chickpea variety ICCV 2 (Swetha), the first Kabuli type short-duration variety released in Peninsular India, has been instrumental in extending chickpea cultivation into cotton, tobacco and chilli growing areas of Andhra Pradesh, a nontraditional niche for the crop.

ICCV 2 has also been released in Myanmar and Sudan - a spillover within Asia and from Asia to Africa, respectively. In Myanmar, where drought and fusarium wilt have been major constraints, chickpea has now become an important export crop and cash earner for smallholder farmers.

Another variety ICCL 82104 and a selection from K 850 x F 378 (Mariye) have become popular in Ethiopia, which accounts lor half of Africa's entire chickpea area. Mariye's rapid spread and its transformation into the predominant chickpea variety is an example of farmer-driven development. Ethiopia regularly exports chickpea to Afghanistan, India, Pakistan and the United Arab Emirates.

Chickpea has also found a new niche in the Barind tracts of Northwest Bangladesh where agriculture in the postrainy season alter rice had been impossible for generations. ICRISAT varieties such as ICCV 10 jointly developed with the national program occupy about 85% of the chickpea area in this region. Within a span of three years, the chickpea area in the Barind has doubled, mainly because of the opportunity to obtain sizeable economic returns from otherwise nonusable rice fallows.

Products of ICRISAT's chickpea research have spilled over beyond its mandate region to benefit the developed world, including Australia, Canada and the USA. Canada is currendy experiencing a chickpea revolution; the area under this crop has grown from 3,000 ha in 1995 to some 485,000 ha in 2001. The ICRISAT-bred variety ICCV 92809 (Myles) covers about one-third of the total chickpea area in Canada.

These achievements were recognized by the CGLAR, which awarded the King Baudouin Award for 2002 to ICRISAT and ICARDA.

Natural Resources Management. Currently, the NRM work is undertaken in all the *regions* jn *Africa* and Asia. In recent years, NRM research has moved on farm, become more holistic, systems oriented and farmer participatory in nature than in the past, and is being carried out on a landscape-watershed-community scale. Apart from low-cost resource management technologies, the products of NRM research include scientific principles, concepts, processes and research methods, which together constitute IPGs with a potential for inter-regional spillover. We provide some examples.

ICRISAT is recognized as one of the pioneers of the watershed management concept for integrated management of soil and water resources in drought-prone rainfed regions. The concept has now been adopted by policymakers and development agencies interested in sustainable rural development. In India for example, the 25-year perspective plan (1997-22) for the development of tainted areas recommended greater emphasis on watershed management, targeting some 90 million ha of marginal land.

Developing packages and components of the vertisol technology has been one of the major outputs of watershed-based NRM research at ICRISAT. The vertisol technology as a package of options was first tested and demonstrated on farmers' fields in Andhra Pradesh, India. The technology components were later adopted in other states like Karnataka, Gujarat, Maharashtra and Madhya Pradesh. The approach gradually spilled over into the vertisol areas of Ethiopia. This technology has been adapted to Ethiopian conditions with the modification of the local plough (maresha) to produce the broadbed maker (BBM). Although little is known about the extent of adoption of the technology, it is considered to have high potential for improving the productivity of underutilized and waterlogged vertisols (about 8 million ha) in the Ethiopian highlands.

Strategic research on cropping systems forms a large part of ICRISAT's resource management work. The Institute has played a catalytic role in enhancing the understanding of key cropping systems in the SAT.

For example, ICRISAT utilized the scientific knowledge on intercropping originally generated in Nigeria and Uganda to develop scientific methods to improve various intercropping systems in India. These scientific mediods were further tested and promoted in Niger and Mali.

Many countries have adopted soil conservation and fertility management components such as tied ridging, wind erosion control, fertilizer placement (micro-dosing), contour bunding, crop residue management and natural rock phosphate application methods developed by ICRISAT and its partners in Africa (Burkina Faso, Mali, Niger, Nigeria and Senegal).

Characterization and modeling of the SAT agroclimatic environment developed at Patancheru and Bulawayo has provided a sound basis for the design and transfer of suitable agricultural technologies throughout the SAT Spillovers from soil-water balance, crop growth and soil fertility management simulation models are finding use in Asia and Africa. More research is required to understand and estimate the actual extent and the potential for inter-regional technology spillovers from NRM research. This is very important, given the limited direct transferability of research products from NRM research. The lessons, experiences, principles and methods seem to be most important for NRM research spillovers.

Socioeconomics and policy. The social science team at ICRISAT works closely with agrobiological scientists in the area of crop improvement and NRM. This makes it difficult to identify separate research outcomes with spillover benefits from the social science work. However, some research products like new research methodologies, databases, policy recommendations, policy briefings, concepts and training activities are likely to generate important IPG benefits.

The Village-level Studies (VLS) of ICRISAT pioneered an effort to develop a longitudinal panel database which could be used for tracking development pathways, evaluating policy impacts and testing several key theories about farmer resource-use behavior in the risk-prone dryland environments. An analysis of this micro-level data has contributed to the identification and understanding of socioeconomic, agrobiological and institutional constraints to agricultural development in the SAT. This has facilitated and informed research priority setting at ICRISAT.

The longitudinal data from SAT villages in Africa and Asia has helped the international scientific community analyze and understand complex behavioral issues pertaining to small farmers. These include the pioneering work on the measurement of attitudes to risk, and studies on time preference, time allocation and labor markets and land use intensification and farm mechanization. Results from these analyses, now used worldwide, have made significant contributions to the discipline of agricultural economics and inspired similar work in other countries.

A number of publications, including several graduate theses and books, emerged from the analyses of these datasets. The datasets are still in demand by scientists interested in examining the changes and dynamics of rural welfare and resource-use patterns. Although this work is generally believed to have generated several spillover benefits, it is difficult to attribute policy changes and desired outcomes directly to it. A more directed and in-depth research is needed to assess the actual impact and extent of spillovers of the VLS work.

The Research Evaluation and Impact Assessment (RF.IA) methodology developed at ICRISAT is widely adopted by several national programs in Africa and Asia. The methodology involves a systematic tracking of the spread of varieties and odier technologies in a target domain.

Recently, ICRISAT has also taken the lead in developing methods to assess the impacts of NRM interventions. Due to its complexity, multidimensional effects and valuation problems, it has been difficult to systematically evaluate outcomes from R&D investments in NRM. Some of these methods are now being tested in selected areas in partnership with national programs and advanced research institutes. A methodology was also developed for estimating consumer preference for food crops, based on a laboratory analysis of market samples for key quality parameters and market prices. The estimated coefficients for selected quality parameters can be used for large-scale screening of newly released varieties. More recently, the methodology was applied on chickpeas in a collaborative study with Muresk Institute of Agriculture (Australia).

Research on the impact of reforms in the fertilizer market in Eastern Africa have led to the identification of strategies to improve fertilizer adoption by small farmers. This work seems to have inspired new trials with a wider range of soil fertility inputs in Kenya and ESA. To date, research programs in Malawi, Tanzania and Zimbabwe are actively conducting experiments with sub-optimal levels of fertilizer. Similarly, research on rural markets in Africa led to the development of a conceptual framework that links technology development, dissemination and market institutional innovations for poverty reduction. A number of partners from R&D organizations are using this framework to implement projects in Kenya, Malawi, Mozambique, Tanzania and Uganda.

Work on seed policy reform in Africa has led to a comparative review of policy discussions relating to seed regulatory harmonization in Africa. This has stimulated inter-country collaboration in seed policy reforms.

The work in Southern Africa to link technology design and markets has inspired new programs to link variety selection, seed supply, crop management advice and trade for sorghum, groundnut, pigeonpea and chickpea in Kenya, Malawi, Mozambique, Tanzania and Uganda.

Key lessons and recommendations

The broad assessment of inter-regional transfer of research products shows important spillovers within each region in Africa and Asia as well as a two-way transfer of germplasm and improved cultivars across the continents. It also reveals ICRISAT's effectiveness in facilitating inter-country collaboration and capacity building within the national programs. The following recommendations and propositions have been advanced for a better understanding of the mechanisms for maximizing spillover effects and assessing their implications for ICRISAT's global research agenda.

- Understanding the potential for spillover of agricultural technologies across locations requires a systematic consideration of socioeconomic as well as biophysical (agroecological) similarities and their implications for technology design and development.
- Where the potential for spillover is high but is actually limited, future work is needed to assess the constraints and identify strategies to enhance spillovers and south-south collaboration.
- In situations where possibilities for spill-in are high and economies of scale exist, it is advisable to have fewer, more centralized and larger research centers rather than many small research stations. Upstream research with high economies of scale like in biotechnology, is an example of this kind of research organization.
- Where the potential for cross-continental spillovers is limited, but regional spillovers are more likely, research needs to be organized along relatively homogenous (considering both biophysical and socioeconomic factors) regions. An example may be crop improvement work that requires farmer participatory breeding and local adaptive trials in specific regions in Africa or Asia.
- Where opportunities for spill-in/spill-out are limited (as in very unique products or ecoregions), international or regionwide research may not be feasible. National programs may have to organize targeted research stations catering to the needs of specific products or ecoregions. In such cases, IARCs should focus on capacity building to enable national programs to develop research programs specific to their own needs.
- Given the importance of spillovers across countries and regions in international agricultural research, future impact assessments should also consider spillover effects/impacts.
- Identification of global and local impact targets, future research priorities, regional strategies and institutional organization of ICRISAT research should be informed and guided by a careful assessment of the potential for spillovers and generation of IPGs for impact.

Results from this broad assessment lead to the following recommendations.

- There is a need to further strengthen sorghum and millet improvement work in WCA and ESA. The potential for technology transfer is limited by the changed structure in Asia and the diverging biophysical conditions and stress factors in Africa and Asia. Experience has also shown that the potential for technology transfer between the two regions in Africa is weak, indicating the need to maintain a twin-region approach towards sorghum and millet improvement in Africa.
- Pigeonpea and chickpea breeding and adaptation research in ESA need to be strengthened. This is consistent with the potential of these pulses for sustainable intensification of African farming systems and for improving the nutritional status and incomes of the poor.
- There is a need to further explore options for a regional approach to breeding and genetic enhancement of groundnuts in Africa and Asia.
- Crop improvement research needs to be linked with changing market *conditions,* shifting *consumer* demand and farmer requirements in both regions.
- NRM and socioeconomic and policy research must focus on priority strategic areas that generate inter-regional research spillovers.

Further detailed analysis and empirical evidence is needed to firm up these set of hypotheses and recommendations. The initial investigation may focus on selected shining examples from each crop in specific regions in order to draw more specific lessons and recommendations. Additional evidence and analysis of potential cases for spillovers and IPG covering the NRM and socioeconomics research products will enhance this documentation.

1. Introduction

International agricultural research centers were established for the purpose of generating technologies that would have wide applicability across countries in order to generate international public goods (spillovers). During the last two decades, agricultural research worldwide has undergone rapid changes to evolve into a complex system of IARCs, regional centers and networks and an extremely diverse range of NARS with broadened mandates that include sustainable natural resources management, poverty alleviation and food security. There is an ongoing effort to align the goals and impact targets of *the* agricultural R&D system with those of the Millennium Development Goals (MDGs) of the United Nations. The 1990s saw a decline, and in many cases stagnation in the resources available to agricultural research. This led to a renewal of interest in the efficiency of research and development investments in national and international research systems. Given the constantly evolving scenario, it becomes necessary to fully demonstrate the comparative advantages of international and national research systems so as to realize the potential of agricultural technology as the engine of growth in the rural economy, to protect the environment and alleviate hunger and poverty, The achievement ol inter-regional research spillover benefits and technology transfer is one of the vital contributions of IARCs towards the attainment of the broader development goals in many poor countries whose economies heavily depend on agriculture. This report presents evidence of the range of ICR1SAT research products that have benefited SAT producers and consumers globally through inter-regional technology transfer.

Producers and/or consumers benefit from agricultural research investments through various interlinked effects such as increased input use efficiency (higher yields tor the same level of input use), which lowers costs of production and increases profits; improved product quality (that may also raise prices); improved sustainability and reduced vulnerability to risk and enhanced resilience. While producers benefit from increased profits and reduced risk (and hence higher expected returns in risky environments), consumers benefit from lower prices (associated with increase in total production) and higher quality of consumer goods. These benefits to producers and/or consumers may arise from direct research investments targeted for agricultural development in the region or from inter-regional technology transfer which provides unintended or external spillover benefits. This study will focus on the latter.

1.1. Typology of spillovers

There are three types of spillovers - inter-regional, cross-commodity and price spillovers (Evenson 1989; Deb and Bantilan 2001). Inter-regional or cross-regional spillovers are external benefits (spill-ins) from research investments undertaken beyond the state (inter-state spillovers) and national (international spillovers) boundaries. Such benefits occur mainly because technologies developed for a given location often have a wider application beyond the political and administrative boundaries of states and countries. Cross-commodity spillovers occur when knowledge and technology generated (developed) for a given crop may be useful for the improvement of other related crops. Price spillovers, also called pecuniary externalities, occur when a shift in the supply of a given product due to technological progress affects the price of the same or related commodities. This may occur in the same area or across regions or political boundaries. Since cross-regional spillovers resulting from inter-regional technology transfer are most vital for international agricultural research, this study will mainly locus on such global public goods benefits from ICRISAT's R&D investments.

1.2. Concern for spillovers

Understanding the potential for inter-regional technology transfer (spillovers) from a given R&D investment is very important for many reasons (Byerlee and Traxler 2001; Alston 2002). First, it helps in defining national and international research policy (eg, assessing the need for co-operation across states and nations through joint funding of research that generates regionwide spillover benefits). Second, it helps in identifying constraints that limit maximization of spillover impacts from international R&D investments. Third, it helps in organizing and defining the scale and size of new research programs in a given location. For example, where possibilities for spill-in are high and economies of scale (due to high fixed costs) exist, it is advisable to have fewer, more centralized and larger research centers than many small research stations. On the contrary, where opportunities for spill-in/spill-out are limited (as in very unique products or ecoregions), international or cross-regional research may not be feasible. Hence, national programs may have to organize targeted research stations catering to the needs of such crops or ecoregions. When economies of scale exist, fewer but targeted research centers within the specific ecoregion would be needed.

In the presence of inter-state and international research spillovers, impact assessments that examine benefits within a given geopolitical unit and ignore spillover effects will underestimate R&D benefits. Many recent studies on spillover of inter-regional technology transfer have shown that such benefits often account for up to half of the measured crop productivity growth. The IARCs are best placed to *address these failures (incentive problems) that* discourage the NARS from undertaking R&D investments in areas that generate international spillover effects.

1.3. Factors affecting the potential for spillovers

The potential for inter-regional spillovers from R&D efforts depends on biophysical, social, political and institutional mechanisms in place in a given country to harness the spill-in opportunities (Byerlee and Traxler 2001).

- **Agroecological factors.** This refers to the agro-ecological similarity between the originating and receiving regions. It defines the biological potential of the new technology in a different eco-region. Different crops may have different niches. However, it is important to recognize that this is a necessary but not sufficient condition for spillovers to occur. Agroecological zones are not also fixed; they can be modified through research and infrastructural investments (eg, irrigation, roads, soil *and water conservation*).
- **Economic conditions (relative factor prices).** Labor-intensive technologies developed for areas where capital is scarce and labor is relatively cheaper may not be suitable in areas where these conditions do not exist. This is the case even when the biological potential exists. These factors also change over time, changing the opportunities for spillovers.
- **Sociocultural factors.** Social values, norms, institutions and political structures differ across countries. South-south collaboration is relatively easier between and among countries sharing common features. Taste and preferences for certain products also differ across regions and countries. For example, the consumption demand for sorghum differs in Asia and Africa. In Asia, sorghum is needed as feed for livestock, while in Africa it still represents an important staple crop for the rural poor in the SAT.
- **Institutional capacity.** The capacity to tap existing spill-in opportunities from other countries or from IARCs varies across countries. Small countries with very weak national research and extension programs may find it difficult to do so, especially when local adaptive research is needed. Many small sub-Saharan countries with weak institutions and lacking skilled human capital face this problem.

Over the last three decades, ICRISAT has played a major role in generating potential spillovers from its research products. Various mechanisms have been used to facilitate this process. Recently, south-south collaboration in agriculture by sharing genetic materials and experiences on the success and failure of technologies has increased among countries with relatively similar agroecological conditions. ICRISAT, with its wide agroecological mandate, has facilitated and brokered technology spillovers through such collaborations among scientists and institutions of developing countries, direct transfer of new products to collaborating NARS, investments in capacity building for technology adoption and adaptation through the creation of regional research networks, training programs, visiting scientists and collaborative NARS-ICRISAT projects.

1.4. Research structure and organization

ICRISAT conducts its research for SAT Africa through three regional hubs - Nairobi (Eastern region), Bulawayo (Southern region) and Niamey (Western and Central region), and for SAT Asia through its regional hub based *at its headquarters at Patancheru in* India.[1] These hubs represent broad ecoregions covering a number of SAT countries. New research products from any of these regional hubs are expected to have a high potential for spillover within the region and sometimes across the regions, including a two-way transfer of technologies between Africa and Asia. Between 1976 and 1985, ICRISAT had stationed scientists in six African countries (Burkina Faso, Mali, Niger, Nigeria, Senegal and Sudan) to improve sorghum and pearl millet productivity. Three regional programs gradually replaced these country-based programs. ICRISAT also had a sorghum improvement program in Latin America from 1978 to 1993. Although ICRISAT no longer has active programs in Latin America, some of the technologies developed in Asia and/or Africa could be useful for this region.

Recendy, ICRISAT restructured its research portfolio away from disciplinary programs - breeding, economics, pathology, etc - towards six broad thematic areas named Global Themes (GTs)[2] focusing

[1]The Southern and Eastern regional hubs in Africa have recently been merged into one regional program for Eastern and Southern Africa

[2]Following the Fifth External Program Review (EPR) in 2003. the number of GTs has been reduced to five since the activities of GT 5 hare been subsumed into GT 2 and GT 3. As a result, the GB will no longer be known bv their numerals

on six major developmental problems:

GT 1. Harnessing biotechnology for the poor

GT 2. Crop management and utilization for livelihood, security and health

GT 3. Land, water and agro-ecosystems management

GT 4. Sustainable seed supply systems for productivity

GT 5. Enhancing crop-livestock productivity and systems diversification

GT 6. SAT futures and development pathways

This structure has given the Institute a more forward-looking and opportunity-driven thematic focus. Although the work is still based on scientific excellence in specific disciplines, the new framework has moved the Institute away from solitary disciplinary contributions towards an interdisciplinary agenda based on realistic developmental goals.

1.5. Research products

In collaboration with its partners, ICR1SAT has developed several hundred varieties of its mandate crops - sorghum (130), pearl millet [76), finger millet (3), chickpea (42), pigeonpea (26) and groundnut (45). Most of them have been developed at ICRISAT-Patancheru and others at ICRISAT's African locations. Some of the varieties developed in each region have spilled over within the region or across regions. Appendices 1 a, 2a, 3a, 4a and 5a present a summary of the different crop varieties developed at ICRISAT locations that may also have spilled over into other countries or regions.

The Institute has also developed screening techniques to evaluate and select lines against important diseases and pests. These include screening techniques for evaluating downy mildew resistance in pearl millet, and rust, late leaf spot and rosette resistance in groundnut. To detect aflatoxin in agricultural products (food and feeds) prepared from groundnut and other crops (eg, pigeonpea and maize), scientists have developed a cost-effective testing technique based on ELISA Aflatoxin is a cancer-causing byproduct of certain species of fungi, and therefore harmful to humans and animals.

Inter-regional spillover of open-pollinated varieties (OPVs) in all the five crops has occurred from Asia to some African countries. ICRISAT-Patancheru-bred sorghum and groundnut varieties have been adopted in some countries across Africa. Since the pearl millet varieties fired at ICRISAT-Patancheru were highly susceptible to downy mildew in WCA, the desired spillover did not occur. A few pearl millet varieties bred at ICRISAT-Patancheru, most of whose parental lines were from West Africa, have been adopted in ESA. Germplasm accessions from Africa have been widely used as sources of disease resistance in sorghum, pearl millet and groundnut improvement programs. For example, pearl millet germplasm from West Africa has been very useful for developing varieties at ICRISAT-Patancheru, contributing to large seed size and downy mildew resistance.

Screening techniques for evaluating downy mildew resistance in pearl millet developed at Patancheru have been adopted by ICRISAT's partners in Africa. The ELISA technique is being adopted in some African countries. Screening techniques to evaluate groundnut lines against rust and late leaf spot developed at Patancheru have also been adopted in some African countries. ICRISAT and its partners in West Africa have adopted a screening technique for rosette resistance developed at ICRISAT-Malawi.

In addition, some of the Patancheru-bred sorghum varieties have been released in some Latin American countries after further selection. Chickpea provides another interesting example of spillover of ICRISAT research products into the developed world (Australia, Canada and USA). The impact of this kind of technology diffusion to the developed world on developing country farmers has not been investigated.

1.6. Facilitating technology exchange

Germplasm movement between institutions constitutes an important building block of agricultural research worldwide. Since its establishment in 1972, ICRISAT has been collecting germplasm of its mandate crops (sorghum, pearl millet, groundnut, pigeonpea, chickpea and also of small millets) from across the globe. ICRISAT's scientists have developed finished products such as varieties; hybrids; parental lines such as seed parents and restorers; breeding populations; and identified and developed sources of resistance for various biotic stresses. These breeding products and germplasm accessions have been exchanged among ICRISAT scientists in all regions and with those from national programs for evaluation in national and regional trials, for further selection and for use in breeding programs. The collaboration has been primarily between and among countries of Asia and Africa.

As a bridge, broker and catalyst lor the transfer and dissemination of research products, ICRISAT facilitates south-south collaboration among developing countries in the transfer, utilization and adoption of research products, skills and materials. This may take several forms ranging from the exchange of information to the acquisition of germplasm and advanced breeding materials from other countries. The Institute supports capacity building and inter-country collaboration through a number of research networks, visiting scientists, training programs, workshops and symposia undertaken across regions. Over the years, ICRISAT has created and hosted many specialized research networks in Africa and Asia which are now part of larger regional organizations such as the Asia-Pacific Association of Agricultural Research Institutions (APAARI), Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), Southern African Centre for Cooperation in Agricultural and Natural Resources (SACCAR), Conseil Ouest et Centre Africain pour la Recherche et le Developpement Agricoles (CORAF), Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel (CILSS) and Communaute economique des etats de l'Afrique de l'Ouest (ECOWAS) in Asian and African developing countries. These networks and regional organizations have become new avenues for research planning, priority setting, joint implementation as well as technology dissemination and inter-regional technology spillover.

Persistent efforts in capacity building within national and regional programs have enhanced collaboration in crop improvement, NRM, socioeconomics and policy research and human resource development among scientists in developing countries. ICRISAT has also contributed to the closer integration of scientists from national programs in the developing world with the global scientific community. This facilitates sustained impact and wider diffusion of technologies to exploit existing potential for inter-regional spillover.

1.7. Purpose and limitations

Despite the importance of technology spillovers for the attainment of the breeder research and development goals of the Institute, very limited work has so far been carried out to assess and systematically document potential and actual inter-regional spillovers from ICRISAT's R&D efforts. Much of the research evaluation and impact assessment work in the past has focused on adoption constraints and estimation of rate of return to R&D investments in a given country without considering spillover effects. However, a few studies have examined the impacts of certain technologies developed in other locations or ecoregions but adopted in a new country or ecoregion. The results summarized here are drawn from these limited studies and have been improved through discussions and consultations with specialists and scientists based in the regions. This study is therefore not exhaustive and only presents broad results from cases where there is some valuable information.

The purpose of this report is therefore to document the extent of spillovers from ICRISAT's investments in sorghum, millets, groundnut, pigeonpea, chickpea, NRM and socioeconomics and policy research, and identify the broad factors that facilitate or hinder inter-regional research spillovers. The study draws heavily from ICRISAT's publications and information provided by scientists engaged in crop improvement, NRM and socioeconomics and policy research across regions. The authors have also drawn from their own experiences at ICRISAT's Patancheru and African locations. An attempt has been made to be objective in describing the extent of spillovers, and in tracking the process when possible, while expert guestimates' are used in some places where data is missing. Scientists' estimates of the extent of adoption of some new-technologies and their impacts in some regions are used without qualification until further verification through more targeted adoption studies. These estimates should therefore be used carefully and may only provide an "order of magnitude" of the diffusion of the technology and its productivity effects. It is important to emphasize that many of the technologies were developed in close partnership with NARS and others. ICRISAT's role in developing the technology ranged from providing advanced lines to the collaborating NARS to delivering finished products. A relatively detailed assessment of a few case studies is provided to shed light on the extent and potential of spillovers from ICRISAT research. This will provide an overview of the extent of technology movement across and within the different regions and the factors that contribute to it. This information will also be useful to re-examine the organization of research at ICRISAT to facilitate wider impacts and benefit from spillover potentials.

More detailed studies are required to fill these caveats and to facilitate a more complete understanding of the extent of spillovers, processes, potential and the limiting factors for a wider adaptation of technologies and innovations across regions.

2. Spillovers from Research Investments in Sorghum

2.1. Technologies developed

Sorghum is grown over nearly 42 million ha globally, with about 80% of the total area concentrated in 10 countries, namely India, Nigeria, Sudan, USA, Niger, Mexico, Burkina Faso, Ethiopia, China and Mali. Sorghum is also grown in many other African, Asian and Latin American countries (Table 1).

Sorghum research at ICRISAT started in four regions - Asia (1973), West and Central Africa (1975), Southern Africa (1984) and Eastern Africa (1984). There was also a program in Latin America based at the Centro Intemacional de Mejoramiento del Mai/ y del Trigo (CIMMYT) in Mexico from 1978 to 1993, and in Sudan from 1977 to 1985. To date, ICRISAT has contributed to the development of about 130 sorghum varieties, of which about 95 have had spillover effects.

There has been exchange of germplasm among sorghum-producing countries primarily facilitated through ICRISAT-Patancheru and the regional hubs in the African locations. Breeding products such as OPVs, hybrids, hybrid parents, segregating progenies, composite populations and resistant sources have been developed by ICRISAT in collaboration with its partners. The seed of these materials have been supplied to various national programs on request through the Sorghum Elite Progeny Observation Nursery (SEPON) organized by ICRISAT-Patancheru in the 1970s and 1980s, regional and international trials and recently through the regional networks.

Open-pollinated varieties, hybrids and hybrid parents are developed at ICRISAT-Patancheru. Several composites (random mating populations) were developed and improved at ICRISAT-Patancheru to develop OPVs and hybrid parents. At ICRISAT's Africa locations, breeding programs mainly developed OPVs and a lew hybrids. Several varieties were developed from selecting in segregating progenies [F_3, F_4, and F_5 generations) and germplasm accessions introduced from ICRISAT-Patancheru. Though ICRISAT's Africa programs have released a few hybrids such as Hageen Durra 1 in Sudan (1983), SDSH 48 in Botswana (1994) and ICSH 89002 NG and ICSH 89009 NG in Nigeria (1996), their adoption and spillover have been limited mainly due to the nonavailability of seed.

Some Patancheru-bred varieties have been adopted in African and Latin American countries (Appendix Ia). In turn, germplasm accessions from Africa have been found to be useful sources of resistance to biotic stresses, and are used in the crop improvement program at ICRISAT-Patancheru (Appendix Ib).

2.2. Spillovers from Asia to Africa

Several promising germplasm accessions and varieties bred at ICRISAT-Patancheru were introduced into ICRISAT's African locations and NARS breeding programs. After testing and evaluation in collaboration with the national programs, they were released for wider use in their respective countries (Appendix Ia). These materials can be grouped under four categories:

- **Advanced progenies.** ICRISAT scientists based in Africa introduced advanced progenies (eg, F_5, F_6, F_7) from ICRISAT-Patancheru for further selection. These were either joindy evaluated in collaboration with NARS or by NARS in on-station and on-farm trials before their release. A good example is S 35; it was introduced into ICRISAT-Nigeria and released in Cameroon and Chad (Appendix Ia).
- **OPVs.** ICRISAT-Patancheru-bred varieties were introduced into ICRISAT locations in Africa for collaborative testing with partners in national and sometimes regional trials. The African locations and their partners played a major role in evaluating these lines, multiplying seed and preparing variety release documents. This was often followed by on-farm trials and training to promote adoption spillovers and impacts. Some examples of the OPVs are ICSV 111 (Nigeria and Ghana), ICSV 400 (Nigeria), ICSV 112 (Malawi, Zimbabwe, Mozambique, Swaziland, Kenya and India), ICSV 1 (Malawi, Ethiopia and India) and SRN 39 (Sudan and Niger). Appendix Ia lists all such varieties developed at Patancheru and used in other regions.
- **Germplasm.** Selected global germplasm accessions (from various countries across continents) maintained at ICRISAT-Patancheru were introduced into ICRISAT locations in Africa for yield testing, where they were evaluated in regional trials/ nurseries, directly or through networks. The national programs then selected a few accessions for release to farmers in their respective countries after appropriate testing. Eighteen germplasm accessions have so far been released to farmers in Africa; their accession number, country of origin, country of release, etc, are given in Appendix Ia.
- **Direct transfer to NARS.** This involved the introduction of sorghum material by NARS scientists from ICRISAT-Patancheru for further selection and testing before their release. Some examples are ICSV 112 (SV 1 in Zimbabwe), A 6460 (SV 2 in Zimbabwe), ICSV 2 and IS 23520 (Zambia), M 90393 (Ingaz in Sudan), M 36121 (Ethiopia) and M 90038 (SEPON 82 in Niger).

Table 1. Area, yield and production of major sorghum-producing countries.[2]

Countries	Area ('000 ha)	Yield (t ha^{-1})	Production ('000 t)
Developing countries	**38,172**	**1.12**	**42,802**
Africa	**22,619**	**0.89**	**20,204**
Nigeria	7,032	1.09	7,662
Sudan	4,645	0.72	3,352
Niger	2,454	0.23	561
Burkina Faso	1,384	0.90	1,245
Ethiopia	1,119	1.31	1,470
Mali	800	0.85	677
Tanzania	622	1.10	683
Mozambique	420	0.70	293
Somalia	300	0.33	100
Uganda	281	1.43	402
Zimbabwe	175	0.59	103
Kenya	140	0.95	133
Others	3247	1.09	3,523
Asia	**11,875**	**0.99**	**11,743**
India	10,023	0.80	8,035
China	812	3.31	2,685
Pakistan	356	0.62	220
Yemen	372	1.02	380
Saudi Arabia	173	1.18	204
Thailand	110	1.49	164
Others	29	1.90	55
Central America & the Caribbean	**2,292**	**2.81**	**6,438**
Mexico	1,897	3.15	5,970
Haiti	132	0.65	86
El Salvador	96	1.55	149
Nicaragua	46	1.85	85
Cuatemala	42	1.21	51
Others	79	1.23	97
South America	**1,493**	**3.18**	**4,750**
Argentina	636	4.69	2,982
Brazil	482	1.73	833
Venezuela	202	2.24	453
Colombia	70	3.16	221
Uruguay	21	5.10	107
Others	82	1.88	154
Developed countries	**4,267**	**3.44**	**14,669**
United States	3,215	3.60	11,570
Australia	737	2.71	2,000
South Africa	102	3.01	307
Russian Federation	56	0.86	48
Others	157	4.74	744
Total	**42,439**	**1.35**	**57,471**

a. FAO statistics averaged over three years (2000-2002).

Source FAO (2002).

A total of about 29 varieties, including germplasm accessions and advanced progenies have spilled over from ICRISAT-Patancheru into 17 African countries. In order to illustrate the spillover of sorghum technologies from ICRISAT-Patancheni to the African region/countries, selected examples are presented.

Variety S 35

The advanced progeny for S 35 (Fig. 1) was developed at ICRISAT-Patancheru and further improved by ICRISAT in Nigeria. It was subsequently released in Cameroon (1986) and Chad (1989), where it is widely grown by farmers. S 35 was not released in Nigeria due to discouraging results. Described here are the breeding, extension efforts and some results from an adoption study (Yapi et al. 1999a; 1999b).

Early breeding efforts in S 35 started in 1978 at ICRISAT-Patancheru and resulted in the development of F_4 progeny of a three-way cross [(SPV 35 x E 35-1) CS 3541] in 1980 (Rao 1983). The ICRISAT sorghum breeder based at the Institute for Agricultural Research (IAR) at Samaru in Nigeria introduced an F_5 progeny (with row number M 91019) from ICRISAT-Patancheru into Nigeria in 1980. At Samaru, S 35 was selected from this progeny in 1981 and tested *in* preliminary yield trials at Samaru and Kano bv the ICRISAT/IAR breeding program in 1982. The variety did not perform well in Nigeria either due to soil/pest problems at Kano or the high rainfall at Samaru (Rao 1983). Therefore, it was never released for wider use.

In 1982, ICRISAT-Samaru sent S 35 seeds to a sorghum breeder of the International Institute for Tropical Agriculture (IITA) in Cameroon, who was working in collaboration with the Institut de la Recherche Agronomique (IRA) and the National Cereals Research and Extension Project (NCRE) at Maroua (Cameroon). On-farm testing of S 35 commenced in 1983 with no stimulating results in comparison with local varieties. In 1984, however, test results led to a resounding success. An overall comparison of yields across 88 test sites showed an 85% mean increase in S 35 over farmers' local varieties (Johnson et al. 1986). The results indicated S 35's overwhelming superiority in 1984 (a year of extremely low rainfall) and its slight superiority over farmers' local varieties during 'normal' rainfall years, such as in 1985, 1986 and 1987 (Yapi et al. 1999a).

On the basis of its high and stable performance (Table 2), S 35 was released in 1986 for wider use in northern Cameroon, supported by a campaign for large-scale seed multiplication. According to Kamuanga and Fobasso (1994), 20 t of S 35 seed was produced at the time of its release by the government's Seed Multiplication Project at Maroua.

In a good example of south-south collaboration, S 35 was introduced in Chad in 1986 by the national program from IRA's breeding program at Maroua. The variety was evaluated at Gassi research station in Chad during the same year, and was found to be early maturing, high yielding and resistant to long smut \Tolyposporium *ehrenbergii* (Kuhn) Patouillard], a yield-reducing disease prominent in Chad. The ivory-grained S 35 produced 2.6 t ha^{-1} of grain whereas *the* red-grained local variety (Nadj-dadj) yielded only 1.4 t ha^{-1}. S 35 took 20 days less to flower compared to the local variety These encouraging preliminary results led *to* the variety being quickly *advanced to* on-farm testing in 1987. Anticipating more extension activities, the Food and Agriculture Organization/United Nations Development Programme (FAO/UNDP)-supported seed project at Gassi research station began large-scale seed multiplication. The on-farm trials were conducted by the government's extension department [Office Nationale de Developpement Rurale (ONDR)) and non-governmental organizations (NGOs) operating in potential release and diffusion zones targeted by S 35 research. Unfortunately, these tests have not been sufficiently documented to allow a clear appreciation of the performance of the technology that led to its release in 1989.

According to Yapi et al. (1999a), who reported on the performance of S 35 in on-station and on-farm trials in Chad during 1988, S 35 produced good results in on-station trials at Guera, outyielding the local variety by 74%; while in the adjacent Chari-Baguinni region, it yielded 20% less grain than the local variety. These mixed results led ONDR to intensify the promotion of the technology only in Guera. In on-farm trials conducted by Action Internationale Contre la Faim (AICF) in 18 sites in five villages of Arenga (Guera) in 1989, the mean grain yield of S 35 was 1.2 t ha^{-1}. (Data was not provided for the local checks.) Based on these results, the national program released S 35 for cultivation in 1989 in Guera region, with the possibility of diffusion to other regions. Later, fanners in Chari-Baguirmi and Mayo-Kebbi regions, where

Table 2. Grain yield (t ha^{-1}) of sorghum varieties in on-farm tests in northern Cameroon, 1984-87.

Varieties and growing conditions	Year				
	1984	1985	1986	1987	1984-87
S 35	1.333	1.689	1.866	1.888	1.694
Local varieties	0.717	1.531	1.721	1.825	1.451
Improved varieties	0.784	1.202	2.185	1.974	1.537
Number of sites	88	79	38	35	240
Rainfall (mm)	529	729	773	614	661
S 35 over locals (%)	85	9.7	8.4	3.5	26.7

Source: Yapt et al 1999a, 1999b

yields increased by 46% and 53% respectively compared to local varieties, also adopted this variety.

The following simple management practices were recommended for S 35 adoption in Chad:

- Late sowing; 2-3 weeks after farmers' local varieties have been sown
- Use of the full quantity of 10 mini-doses of 250 g seed to be sown in 0.25 ha
- Line sowing after ploughing
- A minimum of two weedings.

The total research lag (the time it takes from breeding to the release of a variety} for S 35 was 8 years tor its release in Cameroon and 12 years in Chad. But because oi germplasm spillover from ICRISAT-Patancheru to Cameroon and later to Chad, the local research lags were reduced to only 5 years in Cameroon (1978-85) and 4 years in Chad (1978-89). This availability of germplasm has increased the probability of success in NARS research efforts to secure the S 35 technology at a reduced cost and to transfer it quickly to larmers. Had each country developed the technology on its own, the research and development lags would have been substantially longer; thus reducing the economic returns by 34% in Cameroon and 55% in Chad (Yapi et al. 1999b). Germplasm spillover has therefore increased not only the efficiency in the development and adaptation of the technology but also the economic returns associated with its use.

Yapi et al. (1999a; 1999b) conducted on-farm surveys in 1995 for the periods 1986-95 (for Cameroon) and 1990-95 (for Chad) to track the spread of S 35 in drought-prone areas and to elicit larmers' perceptions. The results from the adoption study show that farmers are substituting S 35 for traditional varieties. Ten years after its release in northern Cameroon, S 35 occupies about 33% of the total rainfed sorghum area (134,967 ha) in the region. In Chad, it occupies an estimated 27% of the total rainfed sorghum area (233,987 ha) in the three southern provinces. A yield advantage of about 51% over larmers' local varieties in Chad is associated with enhanced adoption of S 35 (Yapi et al. 1999a).

Consequently, the estimated net discounted benefits and social profitability of the technology in the two countries have been substantial, ranging from US$4.6 million in Cameroon to US$15 million in Chad, representing an internal rate of return (IRR) of 75% in Cameroon and 95% in Chad (Yapi et al. 1999a).

Coming to the regional distribution of benefits in Chad, Guera region (where rates of adoption were higher) showed higher benefits than Mayo-Kebbi and Chari-Baguirmi. The distribution of gains was in favor consumers (62.5%) as opposed to producers (37.5%). In Cameroon, the benefits to consumers and producers were estimated at 58.3% and 41.7%, respectively (Yapi et al. 1999a).

Farmers have substituted S 35 for traditional varieties because the required crop management practices for its cultivation are simple, familiar and easy to implement from available family and animal labor. In addition, substantial payoffs (high yield and reduced unit cost of production) are associated with these management changes. However, a major problem with S 35 is its susceptibility to bird attacks due to its short duration and sweet grain. The other constraints to adoption described by larmers include soil infertility, nonavailability of pure seed, grain mold and the high cost of grinding.

Variety ICSV 111

ICSV 111 is an open-pollinated sorghum variety developed between 1980 and 1984 at 1CRISAT-Patancheru through pedigree selection in a three-way cross [(SPV 35 x E 35-1) x CS 3541], The parents, SPV 35 and CS 3541, are converted early-maturing parents originating from late-maturing varieties from Ethiopia and Sudan respectively, while E 35-1 is a germplasm accession from Ethiopia. ICSV 111's pedigree is similar to that of S 35. The ICRISAT program in Nigeria introduced ICSV 111 in 1.988 from ICRISAT-Patancheru, and it was released in 1996. The variety, along with others, was evaluated in regional trials coordinated by ICRISAT. Regional collaboration led to its release in Ghana (as Kapala in 1996) and Benin (as ICSV 111 in 1999). Fanners in Nigeria prefer this variety because of its high yield, early maturity, white grain, good food quality and juicy stalks (preferred by animals). It is also resistant to *Striga hermonthica,* an important parasitic weed in WCA.

ICSV 111 was tested at ICRISAT's Bagauda research station in Nigeria from 1989 to 1994. Its grain yield ranged from 2.78-3.05 t ha^{-1} compared to 1.23-2.13 t ha^{-1} for local varieties. In multilocational trials conducted by the Agricultural Development Projects (ADP) between 1991 and 1993 on farmers' fields in the four northern states of Nigeria, ICSV 111 grain yields ranged from 0.59-3.13 t ha^{-1} across 51 tests, compared to 0.36-2.86 t ha^{-1} for farmers' varieties (Murty et al. 1998). ICSV 111 is 1.6-2.1 m tall, matures in about 110 days, can yield 5-6 t ha^{-1} of stover, and its slightly sweet and juicy green stalks are preferred by animals. On the contrary, local varieties are very tall (3-3.5 m). mature in 140-160 days, produce slightly more stover than ICSV 111, have tannin-free grains (no testa) and have good porridge-making quality.

An adoption study on sorghum varieties ICSV 111 and ICSV 400 was conducted in four states of Nigeria (Kano, Katsina, Kaduna and Jigawa) from 1996 to (ICRISAT 2001). The rate of adoption of the two varieties together was between 28 and 30% in three states and only 10% in Katsina. Since then. several on-farm trials and demonstrations have been conducted in all the 10 states of northern Nigeria by extension departments of state governments in collaboration with IAR Samaru, Nigeria and ICRISAT-Kano. The West and Central Africa Sorghum Research Network (WCASRN) supported IAR in conducting on-farm trials in Katsina and promoting the adoption of ICSV 111. This variety was mainly adapted in dry-areas because of its earliness (local varieties are late maturing and suffer from terminal drought). In areas in Nigeria flooded by rainwater in October, farmers lose their crop since local sorghum varieties do not mature by this time. Therefore, they prefer to grow early-maturing varieties such as ICSV 111. Most farmers in WCA grow photosensitive, late-maturing sorghum varieties that mature after the rainy season. Early-maturing sorghum varieties such as ICSV 111 have only specific niches (such as dry areas).

Variety ICSV 112

The variety ICSV 112 (Fig. 2) was developed at ICRISAT-Paiancheru by pedigree selection from a multiple cross involving IS 12622C, 555, IS 3612C, 2219B and E 35-1. The F_5 bulk evaluated in 1979 in ICRISAT's multilocational yield trials in India was found to be a stable high yielder. From 1981 to 1986, the variety was tested in All India Coordinated Sorghum Improvement Project (AICSIP) trials as SPV 475 (ICRISAT Plant Material Description no. 16, 1988). In 1979, ICRISAT-Patancheru distributed this F_6 bulk (ICSV 112) along with other elite progenies to several locations worldwide for evaluation. Different national programs identified this variety for release after appropriate tests.

The variety was released in India (as CSV 13 in 1987) and in several African countries - Zimbabwe (as SV 1 in 1987), Kenya (as CSV 13 in 1988), Swaziland (as MRS 12 in 1992), Malawi (as PIRIRA 2 in 1993), Mozambique (as Chokwe in 1993) and through efforts of ICRISAT's Africa programs and their partners. It was also released in a few Latin American countries. Though it has been released in many countries across continents, data on adoption is limited. An adoption study conducted in Zimbabwe revealed that SV I was not preferred by farmers over SV 2, both released at the same time.

On-station trials conducted by AICSIP from 1982-87 ranked ICSV 112 first for grain yield among varieties. Mean grain yield for ICSV 112 was 3.42 t ha^{-1} compared to 3.27 ha^{-1} for ICSV 1 and 2.24 t ha^{-1} for the local variety. ICSV 112 also yielded substantial fodder (11.4 t ha^{-1}) (ICRISAT Plant Material Description no. 16, 1988). In on-station trials in Zimbabwe, SV 1 yielded 4.06 t ha^{-1} of grain compared to 2.73 t ha^{-1} for the local variety (Obilana et al. 1997).

ICSV 112 is a medium-maturing (110-120 days), rainy-season variety. It grows to a height of between 1.5 and 1.8 m. The plant has a tan-colored pigment and its leaves are of medium size. The stalk is moderately juicy The grain contains about 9.6% protein and 2.6% lysine (100 g^{-1} protein). Food prepared from the variety is good and comparable with that from CSH 5, a popular commercial sorghum hybrid in India.

Variety SV 2. A 6460

This is an example of a variety from ICRISAT-Patancheru tested and released by national programs in their own countries. The Department of Research & Specialist Services (DR&SS) of Zimbabwe introduced A 6460 from ICRISAT-Patancheru in 1980. It was evaluated and released as SV 2 in 1987 for its earliness and higher grain yield. In on-station trials in Zimbabwe, SV 2 provided a grain yield of 3.38 t ha^{-1} that compares with 2.73 t ha^{-1} for local varieties. In on-farm trials, SV 2 yielded 2.15 t ha^{-1}, whereas the local variety produced only 1.56 t ha^{-1}. SV 2 flowered 13 days earlier than the local variety. A 6460 was developed at ICRISAT-Patancheru from a cross between selected germplasm accessions (IS 24704 x IS 10558), which originated from Nigeria (IS 24704) and Mexico.

The sorghum variety SV 2 (Fig. 3), released in 1987, did not record any significant diffusion until 1992. However, this delayed diffusion (caused mainly by lack of seed) has not hindered its rapid and high adoption rate since 1992. Within three years, the area under SV 2 was 40,000 ha, ie, 36% of the total sorghum area (SADC/ICRISAT SMIP 1996). By 1995, roughly 30% of the sorghum area of small farmers was sown to SV 2. There was a gradual increase in adoption by farmers in Zimbabwe from 3.6% in 1990-91 to 37.9% in 1994-95 (Rohrbach et al. 1995).

This white-seeded variety preferred for food is very popular among Zimbabwean farmers in the dry ecological regions (IV and V) for its early maturity (115-120 days) relative to local varieties (160 days).

Germplasm Accession SDS 2583, IS 3923

SDS 2583 was developed at ICRISAT-Bulawavo from germplasm accession IS 3923 (introduced from USA through ICRISAT-Patancheru) and released in Botswana in 1994 as Mahube for its earliness (28 days to flowering) compared to the local variety (86 days to flowering). Its grain yield was superior (0.59 t ha^{-1}) to drat of the local variety (0.51 t ha^{-1}) in on-farm trials but inferior in on-station trials (1.22 t ha^{-1} compared to 2.34 t ha^{-1}). The area planted to it in Botswana in 1995 was 900 ha (1 % of the total sorghum area). SDS 2583 is a red-seeded, tannin-free variety preferred for malting and animal feed (Obilana et al. 1997).

Germplasm Accession SDSV 1513, IS 2391, MRS 13

SDSV 1513 is a variety developed from a germplasm accession identified as IS 2391, which originated from South Africa. It was re-introduced at ICRISAT-Bulawayo from ICRISAT-Patancheru and indexed as SDSV 1513. It is high yielding, has medium maturity and was released in Swaziland (as MRS 13 in 1990) by its Variety Release Committee.

MRS 13 provided the highest grain yield among three test varieties across three locations in Swaziland over two years (1985-86 and 1986-87). On an average, MRS 13 yielded 2.5 t ha^{-1}, which compares with 1.7 t ha^{-1} for the local variety (Ntuli Red). In the second set of trials (1987-88 and 1988-89), MRS 13 had the highest overall grain yield among five entries tested in six environments and yielded twice as much as Ntuli Red (3.2 t ha^{-1} compared to 1.6 t ha^{-1}) (1CRISAT Plant Material Description no. 54, 1995).

Germplasm Accession SDSV 1594, IS 3693, MRS 94

SDSV 1594 was developed at ICRISAT-Bulawayo by selection and bulking of uniform plants from a germplasm accession identified as IS 3693, which originated from USA (and was introduced to Bulawayo via ICRISAT-Patancheru). This variety was released in Swaziland (as MRS 94 in 1990) by its Variety Release Committee because of its high grain yield. It was recommended for general cultivation in southern Swaziland. Based on data from an average of six environments over two years (1987-88 and 1988-89), MRS 94 yielded 2.7 t ha^{-1} compared to 1.6 t ha^{-1} for the local variety Ntuli Red (ICRISAT Plant Material Description no. 55, 1995).

Screening Technique

Scientists based at ICRISAT-Patancheru have standardized a large-scale screening technique for sorghum downy mildew resistance. The research was conducted at *Dharwad* in Karnataka state of India during the 1982 rainy season (Pande and Singh 1992). The infector-row field screening technique for sorghum downy mildew is based on windborne conidia (asexual spores) of *Peronosclerospora sorghi,* the causal organism for the disease. Conidial showers blown by wind from infector rows onto test materials provide the inoculums. This technique was transferred to the Zimbabwean and Zambian national programs in 1987.

2.3. Spillovers from Africa to Asia

Coming to spillovers from Africa to Asia, there are two good examples of sorghum lines introduced from Africa (IRAT 408 and IS 30468) to ICRISAT-Patancheru, which were distributed to the national programs after some selections at Patancheru. NARS scientists evaluated these lines in national trials before their release. These examples are:

PARC-SS 2. This was released in Pakistan in 1991. The variety was derived from a Malian line (IRAT 408) and introduced by ICRISAT through germplasm exchange.

NTJ 2. This *was* released *in* Andhra Pradesh *(India) in* 1990. It was selected at ICRISAT-Patancheru from a landrace (IS 30468) introduced from Ethiopia. Some selection was done at ICRISAT.

Sources of resistance. Another spillover from Africa to Asia includes germplasm accessions introduced from Africa and found to have resistance traits against certain sorghum pests and diseases (Appendix Ib). Several germplasm accessions originating from Africa are now being used as sources of resistance for different biotic stresses. Thakur et al. (1997) have summarized the work of several researchers and reported several lines resistant to many sorghum diseases such as grain mold, downy mildew, anthracnose, leaf blight, sooty stripe, ergot and rust. Three white-grained, grain mold-resistant lines were identified from germplasm accessions originating from Tanzania (IS 7173) and Malawi (IS 23773 and IS 23783). Three lines from Niger (IS 20450, IS 20468 and IS 20478) were found resistant to downv mildew, E 35-1 from Ethiopia is a good source of resistance to sooty stripe. Sources of resistance to rust have also been reported in lines from Sudan (IS 2300 and IS 3443), Uganda (IS 31446) and Ethiopia (IS 18758).

Peterson et al. (1997) reported several lines resistant to stem borer and shoot fly. The resistance sources for these pests are found both in Indian and African germplasm. At ICRISAT, the major source ol midge resistance is DJ 6514, an Indian landrace (Sharma et al. 1994). Two accessions, IS 7005 (Sudan) and IS 8891 (Uganda), showed the highest levels of resistance to midge when tested across seasons, locations and under no-choice (cage tested) conditions.

2.4. Spillovers within Africa

About 19 varieties developed in Africa through ICRISAT-NARS partnerships have spilled over into 17 African countries. In the following section, selected examples of sorghum technology spillovers within the African *ecoregions are given.*

Variety Macia (SDS 3220)

Macia (Fig. 4) is an open-pollinated, early-maturing and high-yielding variety developed at ICR1SAT-

Bulawayo, Zimbabwe, in 1989. It was released in Mozambique (as Macia in 1989). Botswana (as Phofu in 1994|. Namibia (as Macia in 1998). Zimbabwe (as Macia in 1998) and Tanzania (as Macia in 1999). The area planted to it in 1995 in Botswana was 22,000 ha (25% of the total sorghum area) (Obilana et al. 1997).

The initial cross [(GPR 148 x E 35-1) x CS 3541] for developing SDS 3220 was made at ICRISAT-Patancheru. In 1984, a segregating F_3 bulk (known as M 91057) from ICRISAT-Patancheru was introduced to ICRISAT-Bulawayo, where it was further improved following modified pedigree selection at ICRISAT locations in Zimbabwe.

In the F_6, the most promising lines from the introduction were evaluated for 2 to 3 years in on-station trials across the region, together with more than 500 other pure lines. The variety is easily identified by its green foliage and broad leaves after grain harvest. It was later found to possess the stay-green trait, ie, good crop residue and resistance to terminal drought. Following its promising cm-station potential, its performance was tested on farm in 8 of the 10 sorghum-growing countries of the Southern African Development Community (SADC) region for farmer verification, between 1986-87 and 1993-94. The variety was preferred and accepted by farmers, and it was subsequently released by several national programs in the SADC region.

In on-station trials in Botswana (averaged over four years and 2 to 4 locations per year), Macia significantly outyielded (3.25 t ha^{-1}) the popular variety Segaolane by 39%. In on-farm trials averaged over 108 sites, Macia out yielded (0.73 t ha^{-1}) farmer varieties (0.51 t ha^{-1}) by -2 to 84% (Obilana et al. 1997).

In Botswana where on-farm trials were conducted, Macia was preferred by almost all the farmers because of its early to medium maturity (115-120 days), good yield potential, large head and good grain quality (better white grain than Segaolane, whose white grains turn black with extreme mold infection when exposed to late-season moisture). These farmer-preferred traits are in addition to its stay-green trait, broad leaves and juicy thick stem that make it useful as a source of good quality fodder for livestock. Macia is a semi-dwarf variety (1.3-1.5 m) that makes it easier for fanners to harvest the crop (Obilana et al. 1997; AB Obilana, personal communication 2003).

Macia was released in Mozambique after three years of testing at two locations in Umbeluzi and Chokwe; the latter near a village called Macia after which the name was coined. In Botswana, it was released as Phofu (local name meaning food fit for the kings) after on-station trials at 12 locations for three years and on-farm trials at 15 extension farm sites for two years.

Farmers are benefiting from rapid and extensive adoption of the variety in these two countries (Botswana and Mozambique). This was followed by a sequence of releases in three other SADC countries - Namibia (1998), Zimbabwe (1998, it was released by SEED Co. Ltd, a private seed company) and Tanzania (1999). There were also pre-releases and on-farm verifications in East Africa (Eritrea and Kenya) in recent years through the efforts of ICRISAT-Nairobi, and in West Africa (Ghana). These spillovers were attained mainly due to the wide adaptability of Maria's regional germplasm exchanges and sustained multi-lowiiional testing in potential areas for adoption in Africa (AB Obilana, personal communication 2003). The estimated area grown to Macia in 2001 and adoption rates in the SADC countries are given in Table 3.

With the growing popularity of Macia in several areas of Africa, adoption constraints, uptake pathways, spillover impacts and factors that facilitate its adoption and adaptation in new countries and ecoregions need to be investigated.

Variety E 35-1, IS 18758

E 35-1 was introduced from Ethiopia to ICRISAT-Patancheru, India. It was later re-introduced to African countries in the form of exchange nurseries. The variety was released for wider cultivation in Ethiopia (as Gambella 1107 in 1980), Burkina Faso (in 1983) and Burundi (as Gambella 1107 in 1990). It is a good example of germplasm introduced from Africa to ICRISAT-Patancheru and released in African countries. Lack of information prevents us from documenting its important traits, extent of adoption and spillover impacts.

Table 3. Estimated adoption and spread of SDS 3220 (Maria) in the SADC region of Southern Africa.

Country	Released name	Year of release	Approximate adoption area (ha)	Percentage of total area under sorghum
Botswana	Phofu	1994	37.500	25
Namibia	Macia	1998	3.000	10
Zimbabwe	Maria	1998	26.300	15
Mozambique	Maria	1987	22,000	-
Tanzania	Macia	1999	20,000	-

Source AB Obilana. personal communication 2003.

Hybrid SDSH 48

The hybrid SDSII 48 was developed at ICRISAT-BulawayO and released in Botswana in 1994 as BSH 1. It is white-seeded with excellent flour quality, early maturing, high yielding and mainly recommended lor food. BSH 1 produced 3.83 t ha^{-1} of grain in on-station trials in Botswana, 60% more than the local variety. The area planted to it in 1995 was 130 ha (0.2% of the total sorghum area) (Obilana et al. 1997). Adoption has been very slow due to the nonavailability of hybrid seed. Private-public sector partnerships need to be encouraged to facilitate the widespread use of this variety in the SADC region.

2.5. Spillovers within Asia

Several varieties (21 in India and 23 in other Asian countries) have been released in Asia using ICRISAT-Patancheru-bred material (Appendix la). These lines were introduced to the national programs in Asia through the Cereals and Legumes Asia Network (CLAN). After appropriate tests, the national programs released these varieties in their respective countries including China, Myanmar, Pakistan, Philippines and Thailand. Some of the known examples are highlighted.

China. Ten sorghum varieties using ICRISAT parental material were released from 1982 to 1996.

Myanmar. Nine sorghum varieties (including germplasm accessions) have been released in Myanmar from 1980 to 1996. These varieties were directly introduced from ICRISAT-Patancheru into the regional trials.

Pakistan. Two varieties, ICSV 107 (PARC-SSI) and IRAT 408 (PARC-SS 2), were released in Pakistan in 1991. Both lines were introduced from ICRISAT-Patancheru.

Philippines. Two sorghum varieties, IES Sor 1 and IES Sor 4, were developed using ICRISAT germplasm and released to farmers in 1993 and 1994, respectively.

Thailand. Suphanburi 1 derived from ICRISAT germplasm was released in Thailand in 1996.

Very little is known about the adoption and impact of these ICRISAT-derived materials in these countries. Some examples may need to be studied in the future to assess and document the extent of spillovers from ICRISA'T's sorghum research within Asia.

2.6. Spillovers to other regions

ICRISAT-Patancheru-bred varieties were introduced to ICRISAT's Mexico program (1978-93) where they were further improved in collaboration with the national programs. They included both finished and intermediate products. They were evaluated jointly with the national programs in several countries. National programs subsequently released a number of varieties - 5 in Mexico, 2 in Nicaragua, 3 in El Salvador, 3 in Honduras and 1 in Gautemala. Some varieties were also developed by the ICRISAT programs based in Mexico and released in other countries of Latin America (Dominion Republic, Colombia and Costa Rica) (Appendix la). Very little is known about the adoption and impact of these ICRISAT-derived materials in these countries. Studies to assess and document the extent of spillovers from ICRISAT's sorghum research to Latin America may shed some light on achieved impacts and the facilitating factors and processes.

2.7. Summary and conclusions

This chapter provided an overview of the transfer of sorghum-related technologies across countries and ecoregions. Insights into the patterns of technology adoption and inter-regional technology transfer indicate a wide range of experiences and spillovers across Africa and Asia as well as within each of the continents. The technology spillover constitutes advanced progenies, OPVs and exchange of germplasm across countries and regions, brokered and facilitated through ICRISAT.

Table 4 summarizes the number of releases in each region until 2001 from technologies developed across ecoregions. A total of 21 genotypes (including advanced progenies and varieties) developed in Asia have been released in India. Some 23 genotypes (including those developed by NARS using ICRISAT lines) from ICRISAT-Patancheru have also been released in five other Asian countries. About 29 genotypes from ICRISAT-Patancheru (including some developed by NARS using ICRISAT lines) too have been released in 17 African countries across WCA and ESA. The most prominent examples of the transfer of sorghum technologies developed in Asia for Africa are ICSV 111 (Nigeria, Ghana and Benin), ICSV 112 (Zimbabwe, Malawi, Kenya, Mozambique and Swaziland), S 35 (Cameroon and Chad) and SV 2 (Zimbabwe). It is also important to note that about 13 genotypes (including those developed by NARS using ICRISAT lines) from ICRISAT-Patancheru were released in 7 Latin American countries. A good example is ICSV 112 that was released in Mexico and Nicaragua. In addition, at least 19 varieties developed by ICRISAT's Africa locations along with African national programs or developed by NARS based on advanced ICRISAT lines have been released in Africa. A prominent example of a successful sorghum technology within the ESA region is Macia (SPS 3220). It was deve loped through ICRISAT's regional for Sorghum and Millet Improvement Program (SMIP) of the SADC countries, spread to many countries within

Table 4. Summary of inter- and intra-regional technology transfers in sorghum.

Varieties (No.)	Developed by	Country of release
21	ICRISAT-Patancheru with partners	India
23	ICRISAT-Patancheru with partners	5 other Asian countries (Myanmar, Pakistan, Philippines, China and Thailand)
29	ICRISAT-Patancheru with partners	17 African countries (Cameroon, Chad, Ghana, Nigeria, Benin, Mali, Malawi, Ethiopia, Zambia, Zimbabwe, Kenya, Mozambique, Swaziland, Eritrea, Sudan, Niger and Rwanda)
13	ICRISAT-Patancheru with partners	7 Latin American countries (Mexico. Nicaragua. El Salvador, Panama, Guatemala, Colombia and Honduras)
19	ICRISAT-Africa with African NARS partners	17 African countries (Mozambique. Botswana, Namibia, Zimbabwe, Tanzania, Swaziland. Burkina Faso, Burundi, Ethiopia, Sudan, Ivory Coast, Mali, Kenya, Rwanda, Burundi, Uganda and Zambia)
2	ICRISAT-Africa with NARS partners	2 Asian countries (India and Pakistan)
8	ICRISAT-Mexico with partners	5 Latin American countries (Honduras, El Salvador, Dominion Republic, Colombia and Costa Rica)

Southern Africa and is expanding to Eastern Africa. Figure 5 shows the global flow of selected sorghum technologies developed by ICRISAT and its partners.

In addition to the advanced progenies and varieties, a major spillover constituted the transfer of germplasm accessions collected globally and distributed across countries and regions. ICRISAT holds in trust 36,255 germplasm accessions of sorghum collected in Africa (64%), India (17%), other Asian countries (11%) and the rest of the world (8%). This is an important IPG and is distributed across continents and countries based on demand and the signing of certain germplasm transfer agreements. A number of germplasm accessions from Africa have also been identified as sources of resistance for abiotic and biotic stresses. These include sources of resistance to major diseases like grain mold, downy mildew, leaf blight, ergot and rust, and pests like stem borer and shoot fly. These resistance sources are used in breeding programs in Asia and Africa.

The assessment also indicates that WCA has been largely dependent on ICRISAT-Patancheru for the development of sorghum technologies. Other than a few varieties developed by the national programs from advanced ICRISAT lines, there were no technologies developed within this region with significant spillovers across countries. However, there were relatively more improved genotypes developed in the ESA region. Nonetheless, there was no recorded example of varietal transfer across the two major African regions. This is partly because the farmers of these two regions require sorghum varieties of different maturity groups (early to mid-maturing in ESA and late maturing in WCA). These results jointly show the need to strengthen sorghum improvement research in these two regions to meet the growing demand for technologies adapted to the socioeconomic conditions as well as the specific biotic and abiotic constraints in the two ecoregions. Several sorghum hybrids are released in Asia and are quite popular with farmers. However. only a few hybrids were released in Africa and could not be adopted by fanners. This needs to be investigated and hybrid research in Africa needs to be strengthened.

Figure 1. S 35: A variety developed at ICRISAT-Patancheru and grown in southern Chad and northern Cameroon preferred by farmers for its higher yields and eariiness.

Figure 2. ICSV 112: A high-yielding variety developed at ICRISAT-Patancheru and released in several ESA countries.

Figure 3. SV 2: An early-maturing and high-yielding variety developed in ICRISAT-Patancheru and released in Zimbabwe.

Figure 4. Macia: Farmers in several southern African countries are benefiting from adoption of this variety developed at ICRISAT-Bulawayo.

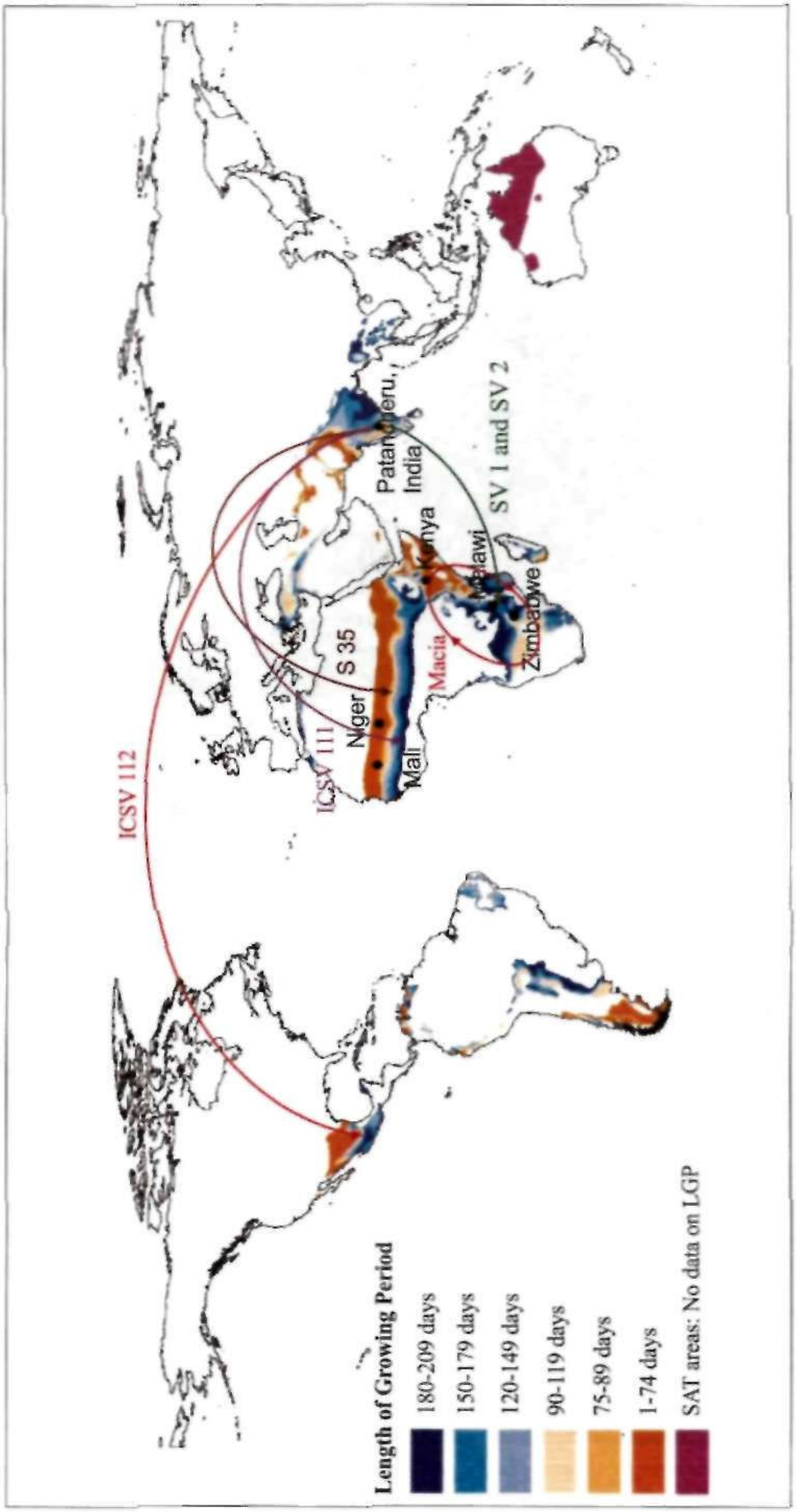

Figure 5. The global flow of selected sorghum technologies developed by ICRISAT and its partners.

3. Spillovers from Research Investments in Millets

3.1. Technologies developed

Millets cover about 36 million ha worldwide (FAO 2002). The major pearl millet-producing countries in the world based on acreage are India, Nigeria. Niger, Sudan, Burkina Faso and Mali (Table 5). It is also grown in Senegal, Chad, Tanzania, Zimbabwe. Uganda, Angola, Zambia, Malawi, Botswana, Namibia, Ghana, Ivory Coast, Cameroon, Benin, Mauritania, Eritrea, Kenya, Pakistan and Myanmar. In India, pearl millet constitutes 58% of total millet production, whereas finger millet's share is 27%. In China, pearl millet contributes only 10% of the total millet produced (FAO and ICRISAT 1996). In West Africa, pearl millet constitutes nearly 100% of the millet produced, while in ESA, both pearl millet and finger millet are important crops among millets.

ICRISAT began its pearl millet research in four regions: Asia (1973), WCA (1976). Southern Africa (1984) and Eastern Africa (1984). The Institute has contributed to the development of 76 varieties (including 42 in India), of which 28 showed spillover effects. Twenty-six pearl millet varieties developed in ICRISAT's African locations have been released for cultivation by national programs. These include 8 varieties from ICRISAT-Bulawayo, 7 from ICRISAT-Niamey and the rest from the former ICRISAT/UNDP-supported programs in Senegal, Niger and Burkina Faso. ICRISAT and its partners developed downy mildew-resistant varieties and hybrids in India and varieties in Africa; some of them became very popular among farmers. These varieties led to increases in productivity; in India farmers abandoned existing downy mildew-susceptible varieties in favor of the new varieties. Acknowledging these achievements, the CGIAR awarded ICRISAT the King Baudouin Award in 1996.

ICRISAT's research in finger millet improvement lasted from 1986 to 1992 in Southern Africa (Bulawavo, Zimbabwe) and from 1985 to 1992 in Eastern Africa (Nairobi).

The major yield-reducing factors in pearl millet are diseases (downy mildew, smut and ergot), insect pests (stem borer and head miner) and drought. Downy mildew is the most important disease both in Asia and Africa. Crop damage due to insect pests is of significance in Africa. Although ICRISAT has been conducting research on all these yield-reducing factors, significant progress has been made only in the case of downy mildew

In collaboration with national programs, ICRISAT has at its various locations developed high-yielding varieties (open pollinated and hybrids) coupled with resistance to downy mildew and increased seed size. At Patancheru, the emphasis has been on the development of hybrid parents, whereas in African locations the focus has been on the development of OPVs. This could be because India's well developed seed industry produces pearl millet hybrid seed whereas the nascent seed industry in most African countries is mainly interested in producing seeds of commercial crops. Nonavailability of suitable seed parents could be another reason why commercial hybrids are not found in Africa.

ICRISAT's millet program has used Indian germplasm as well as that from several African countries, notably from Togo, Nigeria and Uganda. Landraces and breeding lines from India generally provide excellent sources of tillering and earliness whereas those from Africa are sources of characteristics such as resistance to downy mildew and smut, large panicle size and bold grains. African germplasm improved at ICRISAT-Patancheru has been found well adapted in other African countries. The use of ICRISAT-Patancheru-bred seed parents in African programs has been very limited due to increased incidence of downy mildew.

3.2. Spillovers from Asia to Africa

Six ICRISAT-Patancheru-bred varieties have been released in ESA and only one in WCA (Appendix 2a). The parental lines constituting these varieties were primarily of West African origin. Two varieties (ICTP 8203 and ICMV 88908) derived from Togo material have been widely adopted by farmers in Namibia and a few other Southern African countries. Three varieties (WC-C75, ICMV 82132 and Lubasi) bred at ICRISAT-Patancheru and introduced to Zambia by the national program (by a former ICRISAT scientist) have been released and adopted by farmers. The major impact of ICRISAT-Patancheru-bred varieties has been felt in Namibia.

Variety Okashana 1 (ICTP 8203, ICMV 88908)

ICTP 8203 (Fig. 6) is distinctly different from WC-C75 (released in India in 1982); it is large seeded, open pollinated, matures earlier and performs better under terminal drought stress (filling grain more rapidly than WC-C75). It was released in India (Maharashtra and Andhra Pradesh) in 1988 and later in Punjab and Karnataka. Between 1989 and 1994, ICIT 8203 was annually grown on an estimated 0.7 million to 1 million ha in India (Andrews and Anand Kumar 1996).

Table 5. Area, yield and production of major millet-producing countries in the world.*

Countries	Area ('000 ha)	Yield (t ha^{-1})	Production ('000 t)
Developing countries	**35,078**	**0.7-1**	**25,953**
Africa	**20,367**	**0.66**	**13,435**
Niger	5,205	0.42	2,169
Nigeria	5,939	1.02	6,036
Sudan	2.483	0.21	519
Mali	1.255	0.69	861
Burkina Faso	1,253	0.73	911
Chad	820	0.42	342
Uganda	387	1.47	567
Ethiopia	232	1.37	317
Ghana	210	0.73	154
Tanzania	181	0.91	164
Zimbabwe	155	0.28	43
Ivory Coast	95	0.74	70
Kenya	93	0.52	48
Senegal	85	0.60	51
Togo	79	0.51	40
Cameroon	70	1.01	71
Others	1,825	0.33	610
Asia	**14,830**	**0.85**	**12,573**
India	12,341	0.77	9,550
China	1.166	1.76	2,054
Pakistan	408	0.52	211
Nepal	260	1.10	287
Myanmar	240	0.69	166
South America	22	1.68	37
Argentina	22	1.68	37
Others	371	0.62	231
Developed countries	**1,689**	**0.94**	**1,582**
United States	184	1.64	302
Australia	40	1.48	59
Russian Federation	803	0.82	655
Ukraine	257	1.04	269
Others	405	0.74	298
Total	**36,767**	**0.75**	**27,535**

1. FAO statistics averaged over three yean (2000-2002).

Source: FAO (2002)

The Rossing Foundation, an NGO in Namibia, released ICTP 8203 (locally known as Okashana 1) in 1989 for cultivation by pearl millet farmers. It was introduced along with 49 Other millet varieties from ICRISAT-Bulawayo in 1986 and evaluated at Okashana Agricultural Training Center. ICTP 8203 was selected by farmers in on-farm trials at Okashana for two years (1987 and 1988) before its release in Namibia. It is., good example of the success of farmer participatory selection. Multilocational on-station or on-farm trials were not conducted before its release to farmers. The variety has quickly spread to farmers in Namibia be raise of its preferred agronomic and economic traits.

In 1990, the Government of Namibia requested ICRISAT to multiply Okashana 1 seed. ICRISAT-Bulawayo multiplied 11 t of ICMV 88908 during the dry season of 1990 at Muzarabani (Zimbabwe), and shipped this seed to Namibia. ICMV 88908 is morphologically similar to ICIT 8203 but had a yield advantage. This variety produced 17% more grain than ICTP 8203 in on-station trials conducted by ICRISAT in India (Witcombe et al. 1995).In 1990, the Government of Namibia released ICMV 88908 as Okashana 1 for general cultivation (Rai and Hash 1994). Because of their similarities, the new variety too retained the name Okashana 1. This variety was also released as Nyankhombo in Malawi (1996) and as Bonde in Botswana (1998).

ICMV 88908 was developed at ICRISAT-Patancheru by random mating similar populations from Togo and Ghana (ICTP 8203, ICTP 8202, a group of Togo progenies and ICGP 850), and two populations (EGP H 8401 and ECII) derived from Indian and African crosses. Therefore, this variety was constituted from ICTP 8203, similar other populations and some Indian lines.

In 29 replicated trials conducted by ICRISAT in India from 1989 to 1991, ICMV 88908 yielded 2.45 t ha^{-1}, 16.8% more than ICTP 8203. ICMV 88908 flowered in 48 days, the same as ICTP 8203, and 4 days earlier than WC-C75 (Witcombe et al. 1995). It evades late-season drought due to its earliness.

ICMV 88908 is 10-20 cm taller than ICTP 8203 and 10-15 cm shorter than WC-C75. Its panicles are thick and semi-compact to compact. The seeds are round and large (> 13 g 1000 $grain^{-1}$). It showed good resistance to downy mildew, with 3.3% incidence over a 3-year screening in the All India Coordinated Millet Improvement Project (AICMIP) diseases nurseries, compared with 5.6% for WC-C 75 and 85.7% for HB 3 (Witcombe et al. 1995).

Rohrbach et al. (1999) conducted an impact assessment study on the adoption of peari millet variety Okashana 1 during 1998 in Namibia. They found that Okashana I's main advantage in the northern Namibian cropping system is its early maturity, allowing fanners greater flexibility in their management practices. Some farmers sow it at the beginning of the rainy season to obtain an early harvest at a time when household grain stocks are low or exhausted. This variety is also good for late sowing if early-season rains fail. Grain yield, grain size and drought tolerance were also cited by farmers as favorable traits in Okashana 1. The variety allows farmers who sow during the first rains to obtain a harvest 30-50 days earlier than what is possible with traditional varieties.

Two alternative approaches were employed to estimate the adoption rates for Okashana 1 in the impact analysis (Rohrbach et al. 1999). The first rate assumed that all the Okashana 1 seed being sold was sown, and that 75% of the area sown to this variety during the previous year was sown the following season using farm-saved seed. This scenario suggests a steady increase in Okashana 1 area, from 1.1-49% of the national pearl millet area (296,300 ha) in 1997 (Table 6). This level and rate of adoption was confirmed in interviews with farmers and extension agents during the reconnaissance survey in February 1998. The adoption of Okashana 1 provides Namibia with an estimated 21,000 t of additional pearl millet grain during the normal cropping season, nearly a 20% increase in total production.

In the second conservative adoption scenario, the adoption rate each year was assumed to coincide with the amount of Okashana 1 seed sold during that season. Using this assumption, the adoption rate increased from 1.1% in 1990/91 to 26.9% in 1996/97 (Table 6).

The roughly estimated area under Okashana 1 in different countries is as follows: Namibia (100,000 ha), Botswana (10,000 ha), Malawi (10,000 ha) and Zimbabwe (5,000 ha) (ES Monyo, personal communication 2003). The rate of adoption in countries other than Namibia is still low since the variety was released in these countries only a few years ago (Appendix 2a).

The relatively faster spread of the variety in Namibia was the result of the farmer participatory selection approach followed by NGO/NARS in the quick identification of varieties. Before the millet improvement program was set up in Namibia, the Rossing Foundation had been evaluating pearl millet varieties for local adaptation and release. In fact, Okashana 1 was released based on fanners' preferences and using yield data from Rossing Foundation. Thereafter, the Government strongly supported seed multiplication and distribution. ICRISAT-Bulawayo provided seed and technical support in seed multiplication, training of staff and extension of material. ICRISAT also posted a scientist in Namibia to provide technical support in seed production and extension of Okashana 1.

Table 6. Distribution and adoption of Okashana 1 seed in Namibia, 1990/91 to 1996/97.

	Okashana 1 area as % of total pearl millet area	
Season	Optimistic estimate[a]	Conservative estimate[b]
1990/91	1.1	1.1
1991/92	3.1	2.3
1992/93	11.2	8.9
1993/94	11.4	3.0
1994/95	18.4	9.8
1995/96	30.0	16.2
1996/97	49.4	26.9

a. Based on seed sales and assuming that 75% of the previous years' Okashana 1 area was resown with farm-saved seed.
b.Based on seed sales and assuming that no farm-saved seed was resown.
Source: Rohrbach et al 1999.

Variety WC-C75

WC-C75 (Fig. 7) was developed at ICRISAT-Patancheru following recurrent selection in a composite population from Nigeria. World Composite is a composite population developed in Nigeria and introduced to ICRISAT-Patancheru in 1973. In 1975, 441 full-sib families derived from the World Composite were tested at Coimbatore, Hissar and Patancheru. Seven superior full-sib families were selected at Coimbatore. Disease-free plants from these were selfed in a downy mildew screening nursery at Patancheru. The resulting S_1 bulk for each of the seven progenies was sown in the next season's downy mildew nursery, and bulk pollen was used to enforce random mating. The experimental variety produced by this process was named WC-C75 (Andrews et al. 1985).

Andrews et al. (1995) describe the release of this variety and its performance. It was tested in India by the Ministry of Agriculture, Government of India, and was released by it in May 1982 as WC-C75. The variety averaged 98% of the grain yield of a widely grown hybrid (BJ 104) in 140 replicated tests conducted by AICMIP from 1977 to 1981. WC-C75 matures 4 days later than BJ 104 but gives 20% more dry fodder, valued as animal feed- It has good resistance to downy mildew (2.4% incidence in the 1977-81 trials compared to 9.7% for BJ 104), is of medium height (185-210 cm), has robust stems, flowers in 48-51 days and matures in 80-85 days. Its grain protein content is close to the average for pearl millet (9.3% based on 32 tests).

WC-C75 has been cultivated by Indian farmers since 1983, and has been grown annually on one million ha in nine states, ie, about 9% of the total pearl millet area in India (Singh et al. 1993).

During 1984-92, WC-C75 was sown annually on an estimated 0.6-1.2 million ha in India without any significant decline in downy mildew resistance (Rai and Hash 1994). This is one of the few ICRISAT-bred varieties, which has made significant impact in India. Its spillover has been only in Zambia and that too to a limited extent.

A former ICRISAT breeder who joined the national program in Zambia in 1984 introduced several varieties from ICRISAT-Patancheru to the national program. WC-C75 was tested for two years in Zambia (1985-1987); results showed 22% higher grain yields than the local landrace. It was subsequently released as ZPMV 871 in Zambia in 1987. It possesses good resistance to downy mildew and is less affected by ergot and smut than hybrids. It was later withdrawn from cultivation following the release of another ICRISAT pearl millet variety Kaufela in 1989 (Monyo et al. 2002). There is no data on the area sown to WC-C75 in Zambia.

Variety ICMV 82132

ICMV 82132 was developed at ICRISAT-Patancheru by random mating six S, progenies from 3 Smut Resistant Composite (SRC) in 1982. It was introduced from ICRISAT-Patancheru to Zambia through germplasm exchange. It was further improved in Zambia by mass selection. After multilocational tests, it was released in 1989 as Kaufela. It produces 30% more grain yield than the local varieties (2.04 t ha^{-1} vs. 1.48 t ha^{-1}) and matures about 10 days earlier. On-farm performance data is not available. The variety is grown over an estimated 10,000 ha, 19% of the pearl millet area in the Southern Province of Zambia (Obilana et al. 1997).

Variety Lubasi

The Zambian national program also released Lubasi, based on a Late Backup Composite (LBC), a population from ICRISAT-Patancheru introduced through germplasm exchange. Lubasi was developed by selection from an LBC by the Zambian national program. In 1991, it was released in the Western Province for higher productivity. It produced 2.38 t ha^{-1} of grain compared to 1.48 t ha^{-1} for the local variety in on-station trials. It matures about 8 days earlier thar the local variety (62 vs. 70 days). In 1995, Lubasi covered an estimated 20,000 ha, 38% of the pearl millet area in the Western Province (Obilana et al. 1997).

Variety ICMV 221, ICMV 88904

ICMV 221 was developed from a Bold Seeded Early Composite (BSEC), which is primarily based on ICTP 8203 and similar material. It was released in India in 1993 because of its higher productivity. It outyielded ICTP 8203 by 15% in yield trials (Rai and Anand Kumar 1994). This variety was released in Kenya (as Kat/PM 3) and Eritrea (as Kona) in 2001. ICMV 221 was introduced to Kenya from ICRISAT-Patancheru through the ICRISAT regional program in Nairobi. It is likely to make an impact in these countries in a few years.

In the late 1990s, the Danish International Development Agency (DANIDA) sponsored the postgraduate training of a sorghum and millet breeder from Eritrea at ICRISAT-Patancheru. He introduced several varieties into Eritrea and ICMV 221 was the best performer. He evaluated, multiplied and distributed seed to farmers. ICRISAT provided technical support (evaluation, planning of off-season nursery, etc.) to the millet-breeding program in Eritrea through visits by ICRISAT scientists. Since ICMV 221 has superior resistance to downy mildew compared to local varieties in Eritrea, it provides much higher and more reliable-grain yields (CT Hash, personal communication 2003).

Variety 3/4 HK-B78

This variety was developed by ICRISAT-Patancheru in 1978 following recurrent selection in 3/4 Heine Kein (HK) population at Bhavanisagar [India). The population was introduced to ICRISAT-Patancheru from the Nigerian national program and subsequently introduced to ICRISAT programs in West Africa in the early 1980s. The variety was further improved for uniformity and resistance to downy mildew by ICRISAT's Senegal program and released in 1987 as IBMV 8401. Through efforts of ICRISAT-Niamey and the Mauritanian national program, the variety was released in Mauritania in 1995. This is the first dwarf variety (140 cm) released in Africa, and is a good example of the movement of material from West Africa to India and back to West Africa. Lack of data on the variety's performance and adoption rates prevents us from assessing the extent of spillover within the region.

Disease Screening Technique

ICRISAT-Patancheru developed screening techniques to evaluate pearl millet lines for resistance to downy mildew. These methodologies have been adopted by some scientists in WCA (eg, Nigeria and Niger) and Europe (eg, UK) (Appendix 2b).

3.3. Spillovers from Africa to Asia

Several breeding populations, germplasm accessions and sources of resistance to diseases introduced from Africa have been utilized in ICRISAT's breeding program. Based on available data, a few prominent examples considered to be economically important are described.

World Composite

WC-C75 was developed through recurrent selection using the World Composite at ICRISAT-Patancheru and released in India and Zambia. The World Composite random mating population was constituted in Nigeria in 1971 at the 1AR, Ahmadu Bello University, from derivatives of numerous crosses between worldwide sources of pearl millet germplasm and early-maturing Nigerian landraces. A former IAR scientist who joined ICRISAT as millet breeder introduced the bulk seed of the World Composite to ICRISAT in 1973. The World Composite had a highly variable population for several traits for which selection was done. The composite population had better downy mildew resistance, good seed size, good plant height and thick stems contributing to increased stover yield, low tillering and mature 10-15 days later than improved varieties available in India in 1974 (SC Gupta, personal communication 2003).

Iniadi Accessions

Several varieties including ICTP 8203, ICMV 88908, RCB-IC 911, ICMV 221 and BSEC were developed at ICRISAT-Patancheru from Iniadi germplasm. ICRISAT's first source of Iniadi material was the 1977 collection of the International Board for Plant Genetic Resources-French Institute of Scientific Research for Development through Cooperation (IBPGR-ORSTOM) from Togo. However Iniadi types are also found in Ghana, Benin and Burkina Faso. In the former ICRISAT-Kamboinse (Burkina Faso) program, a set of 27 accessions was grown at Farako-Ba during the 1979 rainy season. Among this set, several early-maturing Iniadi accessions were downy mildew free, extra-early maturing and possessed well-filled compact heads. Several individual plants were selfed in these accessions. A bulk of the selfed seed of the selected lines was sown at the Agricultural Research Station at Kamboinse in June 1980 and was observed to be early maturing and free of ergot, smut and downy mildew. In the same year, harvest from this bulk was introduced as the Togo population into ICRISAT-Patancheru (Andrews et al. 1996), which has been widely used in its programs in Asia and Africa. ICRISAT-Niamey developed variety GB 8735 from Iniadi germplasm, which is grown in several West African countries. Iniadi is one of the most useful germplasm collections from smallholder farmers in West Africa widely used by millet breeders across the world (SC Gupta, personal communication 2003).

Serere 10 LA

ICRISAT introduced Serere 10 LA and other Serere populations to ICRISAT-Patancheru from Uganda in 1973. The male-sterile line Serere 10 LA was reselected at ICRISAT-Patancheru and released in India in 1984 as ICMA 834 and ICMB 834. Using a similar selection of Serere 10 LA, a private seed company in India produced MBH 110, a very successful hybrid widely grown in Maharashtra (India). MBH 110 strongly resembled the Iniadi phenotype and was therefore morphologically distinct from any other hybrid in India (Andrews et al. 1996).

Sources of Resistance

Downy mildew, smut and ergot are major diseases in pearl millet, of which downy mildew is the most serious and occurs almost every year throughout Africa and Asia. Smut and ergot occur depending on favorable weather (moist conditions at flowering). Scientists at ICRISAT-Patancheru have identified sources of resistance (Appendix 2c) for downy mildew and smut in African germpiasm. These lines have been used in breeding programs across the region.

Downy mildew. ICRISAT-Patancheru identified and developed best sources of downy mildew resistance in pearl millet lines introduced from Nigeria (SDN 503, 700516, 700651), Mali (P310) and Cameroon (P7). The five lines are being used in breeding pollinators at ICRISAT-Patancheru, while resistance from P7 and 700651 is being transferred into hybrid seed parents. The line 700516 is one of the constituents of two ICRISAT-bred varieties, ICMV 2 (IBMV 8001) and ICMV 3 (IBMV 8004), which were released in Senegal. Similarly, several resistance sources including 700516 and P310 have been used in breeding programs in Southern Africa (Singh et al. 1993).

As stated earlier, four downy mildew-resistant OPVs developed at ICRISAT-Patancheru using the resistance sources (WC-C75, ICMS 7703, ICTP 8203 and ICMV 155) have been released for wider cultivation in India.

Smut. More than 6000 breeding lines and germpiasm accessions from several countries have been screened by ICRISAT-Patancheru and Hissar in India. Six genetic resource accessions (ICMLs 5 to 10) have shown stable resistance for 4-7 years in multilocational trials. Some of these lines are derived from African germpiasm. ICML 5 was developed from the Super Serere Composite (SSC) - parental population from Uganda; ICML 7 and 8 were derived from Nigeria's local variety Ex Borno and ICML 10 from line P 489 introduced from Senegal. Smut-resistant lines are being successfully used at ICRISAT-Patancheru to breed smut-resistant composites, varieties and hybrids. ICMV 82132 was developed and released in Zambia as Kaufela in 1989 (Thakur and King 1988) from a smut-resistant composite made in 1982.

3.4. Spillovers within Africa

Seventeen pearl millet varieties developed by ICRISAT programs in Africa in collaboration with national programs have been released in countries other than their country of origin (Appendix 2a). Two varieties (SOSAT-C88 and GB 8735) developed in West Africa are widely adopted by farmers in West Africa. One variety (PMV 2) developed in ICRISAT-Bulawayo is also grown in Zimbabwe and Botswana. There is no spillover of pearl millet varieties from the WCA region to the F.SA region or vice versa. Data on the adoption and impact of these varieties is not available.

Variety SOSAT-C88

SOSAT-C88 (Fig. 8) *was* developed by JCRISAT-Niamey and the Malian NARS at Cinzana (Mali) by recombining 19 S_1 progenies selected at Cinzana in 1988 from a cross between Souna and Sanio landraces. Souna is early maturing and Sanio late maturing. This variety was released in Mali (1992), Burkina Faso (1996), Chad (1997), Cameroon (1997), Nigeria (2000) and Mauritania (2000). It is widely grown by farmers in Nigeria and other WCA countries. The variety combines good traits from both Souna (earliness) and Sanio (good grain quality) and is highly resistant to downy mildew.

In Nigeria, SOSAT-C88 was nominated for registration as LCIC-MV 1 (Lake Chad/ICRISAT Millet Variety) on 23 August 1999 by Lake Chad Research Institute (LCRI), Maiduguri, to the Registrar of the Variety Release Committee. This is an indication of a strong partnership between ICRISAT and LCRI. It was released in early 2000 for cultivation throughout the millet-growing zones of Nigeria. LCRI has *the* national mandate to develop and improve pearl millet varieties in Nigeria. Since 1995, ICRISAT and LCRI jointly evaluated this variety along with other lines (Gupta 2001), and a description of their performance data in on-station and on-farm trials follows.

ICRISAT began pearl millet research in Nigeria in January 1995 by introducing hundreds of lines or varieties bred by ICRISAT and NARS from Africa and India. In April 1995, ICRISAT and LCRI together developed a work plan to test introduced millet varieties and available lines and to develop new varieties and hybrids. SOSAT-C88 and some other entries were tested at two locations in 1995; all the farmers chose SOSAT-C88 on a visual basis during farmers' field days. The variety has good grain, is medium tall, resistant to downy mildew (a serious disease in Nigeria), matures early (90-95 days), has well tilled panicles, thick stems and only a few tillers. SOSAT-C88 was further evaluated in multilocational trials (1996-1998) in Nigeria. It produced 1.31 t ha^{-1} of grain, ie, 20% more than the local variety and 15% more than Ex Bomo, an improved check variety. It had less downy mildew incidence (highly resistant variety) and flowered 7-10 days earlier than both Ex Bomo and the local variety. Grain yield data across 15 environments suggests that SOSAT-C88 showed the most stable performance.

SOSAT-C88 and a local farmer's variety were evaluated in farmer-managed on-farm trials in six states of northern Nigeria in 1997 and 1998. On-farm trials were conducted in two villages in each state; five fanners were chosen per village. Both in 1997 and 1998, SOSAT-C88 produced more grain yield than the local variety in Borno and Kano states. During 1998, based on all locations, it produced 35% more grain than the local variety and in 1997 their grain yields were similar. SOSAT-C88 flowered in 50-55 days, ie, 6 days earlier than the local variety and showed almost no downy mildew incidence. Farmers preferred SOSAT-C88 because of its well filled panicle, thick stem, downy mildew resistance, high grain yield and good food quality.

Six pearl millet varieties were intercropped with six cowpea varieties at Minjibir during the 1998 main season in collaboration with the International Institute for Tropical Agriculture (IITA), to identify the best pearl millet variety under intercropping. Pearl millet and cowpea varieties were planted in a 1:1 ratio; the row length was 5 m and row-to-row spacing 1 m. Pearl millet varieties were planted two weeks earlier than cowpea varieties. Based on the mean of six cowpea varieties, SOSAT-C88 produced the highest grain yield (3.2 t ha^{-1}, ie, 18.5% more than local variety Minjibir). SOSAT-C88 also produced 6.6% more dry fodder yield than the local variety (Minjibir Local).

To determine SOSAT-C88's acceptance, a survey was conducted by LCRI in the millet-growing zones covering Borno, Yobe, Bauchi, Jigawa, Kano, Katsina, Zamfara, Sokoto, Gombe, Adamawa and Kebbi states of Nigeria. Twenty-five farmers each were interviewed in Katsina and Gombe states, and 20 farmers in each of the remaining states (230 respondents in all). The farmers were asked to list independendy the traits they prefer before adopting a variety. Ninety nine percent of the respondents preferred SOSAT-C88 because of its superior food quality and food taste compared to local varieties. SOSAT-C88 was accepted by 72% because of its earliness, whereas 91% preferred it because of its large grain size and 95% because of its early maturity. Most of the respondents (98%) admired its attractive grain color. SOSAT-C88 was preferred for its higher tolerance or resistance to insect pests and diseases by 84% of the respondents as compared to their local variety. However, SOSAT-C88 Was poor tittering capacity (as indicated by 69% of the respondents) and low stalk production (56% respondents). Seventy percent of the respondents accepted the recommended interrow spacing of 75 cm and intrarow spacing of 50 cm because there is less shade while intercropping with cowpeas, as indicated by 63% of the respondents.

During 2000, the first year of its release, 20,000 ha were expected to be sown with this variety (SC Gupta, personal communication 2003) based on seed availability and economic and institutional support by extension agents, NGOs and the Government. Since the variety has been released in a number of WCA countries (Burkina Faso, Chad, Cameroon, Nigeria and Mauritania), a systematic adoption and impact study is recommended to understand the process and extent of spillover in the region.

Variety GB 8735

GB 8735 (Fig. 9) was developed from progenies selected from a cross involving Iniadi (a landrace from northern Togo) and Souna (an early-maturing landrace from Mali), which has features very similar to Iniadi. It was developed at ICRISAT-Niamey in collaboration with national programs. It has the ability to set seed under high ambient temperature (45°C), and recover and produce near-average yield when normal conditions follow a severe drought (Andrews and Anand Kumar 1996). GB 8735 is characterized by its earliness (70-80 days from planting to maturity compared to 90-110 days for traditional varieties), tolerance to moisture stress, medium height, high tillering ability and bold grain (Andrews and Anand Kumar 1996). Its grain yield is similar to that of local varieties during a good rainfall year and superior to that of local varieties in a year when the rains cease early.

The variety was released to farmers in Chad (1990), Mauritania (1994), Benin (1999) and Nigeria (1998). The seed companies in Nigeria and extension organizations multiplied seed of this variety in 1998 and sold it to farmers. In 1994, this farmer-preferred variety covered an estimated 30,000 ha (10,000-12,000 farmers) in Chad (Andrews and Anand Kumar 1996), while in 2000 it covered about 10,000 ha in Nigeria (SC Gupta, personal communication 2003).

In Mauritania, some farmers call GB 8735 *rijal el ghaiss,* meaning harbinger of good fortune and happiness in Mauritanian Arabic. Farmers in the Kaedi region observe that as GB 8735 matures early they do not have to travel to the capital city Nouakchott in search of employment during the lean period. In Benin, farmers call it *banadabu,* meaning a variety which protects the back because it is possible to harvest a crop in the middle of the cropping season when food stocks are generally very low (Andrews and Anand Kumar 1996). In Gambo Province of northern Nigeria, farmers call it by several names - *mm celo (*savior), *kora yumda* (drives away hunger), *raya marayu* (sustains orphans) and *numan fari* (first to mature) - signifying the importance of early crop maturity (SC Gupta, personal communication 2003).

In some areas, farmers harvest two GB 8735 crops because of its earliness. In the Keita valley of Niger (annual rainfall of 440 mm), two crops are planted and harvested during the rainy season. The second crop matures on "run-in" water that accumulates from areas surrounding the valley. In Western Niger, it is being used in intercropping with late-maturing millet (Hani-Kirei, the traditional local landrace) that matures in 110 days, thus ensuring an early harvest to tide over the hungry period. It is recommended for West Africa's Sahelian zone. It is adopted by some fanners in the Sudanian zone for late planting (August). In Southern Chad, it has been found to escape *Striga* infestation (Anonymous 1999). Given GB 8735's useful traits to the poor farmers of the region, an impact assessment study could identify constraints to adoption and spillover benefits.

Variety SDMV 89004 (PMV 2)

Variety SDMV 89004 was developed by the SADC/ ICRISAT SMIP in Zimbabwe in 1989 from a short-duration composite. The composite population was constituted by random mating 174 different superior medium-maturing varieties (85-100 days to flowering) originating from ICRISAT programs and the SADC region for four seasons before any selection was made. Nine superior progenies were selected out of 361 S_1 progenies tested at four locations during 1986-87. These were random mated at Muzarabani, Zimbabwe, and further improved for early maturity, high tillering, large bold seed and long cylindrical compact heads following Gridded Mass Selection (GMS). The resultant variety was named SDMV 89004 (Monyo et al. 2002). It was released in Zimbabwe as PMV 2 in 1992 and in Botswana as Legakwe in 1998.

PMV 2 was evaluated for four years in on-station trials and two years in on-farm trials in Zimbabwe. Based on the four-year data (1988-1991) and a total of 25 locations, PMV 2 produced 40% more grain than the local variety (2.81 t ha^{-1} vs. 2.01 t ha^{-1}). Based on the average of two years (1990 and 1991) and a total of 10 locations, PMV 2 yielded more than twice the local variety (2.28 t ha^{-1} vs. 1.07 t ha^{-1}). PMV 2 matures almost 25 days earlier than the local variety (ES Monyo, personal communication 2003).

ICRISAT-Bulawayo produced 161 t of PMV 2 seed in 1992 following the severe drought in 1991/92. The project provided a large quantity of good quality seed to small farmers and contributed to the improvement of household food security in Zimbabwe. PMV 2's current estimated acreage is 35,000 ha (14% of the total pearl millet area) in Zimbabwe (Obilana et al. 1997). The percentage of farmers adopting PMV 2 increased from about 6% in 1991/92 to 26% in 1994/ 95 (Rohrbach et al. 1995). Its adoption rate in Zimbabwe can be increased by improving the availability of improved seed to farmers. Data on the extent of PMV 2's adoption in Botswana is not available.

Variety Okashana 2

Okashana 2 (SDMV 93032) was developed at ICRISAT-Bulawayo in 1993 for its high yield, strong stalk and drought resistance. It is composed of SDGP 1514 (a local landrace from Zimbabwe), ICMV 87901 and ICMV 88908. SDGP 1514 was selected for its strong stalk and hard vitreous endosperm kernels. ICMV 87901 and ICMV 88908 were selected for their early maturity and large bold grains. Okashana 2 was released in Zimbabwe in 1996, Namibia in 1998 and in Sudan in 2000. It is also grown in Angola.

Okashana 2 is superior to Okashana 1 in respect of improved stalk strength, better downy mildew resistance (in Sudan) and yield (5%) (Monyo et al. 2002). Okashana 2 has a yield advantage (over 30%) compared to local varieties in normal seasons; it can even provide a twofold yield increase relative to local varieties in drought years. The variety is currently expanding in many of the countries where it has been released (ES Monyo, personal communication 2003). No reliable data exists on the actual extent of adoption and spread of the variety. More careful investigation is required.

Variety Ugandi

The variety Ugandi, released for cultivation in Western Sudan in 1981, was derived from Serere Composite 2 introduced from Uganda (Jain and El Ahmadi 1982). Serere Composite 2 was introduced from ICRISAT-Patancheru to Sudan by ICRISAT-Wad Medani in 1977, where it was developed through selection. Serere Composite 2, an early-maturing and bold-seeded population, was developed by Uganda's national program and introduced to ICRISAT-Patancheru in 1973. This is also a good example of the movement of varieties *from Africa to Asia and back to Africa.*

3.5. Spillovers within Asia

Pearl millet as a grain crop is not grown in any Asian country except India. ICRISAT's focus was primarily on improving pearl millet varieties for grain yield (not fodder yield). Therefore, there has been a limited spillover within Asia. Countries like Pakistan and Korea have used ICRISAT-Patancheru-bred varieties to develop fodder varieties. ICMS 7704 developed at ICRJSAT-Patancheru was released in Pakistan in 1991 as PARC-MS2. ICRISAT provided Pakistan the seed of this variety in the late 1970s through international trial protocols. The variety was selected for its greater fodder yield.

Two fodder hybrids (Suwon-6 and Suwon-7) developed by Korea using ICRISAT lines (81 A and 81 B) were released in Korea (KN Rai, personal communication 2003). However, not much is known about their performance in Asian countries.

Seven varieties and 4 hybrids bred at ICRISAT-Patancheru have been released in India. In addition, the Indian national program has developed and released 4 varieties and 27 hybrids based on ICRISAT plant material.

3.6. Spillovers from research investments in finger millet

Technologies developed

Finger millet is a traditional crop in several Asian (India, Nepal and Bhutan) and ESA countries (Tanzania, Ethiopia, Zimbabwe, Malawi, Zambia, Uganda, Kenya, Rwanda and Burundi). Since FAO statistics does not provide separate data on this crop, the actual acreage of finger millet in different countries and globally is not well known. However, it appears that the acreage under finger millet is declining due to low productivity and its gradual replacement with high-yielding crops such as maize. In fact, finger millet is already extinct in some regions. It used to be grown in Nigeria, Congo, Botswana and many more African countries. To prevent its disappearance, efforts are needed to increase its productivity and utilization. On the request of SADC countries, ICRISAT started a finger millet breeding program in 1986 at ICRISAT-Bulawayo. The center assembled a wide range of germplasm, characterized it and used selected lines in breeding programs. By 1992, several varieties were in advanced testing stages in Tanzania, Malawi, Zambia and Zimbabwe, when the project was shelved due to funding constraints.

Spillovers within Africa

In 1992, Zimbabwe's National Variety Release Committee released two finger millet varieties developed jointly by ICRISAT-Bulawayo and the national program. These varieties had the potential to spill over to other countries in the region had finger millet breeding continued beyond 1992. A genetic male-sterile line (INFM 95001) was developed by ICRISAT-Bulawayo and the University of Nebraska [USA) through mutation breeding. The initial work on mutation breeding was conducted by the late FR Muza towards his Ph.D thesis.

The uptake and utilization of these lines is not yet known. The performance data on these lines are described in the following section.

Variety FMV 1, 25 C

FMV 1 was developed by ICRISAT-Bulawayo in collaboration with DR&SS of Zimbabwe. It was released in Zimbabwe in October 1992 by the National Variety Release Committee because of its superior grain yield (Mushonga et al. 1992).

FMV 1 is a selection from 25 C, a local landrace from Zimbabwe. This variety along with other entries was jointly evaluated (by ICRISAT-Bulawayo and DR&SS) in Zimbabwe for 5 years (1987/88 to 1991/92). FMV I's mean grain yield was 34% more than that of the local variety (2.77 t ha^{-1} vs. 2.07 t ha^{-1}). FMV 1 is similar to the local variety in terms of threshing percentage (64% vs. 58%), ear heads per plant (6.4 vs. 6.0), individual grain weight (2.48 mg vs. 2.39 mg) and fingers per head (8.2 vs. 8.1).

There was no spillover of this variety outside Zimbabwe, maybe due to the lack of regional efforts to test the varieties in other countries. ICRISAT's research in finger millet was discontinued in 1992, the year the variety was released in Zimbabwe.

Variety FMV 2, SDEV 87001

SDEV 87001 was developed by ICRISAT-Bulawayo in collaboration with Zimbabwe's national program. In October 1992, the National Variety Release Committee released FMV 2 for its superior grain yield (Gupta and Mushonga 1994).

In April 1986, ICRISAT-Bulawayo acquired 667 germplasm accessions of finger millet from the Plant Germplasm Quarantine Center in Maryland, USA, for evaluation in SADC countries. Plants from PI 462703 showing a uniform phenotype were selected in the 1986 observation-seed increase nursery at Muzarabani, Zimbabwe. This accession was further purified in the 1986/87 seed increase nursery at Marondera, Zimbabwe. The seeds harvested from this second cycle of selection were bulked to produce FMV 2.

This variety along with other entries was evaluated in yield trials in Zimbabwe (by ICRISAT-Bulawayo and DR&SS) from 1987/88 to 1991/92. The mean grain yield of FMV 2 was 67% greater than that of the local variety (3.46 t ha^{-1} vs. 2.07 t ha^{-1}). FMV 2 is superior to the farmers' local variety in terms of threshing percentage (72% vs. 58%), ear heads per plant (9.3 vs. 6.0) and individual grain weight (2.75 mg vs. 2.48 mg). FMV 2 has fewer fingers per head (6.6) than the local variety (8.1).

In 1992, ICRISAT's program on finger millet in the SADC was discontinued.

Line INFM 95001

INFM 95001 is a genetic male-sterile line of finger millet carrying the genetic male-sterile allele ms_1. This line was jointly developed by ICRISAT-Bulawayo and the Department of Agronomy, University of Nebraska, following mutation breeding. It was released by the ICRISAT Plant Material Identification Committee in March 1996 (Gupta et al. 1997). Finger millet is a highly self-pollinated crop. Crossing is difficult, and parents with contrasting markers are required to identify the hybrid progeny. Crossing between finger millet plants is now very easy due to the ms_1 allele which facilitates transfer of traits and breeding of new varieties.

The ms_1 allele can also be used in studies to investigate heterotic levels and patterns. Random mating populations can be developed using this allele, thereby offering opportunities for recurrent selection in this species. However, we do not know about the extent to which this line was used in breeding programs. There is a need to encourage wider utilization of this line in national finger millet breeding programs in the region.

3.7. Summary and conclusions

This chapter has reviewed the diverse experiences on the adoption and adaptation of pearl millet technologies across countries and regions based on materia] developed in other countries or regions. The major spillover of innovations has occurred from Africa to Asia and back to Africa. Important germplasm accessions and breeding populations collected from WCA have become vital ingredients for developing new varieties adapted in Asia and distributed in Africa. Figure 10 shows the major patterns of technology transfer between Africa and Asia. The prominent examples for these spillovers are Iniadi landraces from Togo and Ghana, which provided the foundation for developing the early-maturing pearl millet variety Okashana 1 widely grown in India, Namibia, Botswana and Malawi. The other examples are World Composite Populations from Nigeria from which downy mildew-resistant variety WC-C75 was developed. This was adapted in Zambia.

Table 7 summarizes the pearl millet technologies developed in each ICRISAT region and that spilled over to other countries and regions. Until 2001, a total of 42 varieties either developed at ICRISAT-Patancheru or by NARS partners based on an ICRISAT material were released in India. Korea and Pakistan also released three varieties based on ICRISAT material. In contrast, about seven varieties developed at ICRISAT-Patancheru were adopted and adapted in eight African countries. Prominent among these are WC-C75 (ICMV 1) and ICTP 8203 (Okashana 1). This shows that ICRISAT's major impact in terms of pearl millet varieties comes from India, which is also the largest producer of millets in the world. On the other hand, several varieties (at least 17) developed by ICRISAT and/or NARS in Africa have been released in some 16 African countries. This includes the downy mildew-resistant variety SOSAT-C88 developed through NARS-ICRISAT partnerships in WCA and GB 8735 developed by ICRISAT-Niamey. These varieties have been released in a number of countries in the region. In Southern Africa, a number of drought-resistant varieties have also been developed at ICRISAT-Bulawayo and by the regional NARS using ICRISAT material. One good example is SDMV 93032 (Okashana 2), which seems to have good potential to expand into the Eastern African countries. It is important to note the limited transfer of millet varieties from Asia to WCA; perhaps because of the heavy disease pressure in this region, technologies from Asia were not found suitable. On the other hand, some of the varieties developed in Asia based on material from WCA have been adapted in ESA where disease pressure is relatively less. This indicates the crucial importance of strengthening the millet improvement program in WCA to develop alternative technologies best adapted to local biotic and abiotic constraints.

Moreover, several breeding populations, accessions and sources of resistance to diseases introduced from Africa have been utilized in breeding programs at Patancheru. Most notable are the 20,258 pearl millet germplasm accessions held in trust for the global community at ICRISAT. About 62% of these collections originated from Africa while 33% came from India. The germplasm is being screened for important agronomic traits (including pest, disease and drought resistance). The distribution of this germplasm worldwide represents one of the most important aspects of technology transfer and research spillovers in millets facilitated through ICRISAT.

In addition to pearl millet, between 1986 and 1992, ICRISAT initiated limited work on finger millets in Southern Africa. Only two varieties (FMV 1 and FMV 2) bred by ICRISAT-Bulawayo and partners in Zimbabwe were released in 1992 in Zimbabwe. There was no spillover to other countries as there was no follow up from regional programs. Research on this minor crop was terminated in the early 1990s due to budget constraints. However, ICRISAT maintains a sizable collection of this and other minor millets in its Gene Bank and accessions are being distributed globally based on demand.

Table 7. Summary of inter- and intra-regional technology transfer in pearl millet.

Varieties (No.)	Developed by	Country of release
42	ICRISAT-Patancheru with partners	India
3	ICRISAT-Patancheru with partners	2 other Asian countries (Pakistan and Korea)
7	ICRISAT-Patancheru with partners	8 African countries (Zambia, Namibia, Botswana, Malawi, Kenya, Eritrea, Mauritania and Senegal)
17	ICRISAT-Africa with African NARS	Hi African countries (Mali, Burkina Faso, Chad, Cameroon, Nigeria, Mauritania, Benin, Niger, gal, Sudan, Zimbabwe, Namibia, Botswana, Mozambique, Malawi and Tanzania)
1	Ugandan NARS	Pakistan

Figure 6. Okashana 1: Developed at ICRISAT-Patancheru and widely grown in several countries of Southern Africa.

Figure 7. WC-C75: Originating from a World Composite from Nigeria, developed at ICRISAT-Patancheru and widely grown in WCA.

Figure 8. SOSAT-C88: Developed by ICRISAT Niamey and the Malian NARS and grown widely in several countries across WCA.

Figure 9. GB 8735: Developed from Iniadi and Souna landraces at ICRISAT-Niamey and widely adapted in WCA.

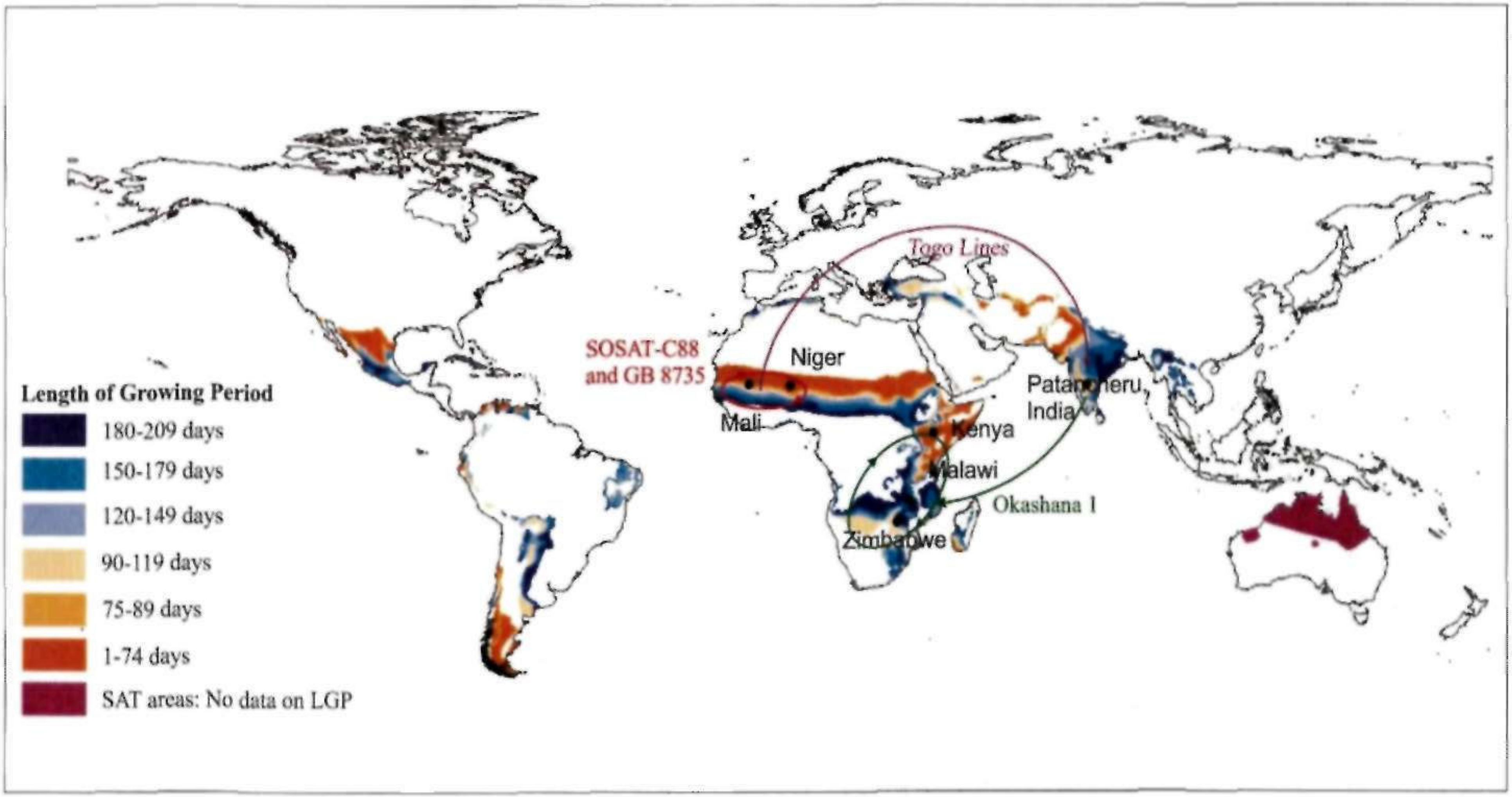

Figure 10. The global flow of selected millet technologies developed by ICRISAT and its partners.

4. Spillovers from Research Investments in Groundnut

4.1. Technologies developed

The global average area under groundnut (2000-02) is about 25 million ha, of which 97% lies in the developing world (FAO 2002). It is widely grown in many Asian countries such as India, China, Indonesia, Myanmar and Vietnam. It is also grown in several African countries like Nigeria, Sudan, Senegal, the Democratic Republic of Congo, Chad, Burkina Faso, Zimbabwe, Mali, Mozambique, Uganda and Tanzania (Table 8).

ICRISAT initiated its groundnut research in three regions - Asia, WCA and Southern Africa - to improve yield, seed size, drought tolerance and resistance to common diseases, In India, it began groundnut, research at Patancheru in 1976. In Southern Africa, it has been improving groundnut since 1982 with a project based at Lilongwe, Malawi. In WCA, its groundnut program was based in Niamey, Niger (1986-95), Kano, Nigeria (1995-98) and in Bamako, Mali (since 1998). The Institute has focused its research on improving groundnut for resistance to major diseases such as aflatoxin, rust, early leaf spot, late leaf spot, bacterial wilt and rosette. In Africa, groundnut fodder is widely used as animal feed.

ICRISAT, in collaboration with the national programs, has developed a number of improved varieties, identified sources of resistance and developed screening techniques against diseases. The improved varieties have high pod yield, mature early, are resistant to foliar diseases and have large seeds. The varieties fired for Southeast Asian countries are resistant to bacterial wilt, a disease specific to the region.

The Institute supplies improved genetic material to national programs either on request, or through international trials. It also assists national programs in evaluating their material, seed multiplication, development of variety release protocols and facilitates the release of varieties.

To date, 45 groundnut varieties developed through ICRISAT-NARS partnerships have been released in 26 countries, of which 36 varieties have shown important cross-regional spillover effects. ICRISAT-Patancheru-bred varieties have been released in ESA (6), WCA (8), Cyprus (3), India (11) and other Asian countries (13) (Appendix 3a). Six out of the seven varieties developed at ICRISAT-Lilongwe have been released in ESA countries other than Malawi. Varieties bred by ICRISAT-WCA are currently under advanced testing in various countries. In the following sections, we present a more detailed picture of the spillover of ICRISAT-bred varieties within and across regions.

4.2. Spillovers from Asia to Africa

To illustrate the spillover of groundnut varieties from Asia to Africa, two examples, one each for ESA and WCA regions are described. In addition to varieties, the ELISA technique developed by ICRISAT-Patancheru and its partners to detect aflatoxin in groundnut products, and a screening technique developed at Patancheru are discussed.

Variety CG 7 (ICGMS 42, MGV 4, Serenut 1R)

CG 7 (Fig. 11) is a widely adapted, high-yielding, alternatively branched elite breeding line suitable for confectionery. It was released as CG 7 in Malawi (1990), as MGV 4 in Zambia (1991) and as Serenut 1R in Uganda (1999) for its high productivity. The variety originated from a single plant selection made in the F, generation of a cross between USA 20 and TMV 10 in 1977/78 at ICRISAT-Patancheru. Through further selection, a varietv named ICGMS 42 was developed in 1982 (ICRISAT Plant Material Description no. 51, 1994).

The variety was introduced by ICRISAT in the SADC/ICRISAT Groundnut Project, Malawi, in 1982. After initial evaluation by ICRISAT in 1982/83 in Malawi, it was included in the regional groundnut variety trial of the SADC region in 1983/84.

In Malawi, the variety was tested against local varieties (Chalimbana, Chitembana, Mawanga and Mani Pintar) in different yield trials during the 1983/84 to 1991/92 seasons (Table 9). Compared to these varieties, CG 7 had a pod yield advantage that ranged from 11-35%.

In Zambia, CG 7 was tested against local variety Makulu Red in 10 trials for five seasons (1983/84, 1985/86 to 1988/89). On an average, it produced 10% greater pod yield than the local variety (which produced 1.75 t ha^{-1}).

CG 7 is as susceptible to early leaf spot and rosette disease as Chalimbana in Malawi and Makulu Red in Zambia. It is also susceptible to rust and late leaf spot, reacting similarly to these diseases as Kadiri 3 in India.

In a study on the potential for the adoption of improved groundnut varieties CG 7 and ICGV-SM 90704 in Malawi, Freeman et al. (2001) suggested a high level of acceptability among farmers who were exposed to them in on-farm variety trials and demonstrations. The study also implied different patterns of adoption among varieties. CG 7 showed the highest level of acceptance and potential for adoption followed by ICGV-SM 90704 across all regions. The lack of significant differences in adoption

Table 8. Area, yield and production of major groundnut-producing countries.[a]

Countries	Area (000 ha)	Yield (t ha^{-1})	Production ('000 t)
Developing countries	**24,428**	**1.35**	**33,071**
Africa	**9,766**	**0.87**	**8,479**
Nigeria	2,705	1.05	2,828
Sudan	1,503	0.66	995
Senegal	*860*	0.98	S40
Congo, Dem. Rep.	474	0.78	369
Chad	464	0.90	418
Burkina Faso	299	0.86	257
Zimbabwe	263	0.53	140
Mali	261	0.82	215
Mozambique	226	0.49	111
Uganda	206	0.70	144
Tanzania	117	0.64	75
Egypt	62	3.21	199
Morocco	21	2.14	45
Others	2,305	0.80	1,843
Asia	**14,224**	**1.67**	**23,748**
India	7,411	0.90	6,660
China	4,975	2.92	14,515
Indonesia	661	1.49	988
Myanmar	577	1.21	699
Vietnam	244	1.47	359
Pakistan	93	1.05	98
Thailand	85	1.54	131
Syria	28	2.61	73
Turkey	28	2.61	73
Others	122	1.25	152
Latin America & the Caribbean	**564**	**1.91**	**1,076**
Argentina	231	2.42	559
Brazil	100	1.91	191
Mexico	*87*	1.52	132
Paraguay	30	0.83	25
Others	116	1.46	169
Developed countries	**715**	**2.74**	**1,959**
USA	554	3.02	1,671
South Africa	104	1.58	164
Australia	21	1.95	41
Japan	10	2.40	24
Bulgaria	10	0.80	8
Israel	4	7.00	28
Greece	0.7	2.86	2
Others	11	1.91	21
Total	**25,143**	**1.39**	**35,030**

a. FAO statistics averaged over three years (2000 to 2002).

Source: FAO (2002)

Table 9. Pod yield (t ha^{-1}) of groundnut variety ICGMS 42 (CG 7) and local varieties in on-station trials, 1983/84 to 1991/92, Malawi.

Sets	CG 7	Check	Number of trials
CG 7 vs. local variety Chalimbana	3.35	2.48	14
CG 7 vs. local variety Mawanga	2.39	2.16	10
CG 7 vs. local variety Chitembana	1.96	1.64	5
CG 7 vs. local variety Mani Pintar	2.61	2.25	6

Source: ICRISAT Plant Material Description no 51, 1994.

behavior between male and female farmers suggested that women farmers are just as likely to adopt the new varieties as male farmers.

The study used two criteria to assess patterns of adoption - while the first considered whether a farmer continued growing a test variety after the trials had ended, the second intended to capture the intensity or extent of adoption and measure the area planted to the new variety after the trials had ended. Eighty percent of the fanners continued growing CG 7 after the trial had ended, with the average area increasing from 0.02-0.07 ha per farmer.

The study showed that informal farmer-to-farmer diffusion led to the dissemination of seeds of new groundnut varieties. This occuned with a considerable lag involving small quantities of seed, and was limited to farmers within close social networks. Because of its low multiplication factor and high seeding rate, large seed stocks are required to enable faster dissemination of preferred varieties of groundnut.

The survey also collected data on farmers' perceptions of the two varieties and the check for a range of plant traits. Median ranking of farmers' overall performance indicated drat CG 7 was the most prefened variety followed by ICGV-SM 90704 (Table 10). In terms of ranking of traits, CG 7 was highly prefened because of its high yield, good taste, reduced cooking time and drought tolerance.

CG 7 is also grown by farmers in Zambia and Uganda. An adoption study to assess its acceptance by fanners in these countries may provide additional insights about the potential of this variety.

Variety ICGV 87157, ICG (FDRS) 4

ICGV 87157 (Fig. 12) was bred at ICRISAT-Patancheru in 1981, introduced to the ICRISAT-Bamako program and released to farmers in Mali in 2001 for its high yield and resistance to multiple diseases and pests. It is becoming popular among farmers in Kolakani region of Mali because of its high pod yield, resistance to foliar diseases, large seed size and taste. It is being used extensively as a parent in hybridization by many national programs (Farid Waliyar, personal communication 2003).

The variety originated from a single plant selection made in an F_3 population of a cross between a Spanish variety, Argentine, and a rust- and late leaf spot-resistant parent, PI 259747. The initial cross was made in 1976. The single plant progeny was further advanced following bulk selection in the disease nursery. It is adapted to the low-input rainfed areas of Mali where rust and late leaf spot are major problems for growing the crop.

This variety was tested between 1983 and 1985 seasons for pod yield in the All India Coordinated Research Project on Oilseeds (AICORPO) trials. It consistently outyielded the popular Indian variety JL 24 by 23.5%. Outside India, it outyielded local varieties in Swaziland, Malawi, Myanmar and the Philippines (Table 11), and showed stable performance in international trials conducted at seven locations (ICRISAT Plant Material Description no. 29, 1991). Data on on-tarm trials and adoption ol this variety is not available.

The variety is resistant to rust, leaf spot, bud necrosis, stem and pod rots and insect pests (groundnut leal miner and leafhopper).

It has better recovery ol pod yield and total biomass from mid-season drought compared to the mean values of 121 erect bunch varieties tested in a line-source sprinkler screening technique at ICRISAT-Patancheru. It matures in about 110 days in the rainy season in India, and has a shelling turnover of 64%. The shells contain an average of 48% oil and 25% protein (ICRISAT Plant Material Description no. 29, 1991). The variety has shown potential for spillover across countries and the region. A detailed study on actual spillover and adoption would be useful to draw important lessons.

Table 10. Median ranking of improved groundnut varieties and the local check in Malawi.[a]

Trait	CG 7	ICGV-SM 90704	Chalimbana (local check)
Good taste	1	3	4
Cooks fast	1	3	4
Large seed size	2	3	1
Easily sold	2	3	1
Early maturing	2	2	4
High yielding	1	3	4
Tolerant to insect pests	2	3	2
Disease resistant	2	2	4
Drought resistant	1	2	4
Overall ranking	1	3	4

a. Ranking is based on a 1-4 scale, where 1 = best and 4 = poorest, based on perceptions of 37 farmers.

Source: Freeman et al. 2001.

Table 11. Pod yield (t ha^{-1}) of groundnut variety ICGV 87157 and local varieties in various countries.

Country	ICGV 87157	Local variety	Improvement over the local variety (%)
India[a]	2.10	1.70 (JL 24)[c]	23.5
Swaziland	2.40	1.60 (Natal Common)	50.0
Malawi	1.20	0.97 (Malimba)	23.7
Mvanmar[b]	1.08	0.61 (Japanese Small)	77.0
Philippines	2.70	I.45(BPI Pn-9)	86.2

a Based on data from seven locations.
b. Based on data from two locations
C. Names in parentheses refer to local varieties.

Source: ICRISAT Plant Material Description no. 29. 1991.

ELISA Test to estimate Aflatoxin in food and feeds

Agricultural products are often contaminated with fungi that can produce toxic metabolites called mycotoxins. Among these, aflatoxins have assumed economic importance because of their influence on the health of human beings and livestock and on the marketability of agricultural products. Aflatoxin is a Group 1 carcinogen proven to cause liver cancer and suppress the immune system. It is produced by *Aspergillus flavus* which mainly occurs before the crop is harvested in the semi-arid tropics, particularly under late-season drought stress conditions. In wet and humid areas, infection predominantly occurs during postharvest.

Most developing countries have limited or no facilities to monitor these toxins. The facilities available are based on physicochemical methods such as thin layer chromatography (TLG), high performance liquid chromatography (HPLC) and ELISA. ELISA is by far the most preferred technique, but the commercial kits available are expensive.

ICRISAT and its partners have developed a low-cost ELISA test to detect aflatoxin contamination in food products, particularly in groundnuts. High-quality antibodies were produced for aflatoxins and methodologies were developed to use these to detect and estimate aflatoxin in different agricultural commodities. The results were comparable with that of HPLC. Comparing costs of the three procedures revealed ELISA to be the least expensive ELISA is a simple and cost-effective procedure that permits analysis of up to 200 samples per day. Constant monitoring of food and feeds will improve human and livestock health and enhance the export potential for improving the income of poor farmers in developing countries. The technology is being adopted in Nigeria, Mali, Burkina Faso, Senegal and Niger, for which ICRISAT provided required laboratory materials (like antibodies) and training. The technology has a high potential for wider adoption, including spillover outside the SAT to the developed world.

Thanks to the low cost of the technology (US$2 per sample compared to US$9 for other commercial kits), some private entrepreneurs in India and Africa have approached ICRISAT to discuss opportunities tor its commercialization. Janaki Feeds, the second largest manufacturer of chicken and cattle feeds in Andhra Pradesh (India), has adopted the ELISA test, saving more than US$20,000 annually. The participation of local businesses in the commercialization of ELISA may help in scaling-up this successful tec hnology. There are ongoing efforts to identify local and international entrepreneurs to market this detection method, and to secure funding support to develop appropriate kits which may bring down costs further (Farid Waliyar, personal communication 2003). More information about aflatoxins and the ELISA test is available at http://www.aflatoxin.info.

Disease screening techniques

ICRISAT-Patancheru developed screening techniques to evaluate groundnut lines for resistance to rust and late leaf spot. These mediodologies have been adopted by scientists in Burkina Faso, Mali and Malawi (Appendix 3b).

4.3. Spillovers from Africa to Asia

There has been no direct spillover of any groundnut variety developed in Africa and released in Asian countries. However, some germpiasm accessions introduced from Africa to ICRISAT-Patancheru have been identified as sources of resistance to aflatoxin and late leaf spot. Singh et al. (1997) reported good sources of resistance to aflatoxin in germpiasm from Nigeria, Uganda, Senegal, Argentina, China, India and USA (Appendix 3c). Several accessions in ICRISAT's Gene Bank (ICGs 1326, 3263, 3700, 4749, 4888, 7633 and 9407) possess resistance to both seed infection and seed colonization, and are of special significance in breeding programs that combine pre- and postharvest resistance to aflatoxin.

Late leaf spot is a very important disease in Africa and Asia. Out of 13,000 accessions screened as sources of resistance for late leaf spot, only 19 have been used in the resistance breeding program at Patancheru. Only one of them (ICG 4747, originating from Argentina) has resulted in the release of resistant varieties such as ICG (FDRS 4) and ICGV 86590 from ICRISAT-Patancheru, and Gimar 1 from the Indian national program. The other commonly used resistance source is ICG 2716 from Uganda (Singh et al. 1997) (Appendix 3c).

4.4. Spillovers within Africa

Six varieties bred at ICRISAT-Lilongwe (Malawi) have been released in other countries of ESA. Their adoption rate is yet to be assessed. ICGV-SM 90704 released in Uganda (as Serenut 2 in 1999) is an instance of a spillover from Malawi.

Variety ICGV-SM 90704

ICGV-SM 90704 (Fig. 13) was developed by ICRISAT-Lilongwe and its partners from a cross between RG 1 (rosette-resistant variety) and Mani Pintar (susceptible variety) following pedigree selection in Malawi. The variety is released in Malawi (2(X)0) as Nisinjiro and in Uganda (1999) as Serenut 2R. The SADC/ICR1SAT groundnut project made the cross at Lilongwe Agricultural Research Station in 1983. The variety was selected for its high yield in areas infected with rosette disease. Under high rosette disease pressure, ICGV-SM 90704 produced pod yield several times higher than CG 7 and the local variety during 1994/95 and 1995/96 seasons (Table 12). It is highly resistant to rosette (only 2%) as compared to the local variety Chalimbana and another improved variety CG 7 (Table 12) (AJ Chiyembekeza, personal communication 2003).

ICGV-SM 90704 along with Chalimbana and CG 7 was evaluated across 28 sites in Malawi from 1992/93 to 1996/97 The variety produced the highest seed yield (1.04 t ha^{-1}) followed by CG 7 (0.84 t ha^{-1}) and Chalimbana (0.52 t ha^{-1}). This variety was tested in 64 on-farm trials throughout Malawi from 1994/95 to 1996/97. It produced higher pod yield (19-110%) than Chalimbana.

Freeman et al. (2001) studied the adoption of ICGV-SM 90704 along with CG 7 in Malawi. Some of the results have been described earlier under variety CG 7. Here we present the relevant adoption results for this variety.

The study suggested different patterns of adoption among varieties. CG 7 demonstrated the highest level of acceptance and potential for adoption across all regions followed by ICGV-SM 90704. Sixty-three percent of the farmers continued growing this variety after the trials had ended, with average area increasing from 0.01 -0.02 ha per farmer.

Data was collected on farmers' perceptions of the two vanities and the check, covering a range of plant traits. Median ranking of farmers' overall performance indicated that this variety was superior to the local variety but inferior to CG 7 (Table 10). The variety was preferred because of its earliness and disease and drought resistance. Differences in adoption pattern could have been a reflection of the farmers' familiarity with CG 7, having been exposed to it for a much longer period through activities by other development agencies in Malawi. Farmers might also have underestimated the performance of ICGV-SM 90704 because it only demonstrated superior performance under high disease pressure (rosette). In years of rosette outbreaks (1994/95 and 1999/2000), the variety consistently outyielded CG 7. There is a possibility of the spread of this variety in the region. It has already been released in Uganda for general cultivation.

Screening technique

ICRISAT scientists in Malawi developed an infector row field screening technique for resistance to groundnut rosette. National scientists in Nigeria and

Table 12. Pod yield, shelling percentage (Sh) and rosette incidence (RI) in selected groundnut varieties under high rosette disease pressure, 1994/95 and 1995/96 seasons, Lilongwe, Malawi.

	1994/95			1995/96		
Genotype	Pod yield (t ha^{-1})	Sh	RI (%)	Pod yield (t ha^{-1})	Sh (%)	RI (%)
ICGV-SM 90704	2.04	67	1.6	1.10	67	2.0
RG 1	1.24		2.0	-	-	-
Chalimbana	0.10	48	95.0	0.00	-	67.0
CG 7	0.03	59	94.4	0.11	56	71.0
RMP 12	-	-	-	0.49	76	13.1

Source: AJ Chiyembekeza. personal communication 2003.

Burkina Faso have adopted it. The methodology has improved the process of identifying resistant varieties with a high degree of accuracy. The technique is mainly useful in research programs to develop resistant varieties or to study the genetics of a trait.

4.5. Spillovers within Asia

Thirteen ICRISAT-Patancheru-bred varieties have been released in various Asian countries (excluding the 11 released in India). ICGV 86015 was released in three countries. Here w_e present its performance and factors that facilitated its spread as an example of spillovers within Asia.

Variety ICGV 86015

ICGV 86015 (Fig. 14) was developed at ICRISAT-Patancheru in 1986. It was selected following the bulk-pedigree method from a cross between ICGS 44 and TG 2E made in the 1981/82 postrainv season. ICGS 44 (ICGV 87128) is an ICRISAT-bred, high-yielding, medium-duration variety released in 1988 for postrainy season cultivation in India. TG 2E is an early-maturing breeding line developed at the Bhabha Atomic Research Center (BARC) in Mumbai, India, from a cross involving Dwarf Mutant and TG 3. The seeds of this variety were supplied by ICRISAT to collaborating partners in Pakistan and Nepal in 1987 and Vietnam in 1988.

ICGV 86015 is an early-maturing, high-yielding and widely adapted breeding line. It was released in Pakistan as BARD 92 (1994), in Vietnam as Hung Loc (1992) and in Nepal as Jayanti (1996). While in Vietnam it was found to be most suitable for inter-cropping with cassava and maize, in Pakistan it was found suitable for double cropping with wheat. This demonstrates how the varieties can be adapted to fit specific niches within a given production system.

ICGV 86015 takes 100-105 days to mature in the rainy season at ICRISAT-Patancheru. In Pakistan, it matures in 120-130 days, ie, 50-60 days less than the local variety Banki. In Vietnam, like the local varieties (Giay and Ly), ICGV 86015 matures in 92-98 days in the rainy or summer-autumn season and in 88-93 days in the winter-spring season.

In Vietnam, it produced on an average 2.0-2.8 t pods ha^{-1}, outyielding the local variety Gray bv 17-25%. In Pakistan, it gave on an average 18% more pod yield than the local variety Banki (1.36 t ha^{-1}). In yield trials at ICRISAT-Patancheru, ICGV 86015 produced on an average 2.88 t pods ha^{-1} (21% more than the popular variety JL 24). In on-farm trials in Nepal, it produced an average pod yield of 2.67 t ha^{-1}, outyielding the local variety (B 4) by 57% in 51 sets of trials (ICRISAT Plant Material Description no. 50, 1994). This remarkable performance has contributed to the spread of the variety in the three countries.

Despite a high potential for spillover in Asia, not much is known about this variety and its performance in farmer's fields. An investigation into this may highlight potentials, constraints and the extent of spillover.

4.6. Summary and conclusions

This chapter has summarized ICRISAT's efforts at developing groundnut technologies suitable for diverse SAT ecoregions in Africa and Asia. Currently groundnuts are important crops mainly in WCA (Nigeria, Sudan, Senegal, Chad, Burkina Faso and Mali), ESA (Mozambique, Uganda, Tanzania and South Africa) and Asia (India, China, Indonesia, Myanma,-, Pakistan and Vietnam). Groundnuts are also widely *grown in* Latin America (Argentina, Brazil and Mexico) and the developed world (eg, USA). Table 13 sumrrarizes the technologies originating from a given region and released in another ecoregion. About 11 varieties developed at ICRISAT-Patancheru have been released in India, which has the largest area under the crop in

Table 13. Summary of inter- and intra-regional technology transfer in groundnut.

Varieties (No.)	developed by	Country of release
11	ICRISAT-Patancheru with partners	India
13	ICRISAT-Patancheru with partners	8 other Asian countries (Bangladesh, Indonesia South Korea, Myanmar, Nepal, Pakistan, Vietnam and Sri Lanka)
14	ICRISAT-Patancheru with partners	11 African countries (Uganda, Malawi, Zambia, Botswana, Zimbabwe, Mauritius, Burkina Faso, Congo, Ghana, Guinea-Conakry and Mali)
3	ICRISAT-Patancheru with partners	Cyprus
6	ICRISAT-Malawi with African NARS	5 SEA countries (Mauritius, Uganda, Zambia, Zimbabwe and Nigeria)

Asia. About 13 varieties have also been released in eight other Asian countries, showing a sizable spillover within Asia. About the same number of releases have occurred in 11 African countries (mainly in ESA) based on material supplied from ICRISAT-Patancheru. In addition, a few varieties (about six so far) developed by ICRISAT-Malawi along with the regional NARS, have been released in five ESA countries. The work in WCA on this crop is yet to yield important outcomes with potential spillover benefits within the region. Except for a handful of varieties and germplasm accessions originating from ICRISAT-Patancheru, no significant adoption and spillover of the groundnut technology developed in Asia or Africa has taken place in WCA (Fig. 15). This indicates that breeding and crop improvement programs need to take into account the different market conditions, farmer and consumer preferences and the biotic and abiotic constraints prevalent in the regions. These constraints that limit the potential for spillover and specific socioeconomic factors that influence groundnut production in the region need to be investigated.

However, a number of resistance sources for *Aspergilus flavus,* early and late leaf spot and rust have been identified from the 15,305 accessions held in trust at the ICRISAT Gene Bank. These are being widely used in research programs worldwide. About 30% of the collections are from Africa, 25% from India and about 38% from the rest of the world. As in the case of other crops, the global germplasm transfer mediated through ICRISAT represents one of the most important spillovers. A related product which has attracted some attention is the low-cost aflatoxin detection kit (based on the ELISA method) developed at ICRISAT-Patancheru. It is already finding use in India (including the private sector), Nigeria, Mali, Burkina Faso and Niger. Quality control and timely detection of aflatoxins is expected to enhance exports and reduce health risks to consumers.

Figure 11. CG 7: Widely adapted and high-yielding variety developed at ICRISAT-Patancheru and being adopted in several countries of ESA.

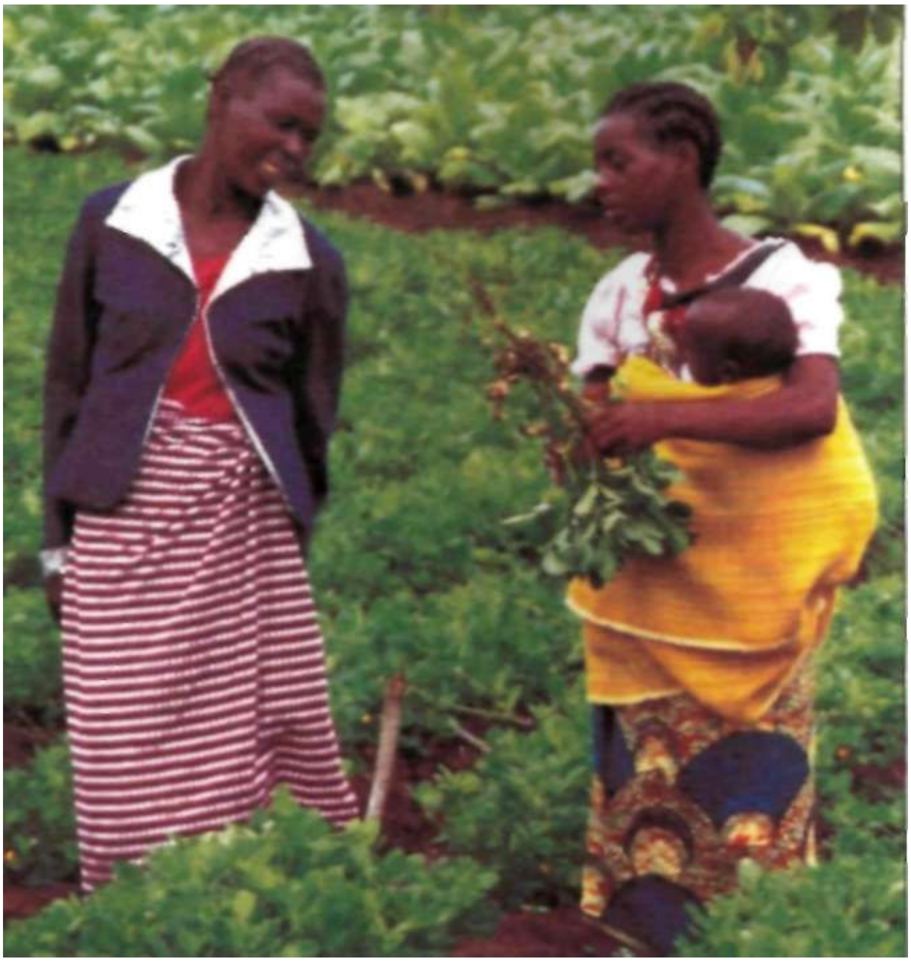

Figure 12. ICGV 87157: A farmer-preferred variety developed at ICRISAT-Patancheru and adopted in Mali.

Figure 13. ICGV-SM 90704: Developed by ICRISAT-Lilongwe and preferred for its high yield even under high rosette disease pressure in Malawi and Uganda.

Figure 14. ICGV 86015: Developed at ICRISAT-Patancheru and most suitable for intercropping with cassava and maize in Southeast Asia.

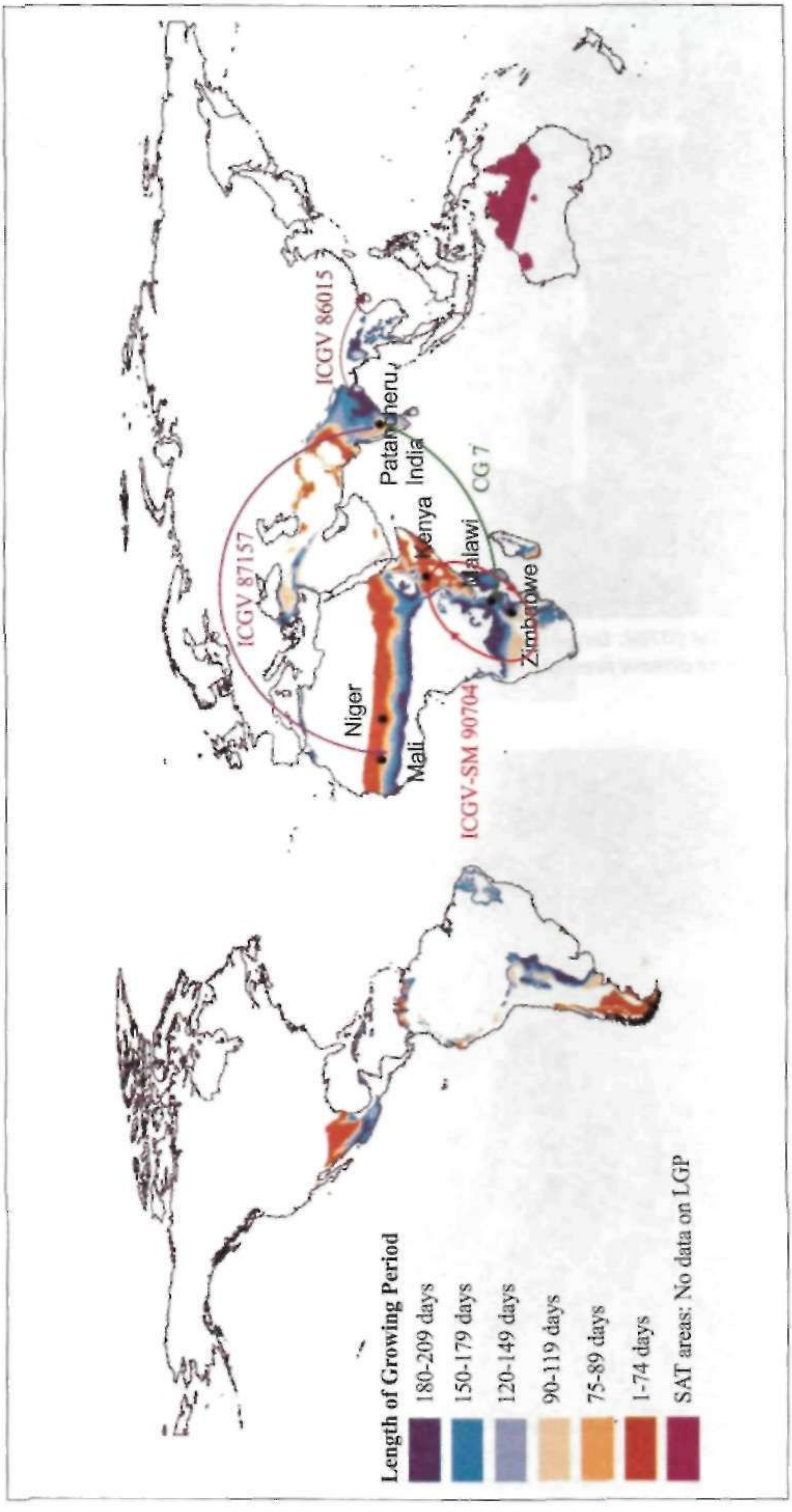

Figure 15. The global flow of selected groundnut technologies developed by ICRISAT and its partners.

5. Spillovers from Research Investments in Pigeonpea

5.1. Technologies developed

Pigeonpea is one of the major pulse crops of the tropics and subtropics. Although it is cultivated on about 4 million ha in Asia, Africa and South America, 84% of the total pigeonpea area is in India (Table 14). The area sown to this crop has been increasing in countries like Myanmar, Malawi, Uganda and Tanzania. Endowed with several important characteristics, pigeonpea finds a valuable place in the farming systems of small farmers in developing countries. It is used in more diverse ways than other grain legumes. Besides being mainly used as *dhal* (dry, dehulled, split seed used for cooking) in India, its tender green seeds are used as a vegetable; crushed dry seeds as animal feed; green leaves as fodder and stem as fuel wood and to make huts, baskets, etc. This high-protein grain (26%) is an ideal supplement to traditional cereal- or tuber-based diets. The woody stems provide fuel and fencing material and the plants grown on slopes reduce soil erosion. The plant fixes nitrogen, providing fertility benefits equivalent to about 40 kg of nitrogenous fertilizer per ha.

ICRISAT's research in pigeonpea, initially conducted at ICRISAT-Patanchem and later extended to Eastern Africa, focused on the following areas:

- Improving traditional cultivation systems by alleviating production constraints in general and controlling wilt in particular
- Reconstructing the plant to exploit the potential of the cropping systems
- Exploiting hybrid vigor.

Crop improvement teams based in Patancheru and later (from 1992) in Nairobi targeted specific production systems in Asia and East Africa to alleviate constraints such as low yield potential, wilt, sterility mosaic, pod borer and drought. Over the past 25 years, ICRISAT's R&D activities carried out with an array of partners, have played a major role in stimulating increases in crop area in India (ICRISAT 1998a). To date, 26 pigeonpea varieties have been developed by ICRISAT in collaboration with NARS (Appendix 4a). The other significant achievements of ICRISAT-led partnerships have been:

- Unique contribution to the conservation and characterization of the invaluable but hitherto neglected crop germplasm pool, including studies revising the taxonomy and origin of the crop.
- Applying science to take advantage of the germplasm collection in order to alleviate major biotic

Table 14. Area, yield and production of major pigeonpea-producing countries.[a]

Countries	Area (000 ha)	Yield (t ha^{-1})	Production ('000 t)
Developing countries	**4,086.0**	**0.81**	**3,086.0**
Africa	**425.0**	**0.62**	**263.0**
Malawi	123.0	0.64	79.0
Uganda	78.0	1.00	78.0
Tanzania	66.0	0.71	47.0
Kenya	155.7	0.37	57.0
Burundi	2.0	0.90	1.8
Asia	**3,629.1**	**0.77**	**2,796.1**
India	3.301.0	0.78	2.583.7
Myanmar	300.0	0.63	188.7
Nepal	23.6	0.91	21.4
Bangladesh	4.4	0.52	2.3
Latin America & the Caribbean	**31.9**	**0.85**	**27.1**
Dominican Republic	14.7	0.98	14.4
Haiti	6.8	0.40	2.7
Panama	4.5	0.04	0.2
Venezuela	2.4	0.83	2.0
Jamaica	1.1	1.18	1.3
Trinidad & Tobago	1.0	2.80	2.8
Puerto Rico	0.7	1.57	1.1
Others	0.7	3.71	2.6
Total	**4,086.0**	**0.81**	**3,086.0**

a. FAO statistics averaged over three years (2000 to 2002).
Sourer: FAO (2002)

Table 15. Pigeonpea genotypes with good agronomic background and resistance to diseases and abiotic stresses identified at ICRISAT.

Pigeonpea genotype	Resistance
ICPL 90002, ICPL 90011	Sterility mosaic disease
ICPL 89020, ICPL 88003	Fusarium wilt and sterility mosaic disease
ICPL 84023	Phytophthora blight and waterlogging
ICPL 88039, ICPL 84023	Drought

Source: Singh et al. 1996.

and abiotic constraints. Appendix 4b provides a list of sources of resistance for different stresses in pigeonpea identified by ICRISAT. Breeders applied this information to incorporate these sources of resistance into breeding populations. Some genotypes with good agronomic background and resistances to stresses widely used in breeding populations are given in Table 15. Some of the pigeonpea varieties developed by NARS from ICRISAT's resistance source material are listed in Table 16.

- Several varieties and hybrids developed by ICRISAT are being used by farmers in India and other countries (Appendix 4a). Adoption rates have been satisfactory because of improved yields, drought escape through earlier maturity and incorporation of resistance to diseases. The most significant achievement has been the innovative reconstruction of the plant into short-duration, short-statured and high-yielding type varieties. Incorporating these varieties into existing cereal-dominated cropping systems stimulated large productivity gains and triggered a major geographic extension of the crop.
- A major scientific breakthrough was the creation of the world's first food legume hybrid to go into commercial production, demonstrating a 25% increase in grain yield, additional stem and leaf biomass for fuel and forage and improved drought, disease and water logging tolerance (Saxena et al. 1996). This led to the release of commercial hybrids in India. Their adoption is however restricted due to seed production, limitations posed by the genetic nature of male sterility. A consortium of interested institutions brought together by the initial hybrid success has now turned its energies towards developing a cytoplasmic male sterility (CMS) system. A good beginning has already been made both at ICRISAT and some ICAR centers in developing CMS-based hybrid pigeonpea technologies. This is likely to bring high benefits to smallholder producers in the drylands.

Ecofriendly ways to control *Helicoverpa* pod borer with the use of natural and biological control alternatives such as neem and the NPV virus have proved successful through partnerships with NGOs. Partnerships across continents to solve location-specific constraints are proving successful. For example, with support from the Asian Development Bank (ADB), ICRISAT has been able to work with the Sri Lankan NARS to design and manufacture a small, portable, medium-volume dehulling mill. A high quality video was locally produced to spread awareness of this project. Similarly, ICRISAT's efforts in Africa were strengthened in 1992, where *the* African Development Bank decided to launch a pigeonpea improvement project for ESA.

Over the last 30 years, ICRISAT's partnership-based pigeonpea research has continued to generate impacts in farmers' fields, in national production statistics and contributed to the improvement of the welfare of the smallholder farmers - particularly that of women. Pigeonpea has turned from orphan to pacesetter crop through fruitful scientific creativity and productive partnerships. In recognition of this achievement, ICRISAT won the CGIAR's 1998 King Baudouin Award.

In the following section we present a few case studies to highlight the spillover impacts within Asia and Africa, Asia to Africa and other regions.

Table 16. Some pigeonpea varieties developed by NARS from ICRISAT material.

Variety	Feature	Locations where released
Birsa Arhar 1	Wilt resistant	Bihar
Bageshwari	Sterility mosaic resistant	Nepal
Rampur Rhar 1	SM tolerant	Nepal
ICPL 295	Will resistant	Philippines
ICPL 87091	Vegetable pigeonpea	Gujarat, Malawi, Latin America, Kenya, China

Source: Singh et al 1996.

5.2. Spillovers within Asia

Diversification of cropping systems with Extra-short-duration pigeonpeas

Pigeonpea is usually grown as an intercrop with cereals such as sorghum and pearl millet. For a long time, yields of traditional pigeonpeas were very low for a crop that spent 6-9 months in the field. The low productivity of the mixed system was insufficient to induce farmers to intensify their crop management much beyond the subsistence level. ICRISAT in collaboration with partners from ACIAR, University of Queensland and ICAR, spotted opportunities for intensifying pigeonpea cultivation through concerted efforts to understand pigeonpea physiology and crop management (Chauhan et al. 1987). They created the opportunity to breed more productive and adaptable, short-duration (4 months) bush-type plants which contrast sharply with traditional, arboreal, asynchro-nous-flowering, photoperiod-sensitive, late-maturing (6-9 months) varieties. Breeding for good agronomic tvpe was carried out at various hot-spot locations under various cropping systems and for resistance to diseases, pests and other stresses in close collaboration with NARS partners. Several short-duration varieties with desirable characteristics (Table 17) were identified, requiring substantially different crop management. They were not very suited to low density traditional intercropping. Monocropping with a fivefold increase in sowing density compared to traditional sowing density was required. The traditional configuration of diversity in space (intercropping) was now supplemented by a varietal option that exploited system diversity in time (multiple cropping).

In collaboration with ICAR, ICRISAT's Legumes On-farm Testing and Evaluation Nursery (LEGOFTEN) staff conducted a series of trials across India to study the potential of short-duration pigeonpea (SDP). The improved variety cropping system package demonstrated a mean yield increase of 58% from about 67 trials during 1989-91. Farmers were quick to adopt these materials. ICPL 87, for example, became popular in the drier cotton and sugarcane belts of Maharashtra and Kamataka. A detailed impact study (Banolan and Parthasarathy 1998) found that the variety/management package resulted in an average 93% yield increase over the system it had replaced.

These varieties were adopted mainly because they facilitated double cropping, enabling farmers to sow their stable postrainy-season sorghum, chickpea and wheat crops. Farmers saw a 30% increase in net farm income. They also benefited in terms of soil fertility and erosion control from adding pigeonpea to the rotations (Bantilan and Parthasarathy 1999). The adoption of short-duration pigeonpea was akin to the introduction of a new crop into regions with traditionally low levels of pigeonpea cultivation, thereby representing a real spillover of the technology. Survey results indicated that the area under pigeonpea increased substantially in western Maharashtra during 1987-95. Introducing SDP and enabling double cropping was an important change that enhanced productivity in the dryland regions of Central India.

Short-duration pigeonpea varieties have also spilled over to the northwestern plains of India, triggering a new pigeonpea-wheat cropping system (Singh et al. 1996). Productivity growth in intensive rice-wheat systems in South Asia's Indo-Gangetic Plains is already leveling off, and even declining in some areas. A solution to this could be to diversify the system by utilizing extra-short-duration legumes, which can break pest/disease cycles and improve soil fertility, Incorporating legumes into the rotation could help make the cereal-dominated system (introduced during the Green Revolution) more sustainable.

ICRISAT breeders tested shorter-duration types maturing in three months. Among the varieties tested, ICRISAT pigeonpea variety ICPL 88039 (Fig. 16) was

Table 17. Characteristics of traditional vs. short-duration pigeonpea varieties.

Characteristic	Traditional varieties	Short-duration varieties
Adaptation	0-30°N and S	0-40°N and S
Duration	6-10 months	3-4 months
Plant type	Tall, treelike	Compact, short
Sowing time	Fixed	Flexible
Multiple cropping	Not possible	Possible
Mechanization	Not leasiblc	Feasible
Drought	Susceptible	Escape
Frost	Susceptible	Escape
Major diseases	Susceptible	Escape
Podfly	Susceptible	Escape

Source. ICRISAT 1998a.

found to be the best. Under the auspicies of the CGIAR systemwide Rice-Wheat Consortium funded by the ADB through the project on "Legume-based technologies for rice and wheat production systems in South and Southeast Asia", ICRISAT and NARS have found that this extra-short-duration pigeonpea (ESDP) can be harvested well in advance of the optimal wheat planting date. Following the recommendations of a workshop on ESDP (Singh et al. 1996), ICRISAT coordinated joint on-farm research and development efforts in the northwestern Indo-Gangetic Plain during 1996-00. Among the varieties tested, ICPL 88039 matured two to four weeks earlier than SDP varieties, yet produced up to 16% higher yields (Table 18). The yield from the following wheat crop was 0.75-1 t ha^{-1} more after ESDP genotypes than after SD varieties or rice (Table 19) (Dahiya et al. 2001). Fanners preferred ICPL 88039 because of its greater yield and early maturity, enabling the timely sowing of wheat. The ESDP also helped reduce *Phalaris minor,* a noxious weed in the traditional rice-wheat system. ICPL 88039 yielded between 1 -2 t ha^{-1}. Besides giving high yield, the variety is known to help improve soil by adding N and carbon and releasing P for use by the subsequent wheat crop.

In the rice-wheat fallows, farmers' perceptions about the new pigeonpea variety have been quite favorable. Its adoption is estimated to be over 10,000 ha and still increasing (KB Saxena, personal communication 2003). ICPL 88039 has been identified for release in the Western Indo-Gangetic Plains. Therefore, it is an ideal example for assessing spillover impacts of research investments in pigeonpea. The efficiency and sustainability gains from the adoption of ESDP in cereal-based rice-wheat cropping systems need to be studied and documented.

Table 18. Mean grain yield (t ha^{-1}) of ICPL 88039 grown during 1996-00 at different on-farm locations in the Indo-Gangetic Plain.

On-farm test location	Manak (165 days to maturity)	ICPL 88039 (145 days to maturity)
Sonepat, Hnryana	1.48	1.28
Ghaziabad, Uttar Pradesh	1.08	1.54
Ludhiana, Punjab	1.66	1.69

Source: Dahiya et al. 2001.

Variety ICPL 87 in Sri Lanka

The success story of SDPs has spilled over to Sri Lanka, where legumes are an integral part of rainfed upland agriculture, with low yields and production that does not meet demand. A huge amount in foreign exchange (US$30 million) is spent annually on importing lentil to meet national requirements (Karunatilake et al. 1996). Though several attempts have been made to intensify pigeonpea production in the past 40 years, each failed to take off either due to insect pests and difficulties in managing them at the field level or because of lack of suitable processing techniques.

Since 1990, an alternative production system was developed to exploit the bimodal rainfall pattern using SDP genotypes (ICPL 87 and ICPL 2). This was done with financial assistance from the ADB and technical assistance from ICRISAT. Field trials were conducted to demonstrate the pigeonpea production package developed by the Department of Agriculture. From a series of on-farm tests and demonstrations, the yield of the ICRISAT-developed ICPL 87 (Fig. 17) averaged 1.4 t ha^{-1} (from 7 demonstrations), with the highest yield of 2.6 t ha^{-1} recorded in one village (Karunatilake et al. 1996). The on-farm demonstration with ICPL *S 7 and ICPL 2 showed a profit of Rs 6, 160 per ha after* accounting for pesticides and labor costs. In spite of their susceptibility to insects, when evaluated under non-sprayed conditions, these varieties confirmed their superiority by yielding 1.2-2.2 t ha^{-1}.

ICPL 87 is a short-statured (80-90 cm), semi-spreading type that takes about 110-130 days to

Table 19. Effect of rice (cultivar Tarawari Basmati), short-duration pigeonpea (SDP) cultivar Manak and extra-short-duration pigeonpea (ESDP) genotype ICPL 88039 on the yield of the following wheat crop, 1997-99, Sonepat, Haryana, India.

	Wheat yield (t ha^{-1})			
Cropping systems	1997[a]	1998[b]	1999[b]	Mean
Rice-wheat		3.58 + 0.074	3.69 + 0.078	3.64
SDP-wheat	3.93 ± 0.076	3.67 ± 0.066	3.76 + 0.062	3.79
ESDP-wheat	4.68 ± 0.066	4.46 + 0,061	4.39±0.068	4.51

a.Wheat cultivar HD 2329 in 1997.
b. Wheat cultivar PBW 343 during 1998/99.
c. Not tested

Source: Dahiya et al. 2001.

mature in Sri Lanka. It is now recommended for sole cropping in rainfed areas in dry and intermediate zones. Packages of agronomic practices have been recommended by the Sri Lanka Department of Agriculture (Saxena 1999). The variety has also been recommended for ratoon cropping to exploit the bimodal rainfall pattern and intercropping in coconut plantations. Research also showed that pigeonpea can he successfully grown on about 91,000 ha of uncultivated land where no other rainfed crop can be grown. Using varieties such as ICPL 87, ratoon cropping can also provide additional income in these dry zones.

Promoting pigeonpea in Sri Lanka has also triggered processing devices - for both small-scale processing at the village level and large-scale processing with commercial mills. Though the direct import of processing machines from the Central Food Technological Research Institute (CFTRI), Mysore (India) failed, the visit of an engineer from the Sri Lankan Department of Agriculture to study the processing machines available led to the design of a suitable prototype to locally produce high quality *dhal.* Since the machine was equally suitable for processing other pulses, it was adopted rapidly. After extensive field-testing and modifications to enhance its stability, the technology was transferred to a private company in Sri Lanka.

Pigeonpea R&D activities in Sri Lanka now cover vital components such as production, processing, marketing, consumption and policy framework. The adoption and impact of a short-duration variety such as ICPL 87 should be monitored and documented to delineate the contribution of this international spillover.

Pigeonpea spillover to the hilly areas of China

In 1998, the Government of China requested ICRISAT for pigeonpea lines adaptable to the hilly rainfed areas of Yunnan and Guangxi Provinces. Among the lines evaluated by Chinese scientists, ICPL 87091, ICPL 87119 and ICP 7035 were found to have good adaptability. Subsequently, ICRISAT was asked to supply large quantities of seeds of these varieties for large-scale on-farm evaluations. Local scientists found that these varieties were able to cover the hilly lands quickly and helped reduce soil erosion. The special traits of these lines, which found a new home in China's hilly areas, are given in Table 20.

The Chinese Government has launched a special program to multiply seeds of these varieties (KB Saxena, personal communication 2003). Pigeonpea has become a favorite crop in Yunnan and Guangxi Provinces where it is mainly grown to prevent soil erosion and its fodder is used by grazing cattle, goats and to feed rabbits. Farmers have also started using green pigeonpea as vegetable. The crop is planted at the onset of the rainy season and remains in the field for 2-3 seasons.

Within a short span of 4 years, an estimated 15,000 ha have come under pigeonpea. The Chinese Government accords pigeonpea high priority as it not only protects soil from erosion and degradation, but also improves soil structure by adding carbon and productivity by improving soil fertility. Local farmers have already recognized the crop's multiple uses as fodder and fuel. In the coming years, the area under pigeonpea is likely to increase manifold. Acknowledging ICRISAT's support, the Chinese Government honored an ICRISAT scientist with a

Table 20. Some Special traits of pigeonpea varieties which have now spilled over to China.

Variety	Original place of adaptation	Special traits
ICPL 87119	Maharashtra, India	Wilt and mosaic resistant, high-yielding line, flowers in 125 days, matures in 170-180 days and yields around 2 t ha^{-1}.
ICPL 87091	Kenya	Excellent short-duration vegetable pigeonpea line, flowers in 65 days, has long pods with large seeds, allows green pod pickings and has seed yield potential of 1.8 t ha^{-1}.
ICP 7035	Fiji	Important source of wilt and sterility mosaic, flowers in NO-150 days, matures in 200-210 days, seeds are sweet, yields *around* 1.5 t ha^{-1} *and* is cultivated for both green *and dry seed* production.

Source: KB Saxena. personal communication 2003.

national award. ICRISAT was also asked to train Chinese scientists in pigeonpea production. A close examination of pigeonpea spillover across China will provide useful insights into the contribution of international research towards food security, sustainability and environmental protection.

5.3. Spillover from Asia to Eastern and Southern Africa

After South Asia, ESA is the next important pigeonpea growing area in the world, accounting for about 7% of the global production. Over the years, ICRISAT has been actively engaged, as a catalyst, helping the African NARS enhance their pigeonpea production systems.

Sub-Saharan Africa has seen a major expansion in maize and cotton in recent decades, stimulated by direct and indirect subsidies such as those on fertilizers. Far-reaching economic restructuring since the mid-1980s has led to disappearing subsidies and increasing fertilizer costs. Farmers required additional cropping options that require less fertilizer and also improve soil fertility. Pigeonpea fitted this situation well. Responding to these forces, pigeonpea production increased rapidly in ESA between 1980 and 1997. It increased by 46% in Kenya, Malawi, Tanzania and Uganda with an annual growth rate of more than 4% (ICRISAT 1998b).

ICRISAT's germplasm exchanges took place mainly with Kenya during the mid-1970s. In 1989, the Institute intensified efforts by launching the Eastern Africa Regional Cereals and Legumes Program (EARCAL). In 1992, the African Development Bank decided to launch a major pigeonpea improvement project lor ESA. Over the years, these partnerships have been instrumental in elevating pigeonpea's profile in Africa. It is now becoming one of ESA's most important legume crop. Policymakers are seeking to increase budgetary and staff allocations to further strengthen pigeonpea research in the region.

Variety ICPL 87091

ICPL 87091 (Fig. 18) is a short-duration pigeonpea line developed at ICRISAT-Patancheru to meet the able pigeonpea needs. It has now found a home in Kenya, where it has shown an estimated yield improvement ot about 200 kg ha^{-1}. The variety has now spread to neighboring Tanzania, Malawi and Uganda, a spillover within Africa through a series of trials run by ICRISAT-Nairobi and the NARS extension services. Farmers have rapidly expanded their pigeonpea areas, using seed harvested from the trials; they have even found buyers in nearby cities. This combination of good field performance, profitability and farmer interest has prompted the national programs to accelerate the release of other pigeonpea varieties such as Kat 60/8 in Kenya and ICP 9145 (Fig. 19) in Malawi. ICRISAT thus acted as a catalyst in stimulating cultivation of improved pigeonpea varieties.

The variety flowers in about 70 days. It consistently outperformed traditional varieties in a range of environments in ESA. Though released only in Kenya, Tanzania exported over 600 t of ICPL 87091 grain in 1997 and Mozambique bought 17 t of seed in a single season for a new, large-scale cultivation in Namgula Province (ICRISAT 1998b).

Another example of spillover within Africa is Kat 60/8, a short-duration variety released in Kenya but which has also spilled over to Uganda. It is now widely grown in Apuch and Lira districts of northern Uganda as a result of several seasons of successful on-farm trials. It is now spreading into the neighboring Gulu district as well even before its official release. A survey of village markets in Gulu showed that nearly one-third of the pigeonpea on sale was Kat 60/8. (Said Silim, personal communication 2003.)

CGIAR centers such as the International Centre for Research in Agroforesty (ICRAF) and the Centra Internacional de Mejoramiento de Ma'iz y del Trigo (CIMMYT) have recently launched several pigeonpea-based research and development programs that link closely with the ICRISAT/NARS pigeonpea improvement project in Africa. For example, ICRAF is using ICRISAT pigeonpea germplasm for testing in agroforestry systems and CIMMYT has been testing the ICRISAT wilt-resistant variety ICP 9145 in its soil fertility network. ICPL 87091 is being used in rotation with maize to control *Striga.*

5.4. Spillover to other regions

During the 1980s, Australia developed several short-duration, high-yielding varieties (such as Hunt, Quantum, Quest) utilizing ICRISAT germplasm and varieties. Fiji also developed a medium-duration, wilt- and sterility mosaic-resistant, large-seeded variety (Kamica) using ICRISAT germplasm - ICP 7035.

Recently, pigeonpea has also shown the potential to fill forage gaps in the USA. Research conducted at USDA, Oklahama, revealed that pigeonpea varieties developed at ICRISAT can produce nutritive fodder in summer. Pigeonpea yields and nutritive values during summer equaled those of other forage crops reported for the region. Farmers can benefit from the resulting reduced cost of livestock production and improved soil fertility. Research is underway to identify more nutritive and high-yielding varieties well adapted to the Great Southern Plains of USA (KB Saxena, personal communication 2003).

5.5. Spillover of wilt-resistant varieties

Wilt caused by *Fusarium udum* is the most widespread and devastating disease of pigeonpea in Asia and Africa. Choking off the plant's water supply, it displays its harshest symptoms when the crop is fully grown and beginning to flower. This is when water demand peaks, causing the plant to wilt and die just as the grain begins to form. Yield losses due to wilt on farms in India during 1977/78 cost the country an estimated US$36.4 million in foregone production (Bantilan and Joshi 1996). Therefore, fusarium research in pigeonpea was high on the list of ICRISAT's priorities.

The research program aimed at identifying resistant lines, conducting multilocational screening for resistance and developing resistant varieties. A combination of genetic resistance and cultural practices was expected to offer farmers a cost-effective method of controlling the disease. Intensive research involved three main thrusts:

- Developing reliable and uniform sick-plot conditions for effective screening (Haware and Nene 1994) during 1974-77
- Exhaustive multilocational screening under the collaborative ICAR/ICRISAT trials involving state universities, ICAR institutions and ICRISAT pathologists during 1978-83
- Extensive national and international NARS/ICRISAT collaborative testing of materials to identify durable sources of resistance.

During the early 1980s, out of 11,000 germplasm sources, 33 lines exhibited, apparent resistance. On-station and on-farm adaptation trials led to ICP 8863 being selected as the fusarium wilt-resistant variety and its official release in Karnataka in 1986 under the name *Mamti. In a* study *(Bantilan and Joshi 1996)* analyzing the impact of this R&D in Central India, the heart of the pigeonpea zone, it was found that the greatest impact was generated by the line ICP 8863 released in Karnataka in 1986. It was selected from a landrace (P-15-3-3. also known as ICP 7626) from Maharashtra. In comparison to the best variety previously available, ICP 8863 gave 57% higher yields, reduced unit costs by 42% and matured slightly earlier. The total net present value of benefits from collaborative fusarium wilt research was about US$62 million, representing an internal rate of return of 65%.

Though officially released only in Karnataka, the technology spilled over into districts bordering Andhra Pradesh, Maharashtra and Madhya Pradesh. Enterprising farmers in the villages of Andhra Pradesh and Maharashtra have taken the initiative of farmer-to-farmer seed distribution.

Using a similar research process, high-yielding wife-resistant varieties are being developed in Africa through the African Development Bank-sponsored pigeonpea improvement project for ESA Resistant germplasm and wilt screening methodologies have been established and are helping scientists identify and test newer and even better sources of resistance. In Malawi for example, many varieties were found to be resistant to wilt and outvielded local varieties by more than 300-450 kg ha^{-1} (ICRISAT 1998b). With the adoption of resistant varieties, it is estimated that farmers in Malawi can produce more than 11,000 t of extra grain every year, worth over USS2 million.

Different races of *Fusarium udum* occur at different locations; so a variety resistant at one location may be susceptible at another. For example, ICP 9145 which Ls resistant in most parts of India and Malawi, suffered 70% infestation in Kiboko in Kenya. A parallel study in collaboration with the University of Nairobi and the University of Gembloux in Belgium is using DNA markers to study such pathogen variability. ICRISAT and its partners actively pursue such international spillover of innovation.

5.6. Summary and conclusions

This chapter has reviewed the state of technology transfer in pigeonpea and the diverse experiences across countries and regions. Pigeonpea is mainly-grown in Asia. The major producers are India and Myanmar. India alone constitutes about 90% of the 3.6 million ha cultivated. However, the importance of this crop has also been increasing in Africa. Joshi et al. (2001) report that the total area under pigeonpea increased from 287.7 thousand ha in 1980-82 to 432.2 thousand ha in 1996-98. The average area under this crop (2000-02) in Africa is about 270 thousand ha. *The major producers in Africa are Kenya, Malawi,* Uganda, Tanzania and Burundi. Table 21 gives a summary of the inter-regional transfer of pigeonpea varieties. A total of 12 varieties and hybrids developed at ICRISAT-Patancheru have been released in India. About 5 genotypes (varieties, hybrids or elite germplasm) selected for short-duration and/or resistance to wilt and sterility mosaic have also been released in other Asian countries. There are also encouraging signs that the crop (not officially released yet) is spreading in the hilly rainfed areas of China for its soil conservation benefits and as fodder for cattle, goats and rabbits. About four varieties have been released in Fiji and Australia, and three in the USA Only two varieties developed at ICRISAT-Patancheru have been released in five ESA countries. However, three varieties developed through ICRISAT-NARS partnerships in East Africa have been released in Malawi, Kenya and Uganda (Fig. 20).

Table 21. Summary of inter and intra-regional technology transfer in pigeonpea.

Varieties (No.)	Developed by	Country of release
12	ICRISAT-Patancheru with partners	India
5	ICRISAT-Patancheru with partners	Myanmar, Sri Lanka, Indonesia and Nepal
4	ICRISAT-Patancheru with partners	Fiji and Australia
2	ICRISAT-Patancheru with partners	5 ESA countries (Kenya, Tanzania.Uganda, Mozambique and Sudan)
3	USA and ICRISAT-Patancheru	USA
3	ICRISAT-Kenya with African NARS	Malawi, Kenya and Uganda

Due to its multipurpose nature, pigeonpea has good potential to expand in ESA, where soil erosion and shortage of fodder for livestock are critical problems. The very factors that drive pigeonpea production in China could play a role in some densely populated hilly regions of Africa (eg, Ethiopian highlands). The current focus of pigeonpea research in Asia has limited the impact in Africa. A more specialized regional breeding and pigeonpea improvement program is essential in ESA in order to address the unique market conditions and biotic and abiotic constraints prevalent in the region.

In Asia, the best example of spillovers from pigeonpea comes from the expansion of a short-duration and high-yielding variety (ICPL 88039) into the rice-wheat fallows in South Asia. The variety enabled diversification of cereal-dominated cropping systems by inserting a legume component and triggered a major geographic extension of the crop.

In addition to inter-regional and intra-regional transfer of improved varieties and hybrids, a number of resistance sources against common pigeonpea pests and diseases (eg, fusarium wilt, sterility mosaic, leaf spot, *Helicoverpa* pod borer, pod fly) have also been identified from the 11,934 germplasm accessions maintained at ICRISAT's Gene Bank. This germplasm is collected globally (76% from India, 11% from Africa, 5% from other Asian countries and 8% from the rest of the world) and distributed worldwide based on requests. This represents a major part of the technology spillover on pigeonpeas.

Figure 16. ICPL 88039: An extra short-duration line developed at ICRISAT-Patancheru and spreading in the rice and wheat fallows of the Indo-Gangetic Plains.

Figure 17. ICPL 87: A short-duration line developed at ICRISAT-Patancheru to exploit the bimodal rainfall pattern in rainfed areas of Sri Lanka.

Figure 18. ICPL 87091: A short-duration line developed at ICRISAT-Patancheru and being adapted in China and spreading in ESA.

Figure 19. ICP 9145: A wilt-resistant germplasm developed at ICRISAT-Nairobi/Kenya and grown in Malawi.

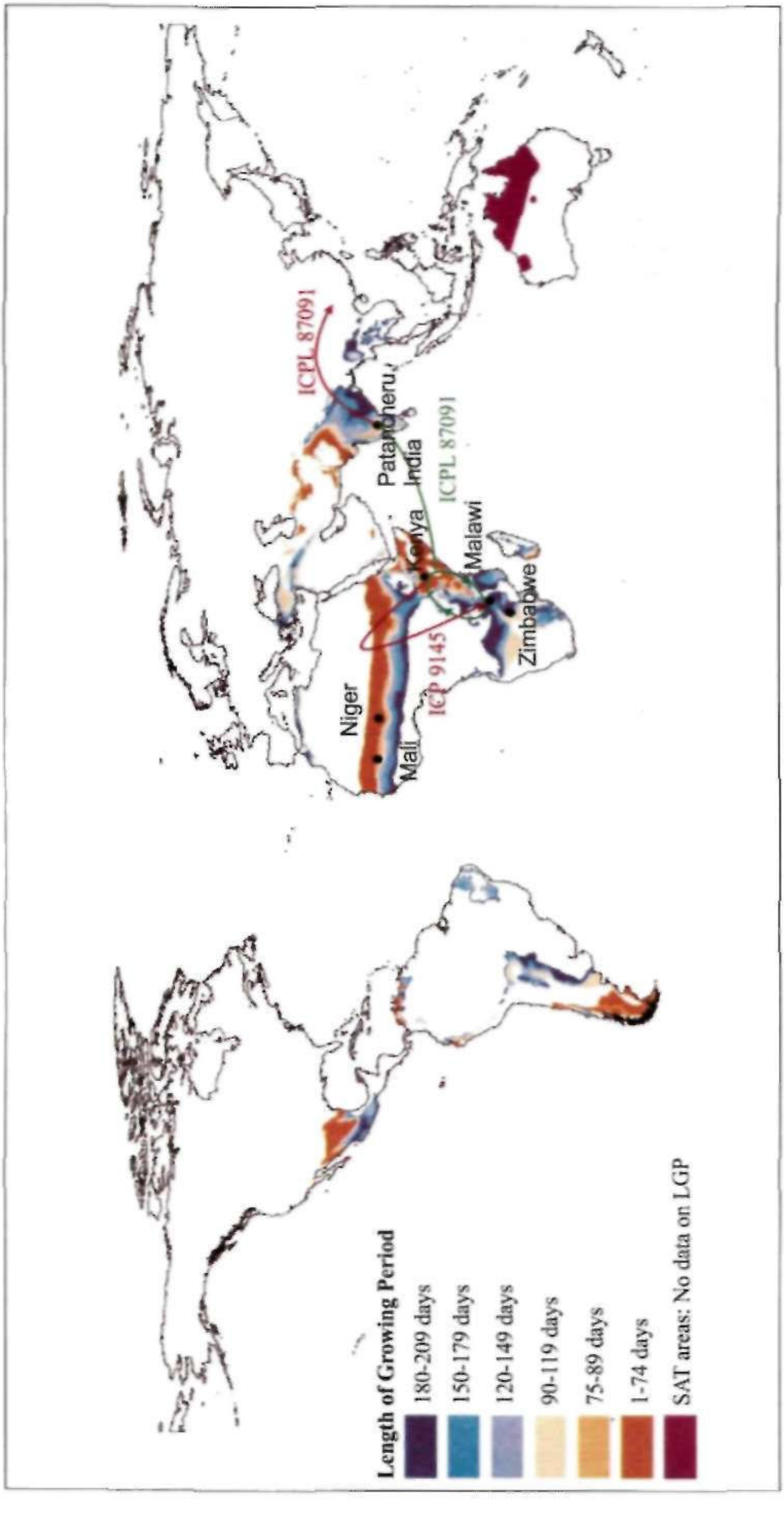

Figure 20. The global flow of selected pigeonpea technologies developed by ICRISAT and its partners.

6. Spillovers from Research Investments in Chickpea

6.1. Technologies developed

Chickpea is the most important leguminous foodgrain in the diets of the people of South and West Asia and northern Africa. It is grown on about 10 million ha worldwide and its annual production averages 7.5 million t. About 63% *of the total* chickpea *area lies in* India alone. The other major chickpea producing countries are Pakistan, Iran, Canada, Turkey, Ethiopia, Mexico and Syria (Table 22). Since chickpea is generally grown in drought-prone, poor soil environments and derives most of its water requirements from stored soil moisture rather than from rainfall, chickpea yield gains over the years have trailed those of cereals and other legumes cultivated in more favorable areas.

There are *two types of* chickpea - Desi, that *is* traditionally grown in warmer climates and found in South Asia and East Africa, and Kabuli, a large-seeded type suited to the more temperate climate of West Asia. ICRISAT and ICARDA share a mandate for the improvement of chickpea. While ICRISAT focuses on Desi types in the tropical latitudes of South Asia and sub-Saharan Africa, ICARDA takes the lead in Kabuli types in the arid temperate zones of Central and West Asia and North Africa (CWANA).

Chickpea research *to* the 1970s was far from promising. Its production and yield at the global level saw no great changes. Taking up the challenge, ICRISAT directed its research at alleviating production constraints under low-rainfall conditions and mainly in low-input farming systems. Wilt, pod borer and drought were rated as extremely important constraints to crop growth between 0° and 20° latitudes. ICRISAT adopted a partnership-based research for development approach to the alleviation of these problems through the use of genetic resistance or tolerance to individual stress factors.

The multidisciplinary research within ICRISAT *and* with *its* collaborators *resulted in the* release *of* about 42 improved varieties worldwide (Appendix 5a). Advances in breeding have facilitated the cultivation of chickpea in nontraditional areas such as Canada, USA and Australia. Several sources of resistance for biotic and abiotic stresses in chickpea were identified (Appendix 5b). The impacts have been in the form of:

- Substantial improvement in productivity and farm incomes
- New cropping options to make farming systems more diverse and sustainable
- Value addition to harvested products
- Fall in crop protection-related expenses, losses and human health risks
- Improvement in national research for development capacities in some of the poorest and most densely populated countries of the world.

In the last few years, new scientific breakthroughs have been achieved - development of super early lines, integrated molecular mapping of the chickpea genome, production of transgenic chickpea plants resistant to pod borer, identification of new genes for earliness, disease resistance, flower and stem colors, early growth vigor and advanced screening techniques for stresses (ICRISAT 2000a).

These achievements that helped improve livelihoods in the marginal environments were recognized by the CGIAR, which awarded the King Baudouin Award for 2002 to the ICRISAT-ICARDA partnership.

For a rainfed crop grown in marginal environments, the realized and potential impacts of chickpea research are very promising. Chickpea research over the last 30 years has triggered a jump in productivity, enhanced the sustainability of production systems and initiated scientific *innovations to accelerate crop* improvement. While it has not been possible to systematically track and document the impacts of each variety over their entire global range of adoption, some potential instances have been identified here to demonstrate the spillover impacts of new varieties across Africa and within each region.

6.2. Spillovers within Asia

Variety ICCV 2

Chickpea is traditionally a temperate crop. It matures far too late when planted in the tropics, succumbing to heat, drought and disease. ICRISAT and its partners have succeeded in breeding types that can be grown below the Tropic of Cancer in South Asia, the most successful example being ICCV 2 (Swetha) (Fig. 21), the world's shortest duration Kabuli variety bred from a cross between five Desi and Kabuli parents. It combines very early maturity (85-90 days) and resistance to fusarium wilt. It has a semi-spreading growth habit with few well-developed primary and secondary branches. It can produce a crop on residual soil moisture and escapes drought due to its early maturity and tolerance to beat stress. It is well adapted to normal and late sowing and fetches a price up to two times higher than Desi types. It is suited to Central and Peninsular India where farmers have benefited from a new

Table 22. Area, yield and production of major chickpea producing countries.[a]

Countries	Area (000 ha)	Yield (t ha^{-1})	Production ('000 t)
Developing countries	**9,165.2**	**0.74**	**6,806.7**
Africa	**467.0**	**0.73**	**343.1**
Ethiopia PDR	184.0	1.02	187.8
Malawi	88.0	0.40	35.0
Tanzania	62.0	0.39	24.0
Morocco	61.0	0.52	31.9
Algeria	17.1	0.44	7.5
Tunisia	15.5	0.59	9.2
Sudan	12.2	1.97	24.0
Egypt	8.0	1.76	14.1
Uganda	6.3	0.52	3.3
Others	12.9	0.49	6.3
Southeast Asia	**154.5**	**0.73**	**112.8**
Myanmar	153.0	0.70	107.6
China	1.5	3.47	5.2
South Asia	**6,871.4**	**0.75**	**5,132.1**
India	5,912.5	0.79	4,653.5
Pakistan	927.3	0.49	452.8
Bangladesh	17.4	0.80	14.0
Nepal	14.2	0.83	11.8
West Asia	**1,511.4**	**0.63**	**954.2**
Iran	712.4	0.36	253.7
Turkey	643.6	0.87	557.7
Syria	97.4	0.73	71.3
Yemen	30.5	1.22	37.2
Iraq	12.5	0.64	8.0
Israel	7.0	1.79	12.5
Lebanon	5.0	2.42	12.1
Jordan	3.0	0.57	1.7
Latin America & the Caribbean	**169.0**	**1.63**	**276.3**
Mexico	159.7	1.67	266.6
Chile	3.7	0.89	3.3
Peru	3.7	1.32	4.9
Argentina	1.2	0.92	1.1
Colombia	0.7	0.57	0.4
Developed countries	**781.9**	**0.94**	**735.0**
Canada	460.0	0.97	447b
Spain	82.3	0.70	57.2
Bulgaria	6.3	0.35	2.2
Italy	4.5	1.29	5.8
Greece	1.6	1.25	2.0
Portugal	2.0	0.50	1.0
Australia	225.2	0.98	219.8
Total	**9,947.1**	**0.77**	**7,543.1**

a. FAO Statistic! averaged over three years (2000 to 2002).
b. Values given at www.pulsetanada.com (2002).

Source: FAO (2002).

cropping option for their marginal lands. ICCV 2 was released for cultivation by the Government of Andhra Pradesh in September 1989. Chickpea cultivation in the state has expanded significantly - from 60,000 ha in 1986 to 200,000 ha by 2000. Productivity too increased from 260-1000 kg ha^{-1}. Andhra Pradesh, long considered outside the chickpea area, now boasts of a productivity 25% higher than the national average. Taken together, both hectarage and productivity in the state have nearly registered a fifteenfold increase in production since 1986. The general characteristics of ICCV 2 are described in Tables 23 and 24.

Table 23. Agronomic trails of ICCV 2 and checks, ICRISAT-Patancheru, 1983/84.

Cultivar	Days to flowering	Days to maturity	100-seed mass (g)
ICCV 2	33	82	24.0
Checks			
L 550 (Kabuli)	59	116	21.0
Annigeri (Desi)	52	100	20.1

Source: ICRISAT Plant Material Description no. 22. 1990.

Table 24. Seed yield (t ha^{-1}) of ICCV 2 and the check in trials in Andhra Pradesh, 1986/87-1988/89.

Cultivar	1986/87 (7)[a]	1987/88 (4)	1988/89 (8)
ICCV 2	1.18	1.01	1.01
Check			
Annigeri (Desi)	1.07	0.50	0.79

a. Figure in parentheses are the number of locations.
Source: ICRISAT Plant Material Description no. 22. 1990.

This silent pulse revolution in the hitherto chilli, tobacco and cotton growing areas (recently plagued by heavy pest damage, rising input costs and falling prices) is attributed to the concerted efforts of the Acharya NG Ranga Agricultural University (ANGRAU) in collaboration with ICRISAT and farmer-to-farmer exchange of seeds during initial years. The switch from cotton to chickpea has been a win-win opportunity - it enhanced farm incomes of farmers and restored soil health, which has seen mdiscriminate use of chemical fertilizers and pesticides over the years. Some progressive farmers have resorted to ecologically sound integrated pest management practices. The environmental dividends and improvements in human welfare and livelihoods are therefore spillover benefits accruing from the introduction of chickpea in these nontraditional areas.

ICCV 2 also spilled over to Myanmar. A major pulse crop here, it commands a premium price in the export market. However, local varieties and landraces frequently suffer heavy losses from fusarium wilt, drought and heat stress. ICRISAT has been exchanging chickpea varieties resistant to these constraints with Myanmar scientists. ICCV 2 was introduced in Myanmar during 1986. After several years of testing it was released in 2000 as Yean 3 for cultivation by local breeders.

The chickpea area is confined to upper Myanmar (dry zone, average annual rainfall of 700 mm) consisting of Sagaing, Mandalay and Magway divisions, whereas lower Myanmar (Yangon, Bago and Ayerwaddy divisions) on an average receives three times more rainfall (2160 mm). The climatic conditions in the dry zone are similar to those in southern India. That is probably why ICCV 2 is in high demand. It is preferred by farmers for two main reasons - its ability to escape terminal drought due to early maturity, and being a Kabuli type, it fetches a higher price premium in the market compared to Desi types.

ICCV 2 has shown a fourfold increase in area in Myanmar during the last three years (Fig. 22). Chickpea area in Myanmar was 192,000 ha in 2001/02, 56% of which was under ICCV 2 and 11% under ICRISAT-bred variety ICCV 88202 (released as Yezin 4 in Myanmar and as Sona in Australia). Sagaing is the major chickpea growing division contributing 54% to the area and 62% to the production of chickpea in the country. ICCV 2 has made a breakthrough here and now covers 85% of the chickpea area. During the last three years, average chickpea yield in Myanmar has increased from 0.7-1 t ha^{-1} and in Sagaing division alone from 0.6-1.1 t ha^{-1}. Myanmar is now a major exporter of chickpea. Results of an ongoing impact assessment of improved varieties in Myanmar are expected to provide a better picture of the spillover impact of ICCV 2.

ICRISAT also shared ICCV 2 with its Sudanese *partners for* further testing *and* selection *across* environments. It is learnt that ICCV 2 has been released as Wad Hamid for general cultivation in Sudan, where there is good potential for expanding chickpea production. This spillover from Asia to Africa may require further study and analysis.

Short-duration Chickpea after Rice in Bangladesh

In the Bannd (northwestern Bangladesh), farmers traditionally left their fields fallow after harvesting rice, because after the rains cease the soils turn rock-hard and cannot be cultivated. But Bangladeshi scientists working jointly with ICRISAT found that chickpeas sown into the stubble shortly after rice harvest can survive and mature on residual moisture, yielding a valuable second crop. This low-labor, low-input technology resulted in intensification and improved resource use efficiency for the extremely poor farmers of this area.

In the early 1990s, the Canadian International Development Agency (CIDA) requested ICRISAT and the Bangladesh Agricultural Research Institute (BARI) to introduce chickpea varieties that could survive rice fallows on receding soil moisture during the dry season. Several ICRISAT-developed varieties were tested by BARI scientists for their adaptability. Trials revealed that economic returns from them matched those from irrigated crops, essentially doubling farmers' incomes Seed priming which involves soaking chickpea seed overnight before seeding (Musa et al. 1999) can dramatically improve early establishment, resulting in significant yield increases. Varieties with better emergence, early growth vigor, greater tolerance to disease, more biomass, more pods and early maturity contributed to the increased productivity. The United Kingdom's Department for International Development (DFID) is currently undertaking an impact assessment of chickpea adoption in the Barind. Preliminary results indicate that ICRISAT varieties developed, evaluated and further selected by BARI - ICCL 81248, ICCV10, ICCL 83105, ICCL 85222, ICCL 83149 and ICCV 88003 - occupied about 85% of the chickpea area. Overall, chickpea gave about three times higher returns than other postrainv season crops. Since 1999, the area sown to chickpea in the Barind has doubled from about 10,000 ha to over 20,000 ha.

ICCV 10 (Fig. 23), released in Bangladesh as Barichhola, is a good instance of spillovers in chickpea. It is a medium-duration (110-120 days), Desi type variety released in 1992 for cultivation in Central and Peninsular India (Tables 25 and 26). It has a semi-crust growth habit with long fruiting branches. Seeds are yellowish brown with a 100-seed mass of about 169 g. It has resistance to wilt and can be adapted widely. Impact studies in Gujarat state of India indicated that the net income of farmers who adopted this variety increased by 84% over the local variety (ICRISAT 2000a).

ICCV 10 has now found a home in Bangladesh through the Asian Grain Legume and Cereals and Legumes Asia Network multilocational testing and further evaluation by BARI scientists. A comparison of the agroecological and socioeconomic conditions in Gujarat and Bangladesh that contribute to the wider adoption and adaptation of this crop across ecoregional boundaries would be instructive.

Another chickpea variety Nabin (ICCL 81248) has also become popular in Bangladesh. It was supplied to BARI by ICRISAT in 1981 /82 as part of an International Chickpea Screening Nursery. The crop monitoring project of CIDA tested Nabin for 2 years in large mini kit plots at several locations (Tables 27 and 28). Yields of up to 3.5 t ha^{-1} were obtained from 25 farmers' fields in contrast to average chickpea yields of 750 kg ha^{-1} in Bangladesh. Nabin can be another candidate for a spillover study

The potential of sowing chickpea in rice fallows is enormous. Over an area spanning about 14 million ha within the Indo-Gangetic Plain across three countries - Bangladesh, India and Nepal - in soils that have been lying fallow for centuries after rice harvest, a crop can now be grown where nothing grew before (Awadhwal et al. 2001; Musa et al. 1998). ICRISAT's chickpea research has played an important role towards realizing this potential. Additional spillover studies in these areas can facilitate greater research impact.

Table 25. Mean seed yield of ICCV 10 in AICPIP varietal trials at various locations, Central Zone, India, 1988/89-1990/91.

Variety	Seed yield (t ha^{-1}) 1988/89	1989/90	1990/91	Weighted mean
ICCV 10	2.36	1.75	1.96	2.02
BG 244 (check)	2.11	1.50	1.71	1.75

Source: ICRISAT Plant Material Description no. 57, 1994.

Table 26. Mean seed yield of ICCV 10 in AICPIP varietal trials at various locations. Southern Zone, India, 1988/89-1990/91.

Variety	Seed yield (t ha^{-1}) 1988/89	1989/90	1990/91	Weighted mean
ICCV 10	2.00	1.55	1.79	1.78
BDN 9-3 (check)	1.40	1.44	1.49	1.43

Source: ICRISAT Plant Material Description no 57. 1994.

Table 27. Agronomic characteristics of ICCL 81248 (Nabin) and the check variety Hyprosola at Ishurdi, Pabna, Bangladesh, 1984-86.

Cultivar	Days to flowering	Days to maturity	Height (cm)	Pods per plant	100-seed mass (g)
Nabin	60	122	67	154	11.8
Hyprosola	72	127	52	110	

Sources:ICRISAT Plant Material Description no-46, 1994.

Table 28. Mean seed yields of chickpea variety Nabin and the check variety Hyprosola at different locations in Bangladesh, 1982-86.

	Seed yield (t ha^{-1})				
Cultivar	1982/83 (1)[1]	1983/84 (2)	1984/85 (3)	1985/86 (5)	Mean
Nabin	2.68	4.12	2.11	2.10	2.75
Hyprosola	1. 55	3.03	1.81	1.80	2.05

a. Figures in parentheses are the number of locations;

Source: ICRISAT Plant Material Description no 45, 1994.

6.3. Spillovers from Asia to Eastern Africa

Mariye in the Ethiopian Highlands

Ethiopia is a major chickpea producer accounting for over half of Africa's entire chickpea area. Once an important chickpea exporting country, Ethiopia stopped exporting due to a decline in chickpea production and greater internal demand for the crop. Segregating and advanced breeding materials with high yields, increased seed size and disease resistance were made available to Ethiopian cooperators by ICRISAT, through international chickpea trials. Four early-maturing and widely-adapted varieties have been released in Ethiopia (Bejiga 1990). One of them, Mariye (Fig. 24), has become very popular. Mariye is a wilt-resistant, wide adaptation material selected from a cross between K 850 x F 378 and further tested under Ethiopian conditions by national breeders. Its yield potential was about 1.8-3 t ha^{-1} while it produced about 1.4-2.3 t ha^{-1} on farm (Table 29). It was released by Debre Zeit Agricultural Research Center in 1985 (Bejiga et al. 1996). It has spread widely in the Bichena region, providing a good example of spillover. No seed agency was involved, reflecting enthusiastic farmer demand, and the variety spread from farm to farm. Almost the entire chickpea area in the province is now sown to Mariye.

Other ICRISAT-developed materials which have shown potential in Ethiopia include ICCL 82106 (Akaki), ICCL 82104 (Worku Golden) and the Kabuli variety ICCV 93512 (Shasho).

ICRISAT materials performed well in the heavy black clayey soils that typify much of Ethiopia's highlands. Variety development with crop and land management technologies allowed farmers to maximize benefits from the new varieties. In 2001, chickpea was grown on about 212,000 ha in these areas, and commercial cultivation has been growing every year. Ethiopia now exports chickpea to Pakistan, India, Dubai and Afghanistan. In domestic markets, it often sells for a higher price than other cereals like maize, sorghum and barlev.

Table 29. Agronomic and morphological characteristics of Mariye in Ethiopia.

Days to flowering	49-61
Davs to maturity	106-120
Growth habit	Semi-erect
Plant height (cm)	31.2
100-seed mass (g)	25.5
Seed color	Brown (smooth surface)
Flower color	Purple
Adaptation area	
Altitude (m.a.s.l.)	1800-2300
Rainfall (mm)	700-1300
Seed rate (kg ha^{-1})	120-140
Planting date	Mid-Aug
Yield (t ha^{-1})	
On station	1.8-3.0
On farm	1.4-2.3
Date of release	1985
Disease reaction	Resistant to fusarium wilt

Source: Bejiga et al. 1996

6.4. Spillovers to other regions

Myles in Canada

ICRISAT's breeding program has also been the source of breeding lines or useful parents beyond the SAT region. For example, commercial chickpea production began in Australia in 1979 with the release of the Indian Desi variety C-235 and a Kabuli line introduced from the USSR. Since then, hybridization programs and further introductions of ICRISAT-developed chickpea lines have produced significant improvements in yield potential and stability, agronomic attributes and seed quality. An average yield increase of 5% over C-235 has been achieved with the development of Desi crossbreeds (Knights and Brinsmead 1990). It is estimated that ICRISAT-developed chickpea lines such as ICCV 88202 (Sona) can contribute up to 2.1% ot the expected 5% yield growth for the five-year period ending in 2002 (Brennan and Bantilan 1999). This gain can lead to an annual cost saving of A$5.21 million for Australia (1USS = 1.38A$). The discounted on gross benefits in 1996 values were predicted at A$39.3 million over the 25-year period (1999-24), averaging A$1.64 million per year as spillover benefits from ICRISAT-developed varieties Heera and Sona.

A similar comprehensive impact assessment study can be conducted in USA and Canada, where chickpea has now spread widely. In the early 1990s, USDA released early-maturing, ascochyta blight-resistant Desi variety Myles (Fig. 25), developed from an advanced breeding line ICCV 92809 (BDN 9-3 x K 1184 x ICP 87440) obtained from ICRISAT. Advanced yield tests and evaluation for ascochyta blight resistance were conducted at several sites in eastern Washington and northern Idaho in 1992 and 1993. Myles showed better resistance to blight - compared to other Desi varieties; an overriding factor in favor of its release. The variety has expanded in Canada in the last 2 years. Recently, it was planted on nearly 100,000 ha in Western Canada, about 35% of the total chickpea area in the country (ICRISAT 2000). Canada is expected to produce record chickpea harvests in the future partly due to ICRISAT-developed blight-resistant and super early chickpea lines.

6.5. Diversification and sustainability benefits

In addition to the direct income benefits obtained through spillover of germplasm and improved varieties, chickpea research has also contributed to diversification of farming systems. This has enhanced the sustainability of production systems in the SAT and in other regions where extensive adoption has occurred. Chickpea has contributed significantly to sustainable production systems by fixing nitrogen, breaking continuous cereal cultivation to interrupt cereal disease cycles and nutrient drains, diversifying farm incomes and adding protein to complement cereals in household diets. A few examples of chickpea-related sustainability and diversification benefits are described.

- Enhanced biological nitrogen fixation by utilizing more efficient *Rhizobium* strains isolated for use as inoculants (Rupela et al. 1997) was observed in on-farm tests in collaboration with partners in Bangladesh, Nepal, India and Vietnam. The nonnodulating and other nodulating variants developed at ICRISAT are now important materials for basic chickpea research on nitrogen fixation processes worldwide.
- A problem pertaining to micro-nutrient (boron) deficiency was resolved by applying boron fertilizer in Nepal. This can have potential impact in the chickpea-growing areas of the Indo-Gangetic Plain in India and Bangladesh, where boron deficiency has been noticed.
- Integrated disease management (IDM) of Botrytis Gray Mold (BGM) developed at ICRISAT-Patancheru (1992-96) and tested in Nepal (Pande et al. 1998) during the 1998-99 cropping season also holds potential for India and Bangladesh. In the deadly BGM epidemic of 1997/98 in Nepal that devastated the chickpea crop, farmers lost their investment and refused to cultivate chickpea in the following season. Scientists from ICRISAT in collaboration with NARS launched a new program to combat BGM. It consisted of employing IDM technology, sowing an improved BGM-tolerant variety, treating seeds with fungicides, spacing rows wider and the need-based application of chemicals. Partners then tried the same technology with promising results. In the 1998/99 seasons, the new chickpea line was sown in 110 farmers' fields. The following season witnessed a fivefold increase in chickpea adoption. By the end of 2000/01, 1100 farmers were sowing chickpea and during 2001/02, the technology was adopted by 7000 farmers. Moreover, the ecofriendly and integrated pod borer control technology [tolerant varieties, monitoring pests using pheromones, application of bio-pesticides like neem products and nuclear polyhedrosis virus (NPV), natural enemies and minimal use of chemicals] developed by ICRISAT scientists is now being adopted by farmers and development agencies in India, Nepal and Bangladesh. Screening techniques for diseases and pests (Nene et al. 1981; Haware et al. 1995) developed at ICRISAT are also being used in India, Ethiopia, Bangladesh, Nepal and by other partners (S Pande, personal communication 2002).

6.6. Summary and conclusions

This chapter has reviewed the experiences and lessons from technology transfer in chickpea across countries and regions. ICRISAT and [CAUDA share the global research mandate for the improvement of this crop in the SAT (for Desi types) and dry temperate (for Kabuli types) regions, respectively. Chickpea is widely grown mainly in south Asia (India accounts for 85% and Pakistan for 14% of the area) and West Asia and North Africa (WANA) regions. Africa accounts for less than 5% of the global production and area (467,000 ha). Ethiopia accounts for about 40% of the area and over 55% of the total production. Countries like Malawi, Tanzania and Morocco have over 50,000 ha under the crop.

Though chickpea research at ICRISAT is mainly based at Patancheru, research activities are conducted throughout chickpea-growing regions of the world in collaboration with national programs. A summary of intra- and inter-regional transfer of improved chickpea genotypes is presented in Table 30. Nearly 23 chickpea varieties developed with ICRISAT-NARS partnerships at Patancheru have been released in India. The best examples are the extra-short duration variety ICCV 2 (Swetha), the first Kabuli type released in Peninsular India that has been instrumental in extending chickpea cultivation into nontraditional tropical latitudes. Chickpea's recent expansion into the nontraditional dryland areas of Andhra Pradesh is a very good example of spillovers across ecoregions, About 13 similar genotypes (varieties developed at ICRISAT or by NARS based on segregating material supplied by ICRISAT) have also been released in tour other Asian countries. Most notable in terms of spillover to Asia is ICCV 10 (Barichhola) in the Barind tracts of Bangladesh, where it has found a new niche in the rice fallows. The other example is wilt-resistant variety ICCV 2 which is widely adopted in Myanmar.

About nine varieties developed at ICRISAT-Patancheru have also been released in three ESA countries, mainly Ethiopia, Kenya and Sudan. A good example of this spillover is the wilt-resistant variety (locally known as Mariye) developed by the Ethiopian national program based on segregating material (K 850 x F 378) supplied by ICRISAT. This and similar varieties are becoming quite popular among smallholder farmers in the highlands of Ethiopia. In view of the limited transfer and impact of the technology developed in Asia, there is a strong need to strengthen the capacity for chickpea breeding and improvement within ESA.

Interestingly, chickpea research products have also spilled over beyond the SAT to benefit the de\ eloped world, including Australia, USA and Canada. The ICRISAT-bred variety ICCV 92809 (Myles) covers about one-third of the total chickpea area in Canada. Similarly, the short-duration variety ICCV 88202 is widely grown in Australia. Figure 26 shows selected examples of the global movement of products of chickpea research. However, the global distribution of chickpea germplasm still represents the largest spillover related to the crop. ICRISAT holds in trust about 16,972 chickpea germplasm accessions (about 82% collected in Asia, 9% in Africa and 9% in the rest of the world), which are being distributed worldwide. A number of resistance sources against common pests and diseases (fusarium wilt, *Helicoverpa* pod borer, ascochyta blight) and drought and cold tolerance are being used in research programs across countries.

Table 30. Summary of inter- and intra-regional technology transfer in chickpea.

Varieties (No.)	Developed by	Country of release
23	ICRISAT-Patancheru with partners	India
13	ICRISAT-Patancheru with partners	4 other Asian countries (Nepal, Myanmar, Bangladesh and Pakistan)
9	ICRISAT-Patancheru with partners	3 African countries (Ethiopia, Sudan and Kenya)
2	ICRISAT-Patancheru with partners	3 developed countries (Australia, Canada and USA)

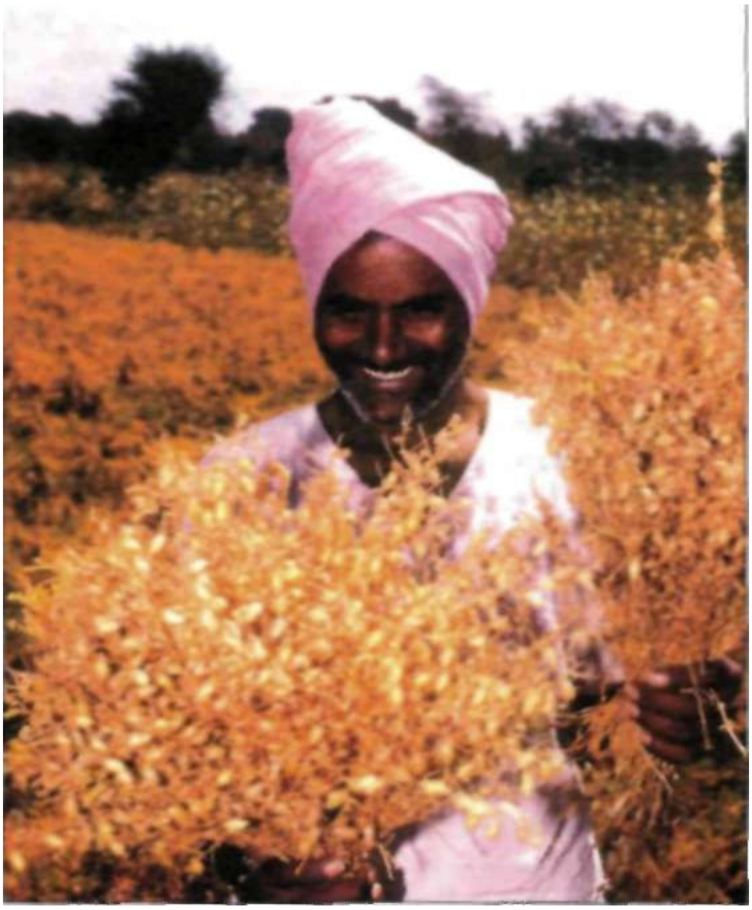

Figure 21. ICCV 2: An extra-short-duration Kabuli type variety developed at ICRISAT-Patancheru and widely grown in Peninsular India and Myanmar.

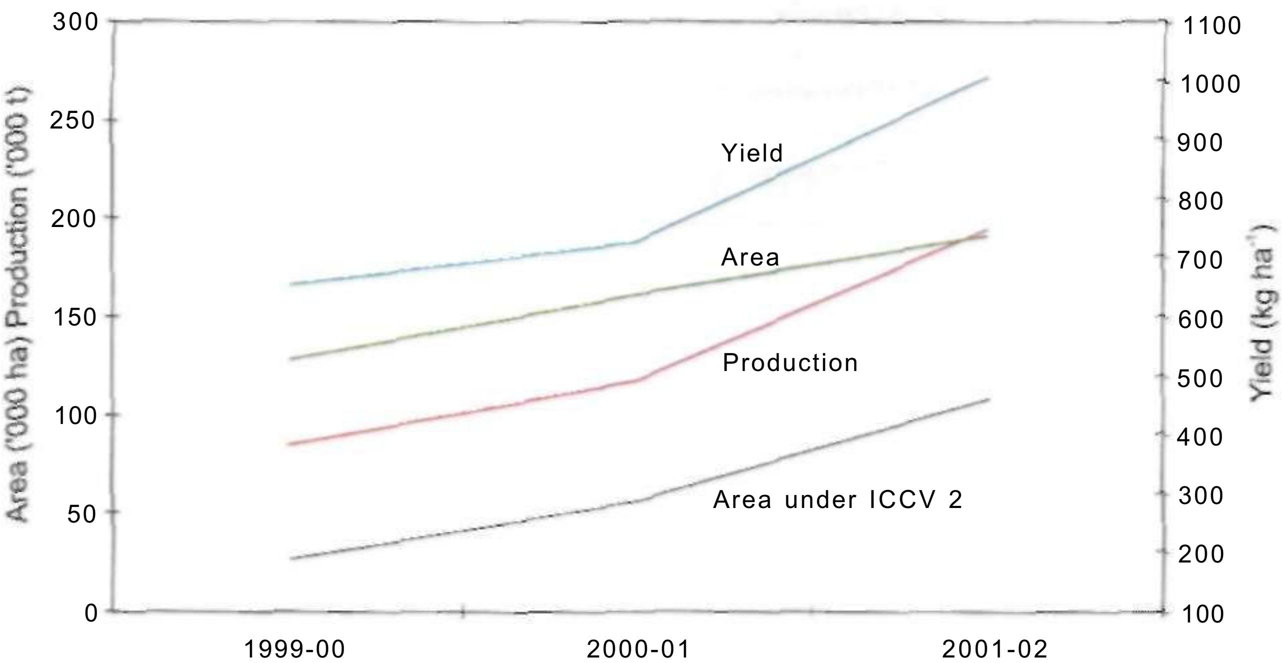

Figure 22. Area, production and yield of chickpea and area under ICCV 2 in Myanmar from 1999-00 to 2001-02.
Source: PM Gaur, personal communication (2002).

Figure 23. ICCV 10: A medium-duration Desi type variety developed at ICRISAT-Patancheru and widely adapted in the Barind tract of Bangladesh.

Figure 24. Mariye: A wilt-resistant Desi type variety developed by Ethiopian NARS based on material supplied by ICRISAT and widely grown in the highlands.

Figure 25. Myles: A Desi type blight-resistant and early-maturing variety developed in the USA based on material supplied by ICRISAT and rapidly expanding in Canada.

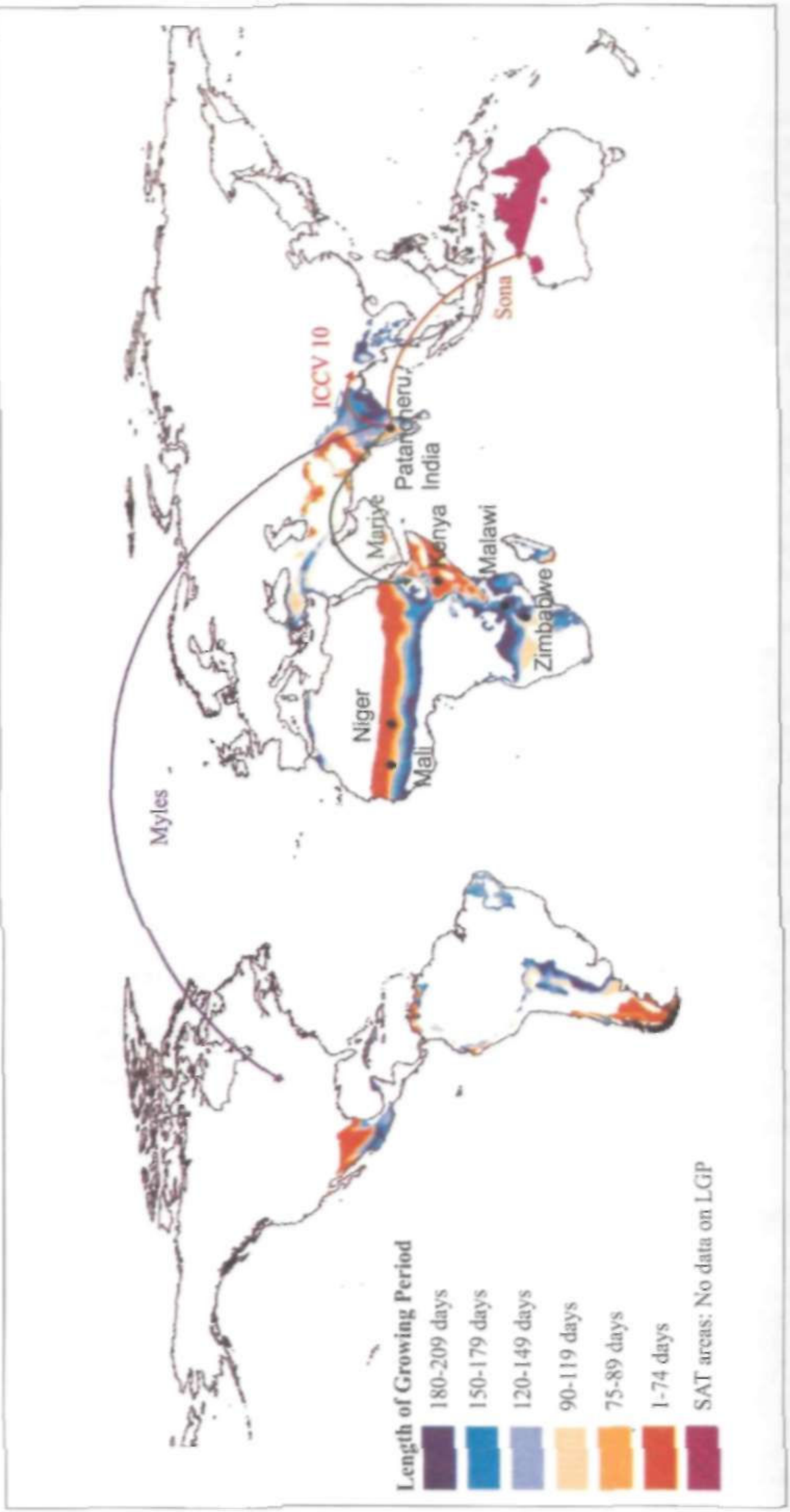

Figure 26. The global flow of selected chickpea technologies developed by ICRISAT and its partners.

7. Natural Resources Management

7.1. Introduction

Right from its inception, ICRISAT has recognized the importance of NRM research for the SAT Though its NRM research program was formally created in 1996, studies on soil, water, nutrient and crop management have been going on since 1972 through its Fanning Systems (1972-80), Resource Management (1980-92) and Integrated Multi-Commodity Systems Projects (1992-95). In 1973, a small watershed, a natural catchment *and drainage area, was* chosen at ICRISAT-Patancheru to conduct research on land and water management and cropping systems. Investigations were conducted on black and red soils on components of cropping systems and natural resource management technologies, with a focus on climatology, soil and water management, soil fertility and biology, cropping systems, animal traction and socioeconomics. The multidisciplinary on-station research was extended to on-farm locations in India during the late 1970s.

By 1982, resource management research turned global with the initiation of research at different African locations. A core multidisciplinary resource management team was placed at the ICRISAT Sahelian Center in Niamey, Niger, strengthened by the presence of special project scientists from various organizations, including CCIAR sister centers [IITA, ICRAF, ILRI and the International Food Policy Research Institute (1FPRI)] and ARIs such as IFDC and University of Hohenheim.

ICRISAT's NRM research was aimed at increasing agricultural productivity in the SAT while maintaining and enhancing the long-term quality of natural resources. Integrated NRM research focused on developing science-based technologies that integrate genetic and natural resources, building on indigenous knowledge and developed and tested through collaborative and participatory research with local stakeholders.

Lately, NRM research has moved more on farm, and become more holistic, systems oriented and increasingly farmer participatory. It is being carried out at the landscape-watershed-community level. Most interventions have been focused on selected benchmark sites, but the products of NRM research also include scientific concepts, principles, processes and research methodologies with potential for wider application. Therefore, impact assessment in NRM is not a straightforward concept because most of the research is broad in scope and involves complex interrelationships between biophysical, environmental, economic and socio-cultural systems at different spatial and temporal levels. The impacts of such research are often intangible, indirect and deferred. However, since CGIAR centers are expected to generate IPGs to address crosscutting development issues, ICRISAT's NRM research has over the years increasingly shifted towards strategic research with wider potential, relevance and applicability. Examples of such issues which are receiving attention are:

- Systems- and process-oriented research approaches at the watershed scale of operation
- Understanding and documenting links and interactions of production intensification on production ecology and agroecology (soil structure, chemistry, biology, pest-disease population dynamics, etc.)
- Simulation modeling to assess long-term impacts in complex systems
- Understanding the process and causes of ecosystem degradation and developing management methods/ practices that provide economic benefits to the poor
- Understanding the role of social capital, markets, local institutions and policies for sustainable intensification and promoting effective options.

During the last 30 years, ICRISAT's NRM research has contributed significantly towards the development of location-specific technologies and NRM tools and methods necessary' to achieve impacts across and outside the SAT. The achievements in this sphere are documented in publications that cover components like rainfall climatology; resource characterization; land, water and nutrient management; water and nutrient interactions; agronomy and cropping systems; agroforestry; integrated pest management (IPM); and socioeconomics and on-farm testing (ICRISAT 2000b). These documents are useful for a more detailed analysis of spillover impacts of NRM research. A few examples with good potential for spillover impacts are summarized in Table 31. In *the* following section, some of these selected examples highlighting the process and extent of spillovers across regions and countries are described.

7.2. The concept of watershed management

ICRISAT is perhaps the first CG center to adopt the watershed management approach to land and water management research. A watershed can be defined as a delineated area with a well-defined topographic boundary with a common water outlet. Hydrological and soil erosion processes within a watershed are interlinked and appropriately assessed within its confine. The Institute's former Farming Systems

Table 31. Components of NRM technologies developed by ICRISAT-led partnerships with potential for spillover impacts in different countries.

Technology/methodology outputs	Origin	Country of adoption/adaptation	Year of spillover
Watershed management concept	ICRISAT-Patancheru	South Asia	1980
		Ethiopia	1985
Vertisol management technology	ICRISAT-Patancheru	Ethiopia, Eritrea Vietnam. Thailand	1995
Scientific basis for improved cropping systems			
- Intercropping	Nigeria/Uganda	India	1978
	India	Niger, Mali	1985
- Legume-based crop rotations	Mali	Niger	
	India	Niger	1990
- Sequential and relay cropping systems	Nigeria		
	India	Mali	1990
- Agroforestry systems	Kenya	India Niger	1985
Animal-drawn implements	ICRISAT-	Mali, Niger	1989
- Broadbed Maker (BBM)	Patancheru	East Africa/Ethiopia	1985
- Broadbed and Furrow (BBF)		Southeast Asia	1995
Soil fertility management	Niger	Burkina Faso, Niger	1990
- P-fertility and micro-dosing	Burkina Faso	Mali, Niger	1996
Agroclimatology and simulation modeling	ARIs	India	1983
		Niger	1985
Optimum tillage and soil *conservation*	Niger	Burkina Faso, Mali	1980
	India	Niger	1983
Wind erosion management techniques (agroforestry)	Niger	Senegal	1985
Steps in improved technology-concept (packages vs. components)	ICRISAT	Niger, Mali	1982

Source: Compiled by SVR Shetty from various sources and based on consultations with scientists.

Research Program adopted a watershed approach to land, water and cropping systems research, which is a holistic approach to the efficient utilization of natural resources. Several small watersheds were developed within ICRISAT-Patancheru to develop principles and techniques for improving rainwater management in order to increase and stabilize agricultural production on farms in the dry SAT. The watershed concept is a systematic approach to integrated research and development and a vehicle for exploration and development of the complex relationships within the local agroecosystem. Since the late 1970s and early 1980s, the concept of operational scale watershed management developed on station is being evaluated on farm to test and develop technologies with the active participation of the local people (Fig. 27).

The objectives of integrated watershed management were to promote the concept as a basis for natural resource management and to design and test specific technologies for alfisols and vertisols. ICRISAT has been successful, particularly in the later years, in projecting the watershed or catchment as a logical and natural planning unit for sustainable agricultural research and development. Community participation is essential for the success of watershed programs.

The concept of watershed management is however not new. In India, its importance in natural resources management has been recognized since the 1950s (Samra and Eswaran 2000). However, it was only after ICRISAT and the Indian Council of Agricultural Research (ICAR) developed joint projects during the mid-1970s that it began to be used extensively for systematic land and water management research. The concept really took off after the countrywide drought in 1987. Table 32 demonstrates the evolution of India's watershed management program.

Table 32. The history and development of the organized watershed management program in India.

Year of commencement	Number of watersheds or total area (ha)	Agency or project	Remarks
1956	42 watersheds	CSWCRTI', Dehradun	Demonstration
1961-62	3.2 million ha (29 catchments)	River Valley projects	Development
1974	8 watersheds	ICRISAT-Patancheru	Research project
1975	4 watersheds	CSWCRTI. Dehradun	Research project
1980-81	0.83 million ha	Flood Prone River Valley Development	
1983	47 watersheds	CSWCRTI & CRIDA	Development and Research (D&R)
1987	99 watersheds (launching)	National Watershed Development for Rainfed Areas	D&R
1991-95	5 million ha	Government of India and international agencies	D&R
1997-02	7.5 million ha	-	D&R
2007-22 (planned)	90 million ha	-	D&R

a. CSWCRTI = Central Soil and Water Conservation Research and Training Institute.

Source Samra and Eawaran (2000).

During the late 1970s, ICRISAT developed joint projects with ICAR [Central Research Institute for Dryland Agriculture (CRIDA)] on soil and water loss, small watershed hydrology, demonstration and extension of improved cropping systems to operational watersheds on farm. ICAR extended these studies to cover the different agroecosystems of India. In 1987, the Government of India launched large-scale watershed management projects. Since then, watershed management has been accorded high priority in the five-year plans. In order to strengthen watershed development activities, a full-fledged rainfed farming systems division was created under the Ministry of Agriculture at the national level and in some State Governments. While the conceptual framework for watershed conservation and development has not altered much, the program activities have shifted gradually towards integrated rural development for food security, environmental protection and poverty alleviation.

ICRISAT has also acted as a catalyst in extending watershed management research projects to Thailand, Vietnam and recently China. ICRISAT and NARS partners have developed an innovative farmer participatory integrated watershed management model (Wani et al. 2002), which is being recognized as an important institutional innovation in development c ircles. ICRISAT and its partners are working together to develop impact assessment methodologies for natural resource management technologies. Continuous monitoring and evaluation of activities and outcomes in watersheds is very critical, for which ICRISAT has developed methods and instrumentation such as automatic runoff and soil loss recorders, which are being used in some countries in Asia, Africa and Latin America. The principle of multi-stakeholder convergence has been adopted in the watersheds to improve livelihoods. The watersheds are used as Important platforms lor launching entry point activities that provide immediate benefits which are gradually diversified to broader livelihood-based programs. This new approach, referred to as watershed plus by some specialists, is quite attractive for participatory livelihood programs. Development investors such as DFID have adopted the watershed plus approach in their livelihood program.

The role of watershed management in addressing sustainability concerns, inducing community participation, utilizing modem technology, systems monitoring, predicting and managing large-scale processes, quantifying economic benefits and developing promising techniques and methods is evident but inadequately documented and quantified. Recendy, ICRISAT reviewed watershed case studies in India to document the lessons learnt and identify the research needs that will provide valuable insights into the watershed approach. The R&D projects on watersheds undertaken since the 1970s need to be critically reviewed to learn from past successes and failures. These experiences should be used to develop strategies for the sustainable management of natural resources. Such a detailed assessment of the concepts, methods, outcomes and information generated by ICRISAT's research on watersheds within an appropriate time frame could form the basis for documenting and quantifying spillover impacts of watershed-based research for development.

7.3. Vertisol management technology

Operational scale vertisol watersheds established on station in 1976 were used to study and develop a package of technologies for managing deep, heavy black soils, which are traditionally fallowed in the rainy season and cropped in the postrainy season on stored soil moisture. The components of the improved technology developed over the years include (Kampen 1982):

- Cultivating land immediately after the postrainv-season crop: dry season tillage
- Improved drainage with the aid of field and community channels and the use of graded broadbed and furrows
- Dry seeding of the crops before the monsoon
- Use of improved varieties, crop mixtures and row arrangements
- Improved fertility, pest and weed management.

The on-station results at Patancheru were highly *promising. Sorghum and pigeonpea together recorded* an average yield of 4.7 t ha^{-1} in the improved system compared to sorghum alone which recorded an average yield of 0.9 t ha^{-1} in the traditional system. Annual growth in grain yield was about 78 kg ha^{-1} in the improved system and only 26 kg ha^{-1} in the traditional system (Fig. 28). Both land productivity and soil quality improved. In the improved system, 67% of the rainfall was used by *the* crops, 14% of it was lost as runoff and 19% was lost as evaporation and deep percolation. In the traditional system, only 30% of the total rainfall was used by the crops, 25% lost as runoff and 45% lost as soil evaporation and deep percolation. There was only 1.5 t ha^{-1} of soil loss in the improved system compared to 6.4 t ha^{-1} in the traditional system (Table 33). This long-term experiment helped establish the sustainability of the technology and opened up new opportunities for studying C sequestration in the SAT. Long-term studies revealed that adopting improved technologies for vertisol management have not only provided increased crop yields but also improved the soil quality substantially in terms of physical, chemical and biological parameters and sequestered an extra 7.4 t C ha^{-1} in 24 years. This study made an important contribution in estimating C sequestration in the tropical drylands where limited information exists (Wani et al. 2003).

The vertisol management technology was first tested and demonstrated in Andhra Pradesh. On-farm trials were conducted later in Maharashtra and Madhya Pradesh. The dynamics of adoption of various components of the technology were also studied (Joshi et al. 2002) and the impact of vertisol technology was assessed. Though farmers did not adopt vertisol technology in toto, its components were widely adopted at different locations. A stepwise *adoption* of *various* technology *options was* observed. Many sustainability benefits were also reported (Wani et al. 2002). With support from the Asian Development Bank, the technology is now being evaluated with NARS in Thailand, China and Vietnam. Over the last couple of years, NARS partners have refined the technology and it is beginning to make an impact with small farmers in Asia.

Table 33. Annual water balance and soil loss (t ha^{-1}) using traditional and improved technologies in a vertisol watershed, ICRISAT-Patancheru, India (1977-2000).

	Water-balance component				
Farming system technology	Annual rainfall (mm)	Water used by crops (mm)	Water lost as surface runoff (mm)	Water lost as bare-soil evaporation and deep percolation (mm)	Soil loss (t ha^{-1})
Improved system (double cropping on broadbed and furrows)	904	602 (67)	130(14)	172(19)	1.5
Traditional system (single crop in post-rainy season and without)	904	271 (30)	227 (25)	406 (45)	6.4

a. Values in parentheses are the amount of water used or lost, expressed as a percentage of total rainfall.

Source; ICRISAT (2000 b).

ICRISAT also assisted in the transfer of vertisol management technology to Ethiopia by setting up the Joint Vertisol Project (JVP) in collaboration with the Ethiopian Agricultural Research Organization, The Alemaya University of Agriculture, the Ministry of Agriculture, ILRI and the Government of Netherlands. The JVP has helped in the spillover of the technology from Asia to the Ethiopian highlands. which comprise about 13 million ha of vertisols (difficult to manage soils). The JVP fine-tuned the technology, adapting it to Ethiopian conditions. It developed a package of technologies consisting of the BBF system developed with a locally-made broadbed maker plough (BBM) and suitable agronomic practices with appropriate crop varieties and fertility management. Following on-station trials, the package was tested on-farm across different locations of the Ethiopian highlands in collaboration with farmers.

On-farm trials showed that greater grain yield and crop residue from using the improved vertisol technology package resulted in higher economic benefits to Ethiopian farmers. Significantly higher yields in wheat were noticed under the improved technology compared to crop yields obtained through traditional methods. The net gain and marginal rate of return from wheat under the improved technology were more than double. In some locations, a fourfold increase in wheat yield was noticed with the improved technology compared to that from wheat grown on vertisols with traditional technology (P Pathak, personal communication 2003).

To help disseminate the technology, the JVP trained farmers to assemble and use the technology's components, The BBM package slowly gained some popularity and the technology was widely adopted in areas where it was promoted. The adoption (1990-95) varied from one area to another depending upon various factors. Some studies indicated that 10 peasant associations comprising 1553 households used BBF technology (in Ginchi, Hidi and Enwari areas), of whi(h 28% of the households participated in on-farm research during 1989-95 (P Pathak, personal communication 2003). A detailed study and analysis ol the adoption and impact ot the vertisol technology in Ethiopia could provide valuable insights into the factors that contribute to the spillover of NRM technologies across continents. Recently, it is learnt that the technology has also spilled over into neighboring Eritrea (B Shapiro, personal communication 2003).

The original concept of watershed management and the vision to improve vertisol areas with reliable rainfall were well founded. Technically, the watershed is also a good approach to manage natural resources. However, a comprehensive review of the vertisol watershed technology, including its impact on food security, environmental protection and poverty alleviation, would be important to justify policy dec decisions for wider dissemination. In addition to adoption and spillover impact studies, steps to refine components of the technology and policy research by NARS in collaboration with ICRISAT would be useful to identify limiting factors and to design better strategies for scaling out and scaling up.

Lessons learnt in Asia and Africa have shown that soil erosion and gully formation are affecting the productivity of the resource base, which is often irreversible. Farming communities need technical advice from public service organizations before embarking upon communal conservation and drainage practices. An important issue which surfaced during recent interactions on collective action in Asia and Africa is: How can resource-poor farmers whose land tenure is not secure invest in watershed-based communal soil and water conservation? Continuing collaborative research on collective action, farmer incentives and investment strategies in the context of watershed management can provide useful insights on how to promote community participation.

7.4. Strategic research on cropping systems

Strategic research on crop/cropping systems management has been a major part of ICRISAT's *resource* management work. While such research is now being conducted in several ICRISAT locations, during the 1970s and the 1980s, ICRISAT Asia Center was the nodal point for cropping systems research. The Institute's cropping systems research aimed at providing a scientific basis to cropping system improvement by enhancing our understanding of the physiology and agronomy of key cropping systems in the SAT. Initial studies at Patancheru focused on intecropping, sequential and relay cropping systems, crop rotations and agroforestry systems.

This research has yielded a wide range of outputs such as:

- Generation and dissemination of new knowledge through various means like publications, conferences and workshops
- Capacity building through training
- South-South collaboration through networking
- On-farm orientation and farmer participatory research.

These outputs are very likely to have generated multiplier effects that stimulate productivity and environmental benefits from the adoption of improved cropping systems. A few case studies on spillover impacts can be identified for further assessment. An example of cropping systems research with a good potential for spillover is highlighted.

Improved intercropping systems for dryland crops

During the late 1970s and 1980s, a series of strategic studies were carried out on crop physiology and agronomy, and a scientific approach to intercropping of less known dryland crops was developed. These provided the basis for understanding the "competition" across space and time, and helped in developing improved cropping systems for the SAT.

Though mixed cropping is a traditional practice in dryland areas (Ayyangar and Ayyar 1942), a scientific approach to improving intercropping of dryland crops was initiated at the Institute of Agricultural Research (IAR), Samaru (Nigeria), during the late 1960s and early 1970s (Norman 1968; Andrews 1972). Studies on plant population to improve intercropping were also conducted in East Africa (Osiru and Willey 1972) and West Africa (Baker and Norman 1975). ICRISAT assembled a core team in Patancheru to conduct research on cropping systems during the late 1970s, and used a scientific approach to intercropping research (Willey 1979). Various principles, processes and methods were developed to define the scientific basis tor improving cropping systems tor dryland crops grown by small farmers. Physiological studies on growth patterns and resource use, and agronomic and agro-ecological studies on crop density, yield stability, role of legumes, weeds, pests and diseases were emphasized (ICRISAT 1981). These strategic studies triggered several studies in India and Africa (Serafini 1985; Shetty 1987; Shetty et al. 1995).

ICRISAT played a key role in accelerating intercropping systems research for dryland crops in the NARS of Asia and Africa. The scientific principles and concepts were further tested in West and East Africa, and are being quoted throughout the world. Cropping system techniques combining the use of selected varieties, fertilization, spatial arrangements and planting dates have led to promising technologies now being adapted and adopted in Niger, Burkina Faso and Mali. In Mali for example, sorghum-cowpea, millet-cowpea and millet-maize intercropping systems have resulted in yield increases ranging between 30 and 40% (Fig. 29) over those produced in the traditional systems (Shetty et al. 1991).

Similar spillover was noticed for concepts and scientific principles of other cropping systems such as legumes in the rice-wheat system, agroforestry and pigeonpea physiology (Anders 1994). The agroforestry spillovers from ICRAF-Kenya to ICRISAT-Patancheru, and later on to ICRISAT-Niamey and Mali illustrate ICRISAT's critical role in stimulating agroforestry research in the SAT.

Since ICRISAT's cropping systems research is mainly based on scientific knowledge, the nature and extent of spillover impact need to be investigated through comprehensive literature surveys. Questions such as how the knowledge is reported, how it is used and by whom, enabling mechanisms, the contributions made to science and the level of use of this knowledge by farmers need to be assessed in future studies.

7.5. Soil fertility and water management

Improvement in soil fertility in the SAT cannot be achieved without improved water management. Over the years, ICRISAT has demonstrated that technologies that combine better soil fertility and water management lead to higher productivity, food security and poverty reduction while at the same time protecting the natural resource base. This concept is now widely accepted, particularly under African SAT conditions. For example, rock and earthen bunds in Burkina Faso, Niger and Mali; tied ridging in Niger; soil ridging and low wind breaks in the desert margins; millet straw residues to prevent erosion and enhancing pearl millet production were adopted for local conditions in the West African Sahel (Shetty et al. 1996). For millet-based systems, technology components included the application of small quantities of P, use of improved varieties, planting on ridges, crop rotation with legumes and incorporation of crop residues that were developed at the ICRISAT Sahelian Center (Bationo and Mokwunye 1991). Research *on* water and nutrient interaction by ICRISAT stimulated research throughout the African SAT, and the concept is being pursued by NARS and other partners in Africa. The knowledge and methods developed at ICRISAT-Patancheru to study soil biology parameters and particularly vesicular arbuscular mycorrhizal (VAM) fungi's role in P nutrition, were transferred to West Africa. ICRISAT scientists set up the facilities at Niamey and studied the soil biota's role in sustaining soil quality and productivity in the African region (Bationo et al. 2000).

ICRISAT's strategic research on soil management has led to the development of methods, tools, principles, concepts and processes that are expected to be used by NARS to develop location-specific technologies to improve soil productivity and enhance sustainability. Some examples:

- Innovative research on participatory research methods
- Comprehensive study on nutrient acquisition through studies on the root system and nutrient cycling
- Diversified systems decrease dependence on chemicals, and enhance the environmental and sustainability impacts, leading to enhanced research efforts on legumes and to the promotion and adoption ol legume rotations in cereal systems

- Recycling nutrients from crop residues, including through composting
- Using modeling as an aid to identify best-bet technologies and on-farm participatory testing that combines low rates of organic and inorganic nutrients
- Understanding the potential of micro-dosing for resource use efficiency in Niger and Mali
- Spread of "zai" technology to rehabilitate degraded lands whereby small quantities of organic material such as manure or compost are added to the soil in small pits dug in the degraded soil (Fig. 30).

Previous research by ICRISAT and IFDC in Niger have shown that a small amount (micro dose) of fertilizers placed close to millet hills could significantly increase millet yields. The technology was tested on farmers' fields in Niger. Initially adoption was low because of the lack of credit facilities to purchase fertilizer inputs. Farmer groups were organized in collaboration with FAO and NGOs to provide access to credit, with stored grain serving as collateral (warrantage or inventory credit). The inventory credit provided to farmers at the beginning of the rainy season gave them greater access to fertilizer inputs leading to higher and sustained yields and facilitated grain sales. Millet yields doubled with only 4-6 gm of compound fertilizers (DAP) per hill, and increasing level of adoption was noticed during 1998-01. This innovation (fertilizer micro-dosing and warrantage) has now been extended to the neighboring countries of Burkina Faso and Mali through the collaborative efforts of the United States Agency for International Development (USAID), local NGOs, FAO and NARS. Large-stale demonstrations conducted in a range of conditions are showing great promise lor this technology to spill over to other Sahelian countries (R Tabo, personal communciation 2003).

A detailed investigation to document the spillover impact of ICRISAT's soil conservation, fertility and water management research is called for.

7.6. Animal-drawn implements

ICRISAT developed an animal-drawn tool carrier (Fig. 31) in the mid-1970s to form broadbeds and furrows to improve surface drainage of vertisols (ICRISAT 1983). It is a multipurpose machine but designed to perform agricultural operations. It can perform all sorts of field operations as a tractor but is pulled by oxen.

The animal-drawn wheeled tool carrier was originally developed for Eastern and West African (Senegal) conditions, and various models such as the tropicultor, the nikart and the agribar are now available. These implements facilitate speedier and precise tilling, planting, fertilizing and weeding operations. The animal-drawn tool carrier was the first machine successfully used for farming operations at ICRISAT-Patancheru. It was extensively used for field operations under vertisol conditions. It is used for BBF preparation and dry sowing in the vertisol areas of the Indian SAT. Until November 2002, a private company (Meakins Agro-Products Pvt Ltd) used to sell 3200 tropicultors within India. These equipments also found niches outside India. According to Meakins, 1100 tropicultors were sold outside India, mainly to different African locations (Nigeria) (SVR Shetty, personal communication 2003).

One of the major spillover effects of the tropicultor is modification of the traditional plough. For example in Ethiopia, the traditional plough - maresha - was modified to design a broadbed maker (BBM) from two shortened mareshas framed together (Fig. 32). The latest version of the BBM was developed by connecting two mareshas in a triangular shape. Attachments to the BBM used to reduced tillage, for weeding and seeding to allow a permanent broadbed system, were also used extensively by the JVP. Although the number of BBMs diffused is not known, it has been estimated that there are over thousands of them in use now in Ethiopia (P Pathak, personal communication 2003).

The tool carrier concept was further modified and adapted for West African conditions. A donkey-drawn cultivator-cum-seeder was developed (in Mali) and tested for field operations in the West African SAT where soils are light and sandy (Awadhwal et al. 1992). An ICRISAT scientist invited by the Malian NARS to plan and develop a low-cost cultivator-cum-seeder to be drawn by a donkey, worked with NARS colleagues at the Cinzana Research Station and developed a cultivator made of wood and iron. It was simple and could be fabricated with locally available material. It was even cheaper than the existing donkey-drawn seeders and cultivators and farmers could perform seeding and weeding operations faster with it compared to the manual operation. The design of the donkey-drawn cultivator-cum-seeder is now being used locally to improve the equipment.

Research on donkey traction has also spread to neighboring Niger. In collaboration with the University of Hohenheim, ICRISAT developed the HATA, a low-cost weeding implement. Costing about 90 kg of millet, the implement reduces weeding time significantly and maintains 90% weeding efficiency compared to manual weeding (ICRISAT 2000b).

Another interesting feature of ICRISAT's farm implements research was the spillover of NRM technology to other crop management situations. The use of the BBF system in groundnut production illustrates this indirect or cross-commodity spillover (Joshi and Bantilan 1997). The groundnut farmers in India accepted the BBF system but not the tropicultor since it was expensive. Farmers generally used a locally fabricated, bullock-drawn bed former to make beds and furrows (Joshi and Bantilan 1997). Encouraged by ICRISAT, fanners modified the recommended BBF method and made beds 75 cm rather than 150 cm wide. The bed-former, locally known as the "marker", was designed and manufactured using the tropicultor concept. The Government of Maharashtra provided a subsidy for this technology to encourage the adoption of the raised bed-and-furrow concept. By 1993/94 a firm had sold 425 marker sets. As many as 220 ferti-seed-drills with an attached marker were sold in 1992-93. About 55% of the farmers in the study area in Maharashtra adopted the concept of raised BBF in 1992 and the rest adopted it the following year. The BBF with modified implements was also becoming popular with chickpea, soybean, sorghum, pigeonpea, okra and minor legumes.

7.7. Agroclimatology and simulation modeling

A series of agroclimatological studies on characterization and modeling of the SAT agroclimatic environment has provided a sound basis for the design and transfer of agricultural technologies throughout the SAT. ICRISAT's agroclimatologists, in collaboration with the national meteorological services and the World Meteorological Organization (WMO), focused on a wide array of research areas such as agroclimatic resource characterization, temporal and spatial variations in rainfall, rainfall probabilities and probability analysis for defining moisture environments, empirical analysis of dry spells for agricultural application and population dynamics of pests. Publications emanating from these studies are widely used across the SAT. In addition to India, ICRISAT's agroclimatology services were sought by Thailand, Ethiopia and the West African NARS.

Simulation modeling has been one of the major activities of ICRISAT's NRM research. Since 1982, scientists have collaborated with national and international institutes in the development, testing and validation of water balance, crop simulation and soil management models for the SAT. These models can predict crop responses to soil and crop management, and their effect on resource use and conservation can be used to evaluate management options. They can also be used to evaluate the suitability of certain systems under given environments to evaluate ex-post and ex-ante productivity and sustainability impacts. As most of the crop models were developed in environments other than that of the SAT, they required calibration and adaptation to SAT conditions. Based on new knowledge and evidence, appropriate changes were made to improve the reliability of the models. NARS scientists were trained in the management of databases and model application in their environments. Some recent examples of simulation modeling activities are the Decision Support System for Agrotechnology Transfer (DSSAT), Agricultural Production Simulator (APSIM), the Productivity, Erosion, Runoff Functions to Evaluate Conservation Technologies (PERFECT) and Crop Estimation through Resource Environment Synthesis (CERES) model. Some of the important linkages established by ICRISAT in relation to simulation modeling include:

- CERES models lor sorghum and pearl millet
  - Michigan State University, USA
  - IFDC, USA
  - IBSNAT Project, USA
- Groundnut modeling
  - University of Florida, USA
  - IBSNAT Project. USA
  - Indian Agricultural Universities
- Chickpea modeling
  - University of Florida, USA
- PERFECT model
  - Queensland Department of Primary Industries (QDPI), Australia
- APSIM modeling (CARMASAT)
  - ACIAR, Australia
  - Southern Africa (Zimbabwe)
  - East Africa (Kenya, Uganda)
  - West Africa (Niger)
  - India.

ICRISAT played a pivotal role in developing and adapting these models by acting as a catalyst and linking advanced ARIs and NARS of the SAT. The models not only enhanced capacity in the collaborating countries (NARS), but also indirectly contributed to facilitating spillover impacts of international agricultural research.

7.8. Summary and conclusions

This chapter assessed the state of technology transfer across countries and regions from research products in NRM. Currently, NRM work is undertaken in all the regions in Africa and Asia. Over recent years, it has gone more on farm, and become more holistic and systems oriented. The farmer-participatory approach is the guiding philosophy in technology design, testing and development, especially for much of the work carried out at the landscape-watershed<ommunity scale.

The CGIAR's research investment in the area of NRM has been increasing steadily since the early 1990s. ICRISAT also has a long experience of involvement in NRM research. It is one of the pioneers of watershed management research where substantial effort has gone into developing concepts, methods and options for managing the underutilized black soils in India. Unlike crop improvement work, research products in NRM may not be directly transferable across countries and regions. At best, what is likely to spill over are the methods, lessons and experiences rather than the component technologies developed for specific biophysical conditions. A good example is the manner in which the micro-watershed management approach developed at ICRISAT-Patancheru is expanding to other parts of Asia (Vietnam, Thailand, China and Nepal). This approach has also been tested widely in the African context, initially in Ethiopia which has vast areas of largely underutilized black soils. The bullock-drawn tropicultor developed for vertisol management in India has been adapted under local conditions in Ethiopia, where the oxen-drawn local plough (maresha), has been modified to suit local needs.

Strategic research on cropping systems has formed a large part of ICRISAT's resource management work. It has contributed to enhancing the understanding of the physiology and management of key cropping systems for the less-known crops of the dryland tropics. For example, ICRISAT utilized the scientific agroecological knowledge on intercropping originally generated in Nigeria and Uganda to develop scientific metfiods to improve intercropping systems in India. These were further tested and evaluated in Niger and Mali. Recently, this research has expanded to include diversification of production systems in tfie semi-arid regions through crop-livestock integration. The nature of demand for coarse cereals in Asia is shifting towards feeding livestock. The crop by-products are also an important source of fodder for livestock in many-mixed crop-livestock systems across the SAT. Livestock provide traction power and manure needed in crop production while the sale of animals provides cash for small farmers to buy improved seeds and fertilizer.

Characterization and modeling of the SAT agroclimatic environment developed at Patancheru and Bulawayo have also provided a sound basis for the design and transfer of suitable NRM technologies well integrated into production systems of the SAT. Simulation modeling is a very powerful tool tor identifying best management practices and for up-scaling and disseminating new approaches. The low-cost and profitable methods of soil fertility management and soil and water conservation developed in WCA in partnership with NARS and otfier partners are also expanding in tfie region. This includes tied ridging, wind erosion control, fertilizer placement (micro-dosing), contour bunding, crop residue management, natural rock phosphate application, etc, being used in Niger, Burkina Faso, Mali, Nigeria and Senegal.

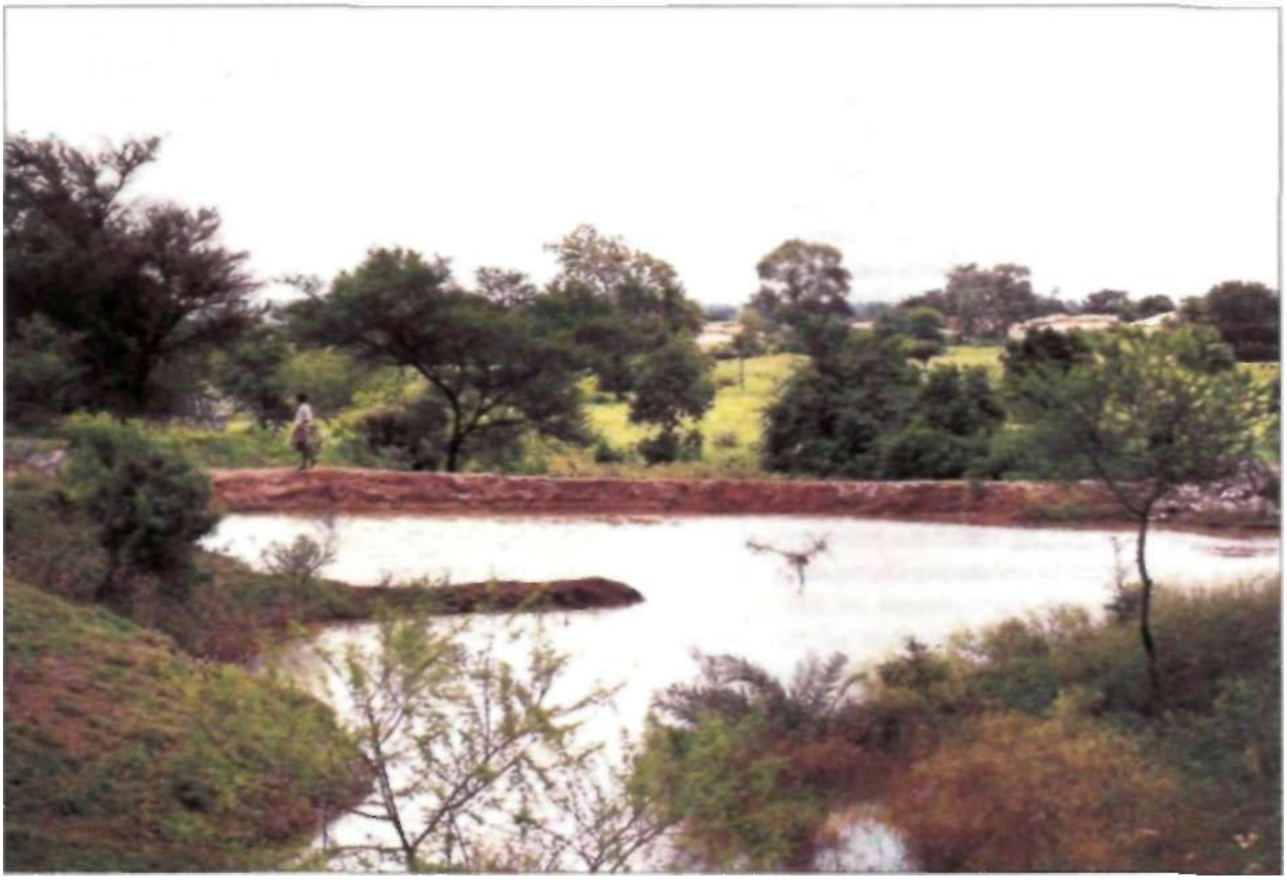

Figure 27. The watershed management concept developed at ICRISAT is now being used for in-situ water conservation and rainwater harvesting across the dryland tropics of India and is spreading to Thailand, Vietnam and China.

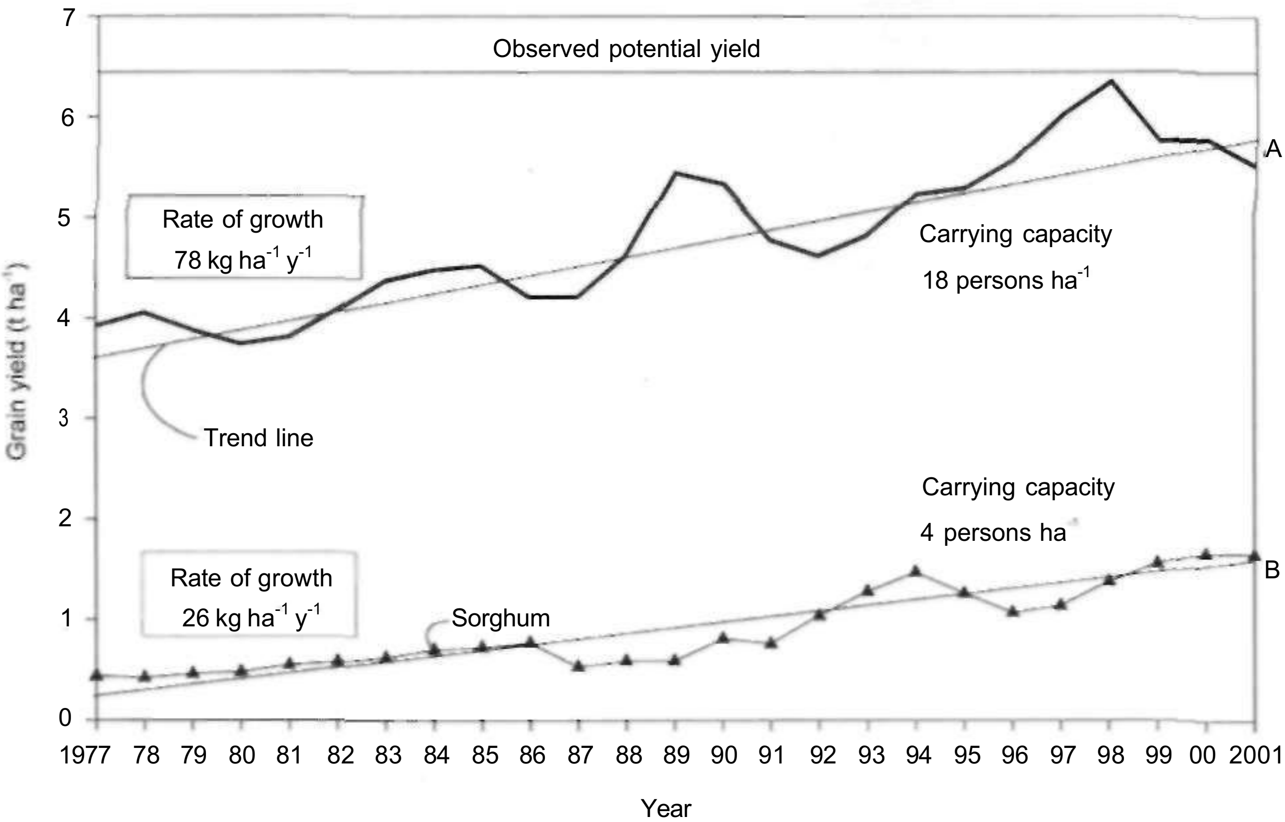

Figure 28. Grain yields under improved (A=sorghum/pigeonpea system) and traditional (B=fallow-sorghum system) technologies on a Vertisol watershed at ICRISAT, 1977-01 (Wani et al. 2003).

Figure 29. In Mali, intercropping systems have led to 30-40% yield increases over traditional systems.

Figure 30. 'Zai' technology to rehabilitate degraded lands in WCA.

Figure 31. The animal-drawn tool carrier (tropicultor) developed by ICRISAT for Indian vertisols, facilitates speedier and precise tilling and planting.

Figure 32. The broadbed maker for vertisol management in Ethiopia is developed based on the tropicultor concept which was developed by ICRISAT for vertisol areas of India.

8. Socioeconomics and Policy Research

8.1. Introduction

The social science team at ICRISAT works very closely with scientists from agrobiological sciences in several crosscutting and interdisciplinary projects. The impact of the work done in socioeconomics and policy is therefore an integral part of the crop improvement and natural resource management research described earlier. This section highlights the more specific achievements and research products from social science work that has the potential to generate IPG benefits. The IPGs from socioeconomics research include outputs like new methods, policy recommendations, databases, concepts/knowledge, analysis of future outlooks and scenarios for the SAT, synthesis of results over time and across commodities to understand emerging issues and training and capacity building.

Policy recommendations and briefings related to SAT futures and development opportunities play an important role in sensitizing and informing research managers and policymakers to facilitate informed decision-making. The commodity situation and outlook reports provide useful analytical data to all countries in the SAT. A comparative analysis of seed policy and systems across countries and regions also provides useful lessons regarding optimal seed strategies ranging from the community to the commercial level. A significant part of providing IPGs consists of training and outreach programs that help in disseminating knowledge and techniques developed by ICRISAT and its partners to NARS. This takes several forms such as attending workshops and field days, and training visiting scientists and scholars in customized programs like participatory research and impact assessment methods, policy analysis methods and simulation modeling.

Some of these IPGs from the social science work have already spilled over while others have the potential to do so. Highlighted here are some of the research products with particular reference to their potential for spillover across regions and countries.

8.2. Selected IPGs

Village-level Studies (VLS)

ICRISAT pioneered an effort to develop a longitudinal panel database, which could be used for tracking development pathways and testing several theories and policy impacts. The database has helped scientisis identify and understand socioeconomic, agrobiological and institutional constraints to agricultural development in the SAT. The villages also served as the real-world platforms for testing technologies generated by ICRISAT.

The longitudinal data from SAT villages in Africa and Asia has made it possible for the international scientific community to analyze and understand very complex behavioral issues of small farmers. These include the pioneering work on measurement of attitudes to risk, studies on time preference, time allocation, labor market, land use intensification and farm mechanization. Useful results from these studies, now used worldwide, have made significant contributions to agricultural economics and inspired similar work in other countries. The VLS datasets provided a basis for testing and refining several new theories and methodologies in the social sciences. A number of quality publications) including several graduate theses and books, emerged from these datasets. Research publications and the subjectwise distribution of theses are given in Table 34.

Some governments have adopted some of the policy recommendations while the datasets are still in high demand by scientists interested in examining the changes and dynamics of rural welfare and resource use patterns. Although this work has generated several IPG benefits, it is difficult to attribute changes and desired outcomes directly to this research.

NARS partners in ICAR and agricultural universities in India are now applying VLS methods and approaches across diverse locations. This will broaden generation of useful micro-level data for decision making not just in SAT environments but also in other agroclimatic regions

Table 34. Publications, theses and dissertation areas using VLS databases (up to 2002).

Publication media		Topics covered in dissertations	
M.Sc & Ph.D dissertations	38	Risk and insurance	7
Journal articles	106	Resource management	9
Research papers	108	Rural livelihoods and institutions	7
Special-purpose surveys	21	Labor economics	9
Biological investigations	18	Production economics	4
Books	4	Land tenure	2
Total	295	Total	38

in India. This has allowed the expansion of the VLS to an additional 49 locations since 2003, distributed across the country through collaboration with NCAP (ICAR). In India, socioeconomic statistics is published with a lag of 5-6 years. However VLS can provide useful data that would facilitate decision making in a relatively short period of time. Similarly in Africa, the VLS methodology and approach that started in Burkina Faso has a good potential for spillover to other African countries like Niger, Zimbabwe, Malawi, Kenya, etc. The panel data from Indian and African locations needs to be regularly analyzed to inform important policy decisions and R&D priorities for ICRISAT and its partners. This is a key contribution of the wealth of micro-level data collected across sites over a period of years.

Some examples of the useful impacts VLS generated for research and development policy are cited.

- Farmer risk behavior and implications for technology design and development in the SAT (Binswanger et al. 1982).
- Given the required infrastructure, marginal returns to investment in low potential areas may be comparable to more favorable areas (Fan et al. 1998).
- Adoption of improved seed is generally a precursor to the adoption of other improved crop management practices. These adoption rates are closely related to the degree to which households are integrated into the wider product market. This finding has led to the strengthening of seed systems development and market integration (Walker and Ryan 1990).
- Targeting technologies specifically for small and marginal farmers may not be an effective strategy for poverty reduction because of the parity in factor use ratio and risk preferences among them. This finding influenced plant breeding strategies and farming systems research approaches. It was acknowledged that it was preferable to address factor market distortions and imperfections in order to benefit poor farmers rather than search for technologies with particular relevance to them (Binswanger and Ryan 1979).
- In the design of watershed-based interventions, the VLS work on land fragmentation proved to be crucial. Unlike in irrigated agriculture, the VLS found that in the SAT, land fragmentation was not a major constraint to improving productivity and that it had risk diffusion benefits. Hence land consolidation would not necessarily lead to improved welfare (Ballabh and Walker 1986).
- The findings that seasonality and covariate risk limit the scope of credit societies to finance agricultural investment in the Indian SAT had an effect on rural credit policy (Jodha 1978).
- The Government of India recognized the need for more flexible lending policies for dryland agriculture (Walker and Ryan 1990).
- VLS was instrumental in documenting the importance of common property resources in the incomes and nutrition of the poor (Jodha 1985).
- VLS findings were used to devise program components in biofuel and fodder production (Kelley and Parthasarathy 1994).
- The VLS databases were used to incorporate development components in relief works in India, especially in the case of minor irrigation and water harvesting structures (Krishnagopal and Ryan 1983).

Research Evaluation and Impact Assessment (REIA)

Impact assessment studies at ICRISAT attempt to measure those dimensions most important to the poor, and to the broad mission of the CGIAR. Twenty-four case studies of adoption and impact have been completed or are in progress. They deal with food security, biodiversity, increased farm income, sustainable productivity, benefits to women, spillover effects and NARS capacity building. ICRISAT's impact studies, conducted jointly with national and local institutions, are widely distributed across the SAT.

REIA work is carried out in close partnership with national programs and other partners. This was facilitated through training modules for capacity building and skill development. The development of the training modules on REIA was a collaborative project between ICRISAT and the Australian Centre for International Agricultural Research (ACIAR). Additional modules were based on ICRISAT's training program on REIA conducted for various countries in Africa and Asia. More modules were added during the Training Workshop on Impact Assessment held at Kasetsart University, Bangkok, in 1998.

Modules completed include those on basic methodology, empirical issues, research evaluation, minimum datasets, research costs in project-level evaluations, cost analysis, adoption, research lags, probability of success, research spillovers, new products, supply shift assumptions, validity of claims on impact and other methodological issues. Hands-on exercises using research evaluation models have also been developed and piloted in several workshops held in Asia and Africa. Completing a training manual is important in strengthening the capacity of NARS partners to conduct impact assessment studies. It facilitates the technical backstopping function of ICRISAT as it seeks to undertake joint impact studies with national program partners.

Some lessons from impact studies

- The role of a strong ICRISAT/NARS partnership, close collaboration between farmers and researchers and complementary investment in seed production for successful technology development and dissemination. This lesson was derived from case studies conducted on Okashana 1 in Namibia, groundnut in Vietnam and sorghum in Botswana (Rohrbach et al. 1999; Bantilan et al. 1999a).
- The role of cultivar traits important to small farmers for the adoption of improved pearl millets. These include high yield and downy mildew resistance; short duration and good grain quality- and good fodder quality in Rajasthan, Gujarat and Haryana. This lesson was obtained through pearl millet adoption and impact studies conducted in five major states (Maharashtra, Gujarat, Rajasthan, Haryana and Tamil Nadu) of India (Deb et al. 2000; Ramasamy et al. 1999; Ramasamy et al. 2000).
- The important role of a functioning seed sector for the adoption of new varieties.
- The critical role of collective action, property rights and benefit sharing for the sustained participation and adoption of watershed technologies.
- The role of social capital for the successful uptake, diffusion and impact of agricultural innovations (Parthasarathy and Chopde 2000).
- The need to incorporate views and perceptions of both genders of the farming community during technology generation and development. A research and development agenda that incorporates analysis of gender disaggregated farmer perspectives is likely to lead to a more appropriate and acceptable technology that will gain wider adoption (Rama Devi and Bantilan 1997; Padmaja and Bantilan 1998).
- The need lor technological innovations to offer new- opportunities for diversification of livelihood strategies, especially for farmers working under conditions of uncertainty or high risk. Technologies should address productivity problems in novel ways, by identifying new opportunities to empower farmers and widening the basket of options to suit different conditions. This has contributed to the development of OPVs which are high yielding and suit different patterns of rainfall, soil types and growing periods in the SAT (Bantilan et al. 1999b).

Methods for NRM impact evaluation

Recently, ICRISAT has also taken the lead in developing methods for scientific assessment of the impacts of NRM interventions. Because of its complexity resulting from multi-dimensional effects and valuation problems, it has been difficult to systematically evaluate the effects of R&D investments on NRM. This is contrary to the routine application of impact evaluation methods for agricultural technologies, especially new varieties. An international workshop was convened at ICRISAT in Dec 2002 to discuss recent advances in NRM impact evaluation methods (Shiferaw and Freeman 2003). Selected methods of NRM impact assessment are now being pilot-tested in selected areas in partnership with national programs and ARIs.

Research on the impact of fertilizer market reforms in Africa

This study examined the impact of fertilizer market reforms on the adoption behavior of smallholder farmers in Kenya. The underlying hypothesis was that market reforms have led to changes in farmers' response, which had important implications for technology development and testing. The study was developed through a collaborative project involving ICRISAT, the Kenya Agricultural Research Institute (KARI) and Moi University. The potential beneficiaries of the project were researchers developing and testing improved soil fertility technologies. It was also expected that this would lead to more practical soil fertility management options that would benefit smallholder farmers. The direct impact of this research was that KARI refocused its soil fertility research program and started conducting trials with a wider range of soil fertility inputs. Several of these treatments involved smaller quantities of fertilizer that farmers were observed to be using. These results - farmers' inclination to start experimenting with smaller amounts of fertilizer following a liberalized market - quickly spread and influenced many soil fertility management practices and approaches in the region. To date, research programs in Malawi, Tanzania and Zimbabwe are actively conducting experiments with sub-optimal levels of fertilizer (Ade Freeman. personal communication 2003).

Research on rural markets

The manner in which an improved understanding of market constraints and opportunities can enhance the adoption of improved technologies was examined. The research was a component of a wider project on improving productivity of pigeonpeas in ESA. It involved a broad range of partners including NARS, NGOs and the private sector. The result of this and other research led to the development of a conceptual framework that links technology development, technology dissemination and market institutional innovations to reduce poverty. A number of partners from R&D organizations are using this framework to implement projects in Kenya, Tanzania, Uganda, Malawi and Mozambique. The beneficiaries of these projects are smallholder farmers who stand to gain from higher incomes generated from the project activities (Ade Freeman, personal communication 2003).

Research on rural livelihoods

Factors inhibiting as well as enhancing the ability of poor people to work their way out of poverty were researched. A collaborative effort between ICRISAT, the University of East Anglia and researchers in Kenya, Tanzania, Uganda and Malawi, findings from the study are influencing current thinking on poverty reduction policies by donors and policymakers in these and many other African countries. The beneficiaries are policy-makers and development planners who formulate policies and strategies with an improved understanding of the micro-level realities of rural households (Ade Freeman, personal communication 2003).

Consumer preference for foodgrain quality

A methodology was developed for estimating consumer preference for food crops based on a laboratory analysis of market samples lor key quality parameters and the collection of relevant data on price, lot size, etc, from traders. The estimated coefficients For selected quality parameters from the market samples can be used for large-scale screening of newly released varieties of particular crops. Recently, the methodology was applied on chickpeas in India through a collaborative study with Muresk Institute of Agriculture (Australia) (Agbola et al. 2001; Agbola et al. 2002).

Seed policy reform

Recently, ICRISAT supported a comparative review of policy discussions relating to seed regulatory harmonization in West, East and Southern African. ICRISAT identified a range of factors limiting and supporting the success of each of these endeavors. This was discussed with key stakeholders from each region in a summary workshop held at Bulawayo. This was the first time some of the key stakeholders involved in these regional policy discussions had met. This has created opportunities to develop a new-project to facilitate seed policy discussions across the three regions. The Institute has been asked to be in charge of implementing policy analyses relevant to seed policy reform. One of the key issues raised by this project and the follow-on discussions was the value of regionalized release and registration of new varieties (David Rohrbach, personal communication 2003).

Regionalized breeding

During the last four years, ICRISAT has been spearheading the development of regionalized breeding programs designed to more firmly link NARS breeders with one another and promote technology spillovers in Southern Africa. Statistical analysis has been used to identify a small sub-set of experimental stations that can be targeted for regional breeding since they represent the major agroecological zones in Southern Africa. National breeders have shown interest in taking the lead in organizing and implementing targeted programs with anticipated regional benefits such as breeding programs for drought resistance, tolerance to *Striga* and for photoperiod-sensitive sorghums. ICRISAT and national breeders remain challenged by the fact that national research managers prefer to focus attention and funding on national rather than regional problems. However, NARS scientists now recognize the value and importance of technology spillovers (David Rohrbach, personal communication 2003).

Linking technology design and markets

In an effort to strengthen technology adoption and impacts, SADC/ICRISAT SMIP developed new-strategic linkages between scientists and traders or grain processors. This was first done by linking variety development, dissemination and trade in the context of the milling and brewing industries of Zimbabwe. The SMIP steering committee was broadened to encompass representatives of the input trade, product trade and NGOs. A wider range of NARS and NGOs are now keen on this strategy. During the last few years, new programs have been initiated to link variety selection, seed supply, crop management advice and trade for sorghum, groundnut, pigeonpea and chickpea in Kenya, Uganda, Tanzania, Malawi and Mozambique. A similar program is being planned for South Africa (David Rohrbach, personal communication 2003).

Market access, trade and agricultural productivity

Studies at ICRISAT in the 1980s found that market access and free trade (internal trade without restrictions) led to an increase in agricultural production in India (von Oppen and Gabagambi 2002). These findings were discussed in various platforms. Although it is difficult to attribute this to ICRISAT research, starting from the mid-1980s, the Government of India started lifting trade restrictions on internal trade for foodgrains, pulses and oilseeds. Free trade is now advocated at the global level.

8.3. Knowledge base on SAT production systems

In addition to the VLS databases for which ICRISAT is well known, a number of other databases were developed over time covering district-level data, technology inventory and technology adoption. These are IPGs widely and freely available to researchers and development planners.

- Varietal and plant material database: This is a catalog of the genetic materials developed through ICRISAT's collaborative research with N'ARS on its five mandate crops - sorghum, millets, groundnut, chickpea and pigeonpea.
- Database on ICRISAT/NARS technologies in Asia and Africa: This documents the data collected from adoption and impact case studies. It also covers the results of a recent survey by ICRISAT scientists from all its regional centers. Scientists from a wide range of disciplines have identified final and intermediate scientific products. The dataset compiled for the two regions of Africa represents a first attempt to inventory the technology options developed by ICRISAT in collaboration with the NARS in Africa.
- Database on research priority setting for medium-term planning (MTP): This database is maintained and updated to support the process of research priority setting at ICRISAT.
- Impact assessment database: This is a set of *primary data on adoption/impact and* related variables generated from on-farm formal and informal surveys conducted for the case studies on ICRISAT/NARS improved technologies.
- District-level database: Collected from secondary sources, this includes data on more than 200 variables lor 450 districts in India covering the period from 1966 to 1998. This comprehensive dataset has been extensively used by lead research institutes. universities and CG centers. During the last *3-4* years, a number of requests for them have been processed.

8.4. Summary and conclusions

The social science team at ICRISAT works closely with agrobiological and biophysical scientists in the area of crop improvement and natural resource management. Hence, the IPGs discussed in relation to the mandate crops and NRM across regions have had social science inputs. Nevertheless, social science research has also generated more specific research products with a high potential for spillover across regions and countries. This chapter has reviewed some of these research outcomes and the experiences in terms of impacts in different regions of Africa and Asia.

The review shows that the socioeconomics work has resulted in new research methodologies, databases, policy recommendations, policy briefs, training materials, etc, which have generated important IPGs benefits within the SAT and worldwide. The unique longitudinal datasets and several seminal studies on resource use and economic behavior of rural households generated through the VLS are prominent examples. These studies which started in Asia quickly expanded to cover some countries in WCA and lately a few places in ESA Results from the analysis of longitudinal data have enhanced the understanding of the wide-ranging changes taking place in the SAT and how R&D investments could be better targeted to address the changing circumstances. The future of SAT agriculture and designing more sustainable development paths require a better understanding of the micro and meso-level impacts of macro and global changes.

The micro-level datasets provided a basis for testing and refining several new theories and methodologies in social sciences. Attributing outcomes to research products of the socioeconomics group is not easy. However, given the increasing awareness of policy-makers and the research community through studies and policy briefs, many of the policy recommendations are likely to have influenced policy decisions and R&D priorities for the SAT More focused and in-depth research is needed to assess the actual extent of spillovers and impacts of the VLS work. The resulting REIA methodology invokes the systematic tracking of the spread of varieties and other technologies in a target domain.

Among *the other* methodologies developed included those for estimating consumer preference for food crops based on laboratory analysis of market samples for key quality parameters and market prices. This was expected to facilitate the inclusion of market and consumer preferences within crop breeding and improvement programs. Recendy. ICRISAT has also taken the lead in developing methods to assess the impacts of NRM interventions.

Research on the impact of fertilizer market reforms in Eastern Africa identified strategies to improve adoption of fertilizers by small farmers. Similarly, the research on rural markets in Africa led to the development of a conceptual framework that links technology development, dissemination and market institutional innovations for poverty reduction. A number of partners from R&D organizations are using this framework to implement projects in Kenya, Tanzania, Uganda, Malawi and Mozambique.

The work on seed policy reform in Africa led to a comparative review of policy discussions relating to seed regulatory harmonization, which has stimulated inter-country collaboration in seed policy reforms. The work in Southern Africa linking technology design and markets has also inspired new programs to link variety selection, seed supply, crop management advice and trade for sorghum, groundnut, pigeonpea and chickpea in Kenya, Uganda, Tanzania, Malawi and Mozambique.

9. Capacity Building and South-South Collaboration

9.1. Introduction

Sustained improvement in the productivity of SAT agriculture through enhanced agricultural research, extension and development requires strong and effective institutions. Building the institutional capacity for research and development among its national program partners has therefore been an important goal of ICRISAT's engagements in the SAT in the last 30 years. The Institute has intentionally followed the process of partnership-based research for development, which played a crucial role in developing capabilities within several NARS partners in the south through hands-on training and other outreach activities. Its capacity-building strategy lays emphasis on a diverse and learning-by-doing approach, in which collaborating scientists and ICRISAT staff jointly work through the practical problems of research planning, fund raising, project execution, monitoring, information exchange and impact assessment. Through this process, partners absorb the whole range of technical and management skills required for sustaining a research-for-development thrust into the future. The capacity-building initiatives include training programs, regional and global networks and seminars and workshops organized by ICRISAT and its partners. Each of these contributes to capacity building within the national programs and fosters south-south collaboration in terms of sharing scarce information and available skills. ICRISAT has also played an important role in catalyzing the integration of scientists from the national programs into the global scientific community.

ICRISAT offers three types of training-oriented capacity-building opportunities: a) scholarly studies, b) joint project attachments and c) specialized skills. In addition to the training activities, ICRISAT hosts and provides technical and management support to several regional networks in Asia and Africa. Apart from serving as vehicles for the widespread testing and evaluation of new technologies, networks contribute to *capacity* building and timely exchange of scarce skills and information in the national programs. The networks also organize regional and international workshops, conferences and meetings that contribute to sharing of experiences and improving the qualitv ol research products.

Until 1996, apart from customized and degree-oriented training activities, ICRISAT also provided in-service training programs (for six months), especially to technicians in different disciplines from Asia and Africa. This has contributed to enhancing the capacity of national program partners towards improving the effectiveness and efficiency in carrying out their research and development programs. It may be noted that despite the increasing recognition of the need for enhancing the capacity of national program partners, especially in the African locations, funding limitations have strongly affected the Institute's capacitv to vigorously promote and support training and capacity-building initiatives. The mid-term plan for 2003 and beyond identifies capacity building as one of the Global Impact Target Areas (GITAS) which may perhaps help in garnering the funds required for revitalizing and strengthening the Institute's capacity-building schemes.

The following sections briefly oudine the capacity building efforts related to training activities and networks for south-south collaboration that ICRISAT has facilitated, nurtured and supported in the SAT. The report is not exhaustive since the periods covered are quite long (30 years) and some capacity building efforts by individual scientists across regions were often not clearly documented. However, an effort has been made to highlight major and outstanding achievements in national and international capacity building for R&D in the SAT.

9.2. Training activities

Three types of training-oriented capacity-building opportunities offered by ICRISAT are summarized below.

Research scholars

Research scholars are candidates working towards a degree program (mainly M.Sc. or Ph.D.) and carrying out their thesis research at an ICRISAT location, often after completing their course work at a recognized university, either in a developing or developed country. In the spirit of learning-by-doing, the diesis work must congruent with a priority area of the shared ICRISAT-NARS research agenda, involving the scholar in an active research thrust. During their association with ICRISAT, research scholars are provided close follow up and guidance for the proper implementation of agreed research protocols.

During 1974-02, a total of 394 research scholars received training at ICRISAT-Patancheru, of which 58 were from 16 African countries and 4 were from Brazil (Table 35). Within Asia, most of the scholars were from India (222) and about 13% of the total number of scholars were from other developing Asian countries. This suggests that a good number of

Table 35. Capacity building initiatives undertaken at ICRISAT-Patantheru from different regions (1974-2002).

Type	Eastern and Southern Africa	West and Central Africa	Latin America	Asia (excluding India and Japan)	India	Other countries	Total
Research scholars	41 (9)[a]	17 (7)	4(1)	52(13)	222	58 (10)	394
Joint project attachments	130(16)	43 (12)	25(5)	4-4(20)	369	57 (19)	1098
Specialized skill course	234 (16)	40 (10)	8(5)	268(18)	591	141 (17)	1282
In-servicetraining	452 (18)	437 (17)	33(9)	296(16)	4	11 (3)	1233
PDF	6 (4)	6 (3)	1	3 (2)	40	52 (10)	108

a. Figures in parentheses are the number of participating countries.

Source: Compiled from ICRISAT's Learning Systems Unit database

scientists from the developing regions of the SAT improved their research skills by participating in advanced training and research opportunities provided by ICRISAT in Asia.

At ICRISAT's Africa locations, 250 research scholars were trained for degree programs (Table 36). Most of them were trained at ICRISAT-Bulawavo (150) and ICRISAT-Niamey (80), ICRISAT's two regional hubs in Africa. ICRISAT-Bulawayo supported training in advanced degree programs for scientists from 10 SADC countries. Similarly, ICRISAT-Niamey supported candidates from WCA. These scientists received degrees from universities in the USA, Canada, Brazil (for Portuguese speakers from Angola and Mozambique) and various African institutions. At other ICRISAT locations in Africa, there have mainly been in-country training programs (13 in Nigeria, 6 in Mali and 1 in Kenya).

Joint project attachments (Research Fellow/Visiting Scientist)

Joint project attachment is not a degree-oriented program but provides a practical yet leading-edge opportunity for partners to learn-by-doing while contributing to the shared ICRISAT/NARS research project agenda. This opportunity is also provided for research support and administrative functions, because these too are important to the overall institutional capacity building. The duration of the joint project attachment varies depending on the task and objectives of the participant. A total of 1098 scientists were trained at ICRISAT-Patancheru under this category from 1974 to 2002 (Table 35). This included 130 scientists from ESA, 43 from WCA and 25 from Latin America. A large proportion of scientists (about 43%) were from Asia (excluding India). Twenty-one scientists received such training at African locations and about half of them at ICRISAT-Bamako (Table 36).

Specialized skill courses (apprentice)

Specialized skill courses on new cutting-edge technologies, research methods, concepts and important issues are held from time to time as ICRISAT acquires the relevant expertise. By gaining these skills, the national partners are better equipped to contribute to the shared research-for-development agenda. This kind of training has so far benefited 1282 scholars, including 591 from India and 268 from other Asian countries. About 234 scholars from ESA, 40 from WCA and 8 from Latin America received such training at ICRISAT-Patancheru.

Table 36. Number of national program staff trained at ICRISAT's locations in Africa (1976-2002).

ICRISAT	Research scholars	Joint project attachments	Specialized skill course (apprentice)	In-service training	PDF	Total
Kenya	1	1				2
Malawi			53			53
Mali	6	12	88	145	1	252
Mozambique			3			3
Niger	80	6	78	46	6	216
Nigeria	13	2	12	12		39
Zimbabwe	150				2	152
Total	2?0	21	234	203	9	717

Source: Compiled from data provided by ICRISAT locations-

Specialired skill courses were also arranged by ICRISAT at its African locations where 234 scholars received training (Table 36). Such training was provided in all ICRISAT locations in Africa except Kenya. However, a signiiicant number of scholars from East Africa have received such training at ICRISAT-Patancheru.

In-service training

The 6-month in-service training to technicians working in the national programs was provided at ICRISAT-Patancheru from 1974 to 1996. This was meant to enhance the capacity of technicians to conduct quality research. A total of 1233 national staff members were trained in various disciplines such as plant breeding, plant protection, agronomy and natural resource management. About 72% of the technicians trained at ICRISAT-Patancheru were from 35 African countries and about 24% from Asian countries other than India (Table 35). During 1997, this training program was discontinued in favor of advanced degree programs considered important by NARS.

9.3. Networks

Agricultural research results could be applicable in a wider environment but adjustments are often required to ensure that these results are locally relevant through applied and adaptive research. With the advent of communications, research results have been disseminated widely and humanity has largely benefited from the technological progress. These exchanges of research results, information and technology were informal and sometimes took a long time to spread to farmers. These informal linkages led to research collaboration among institutions, and expanded to regional, country and global levels. Networking became highly popular in ICRISAT in the 1980s, as a means to link researchers in an effort to avoid duplication. It was also meant to engage a critical mass of scientists to solve specific problems, at a relatively low cost. It is a tool to strengthen agricultural research in both developed and developing countries. Networks enhance interaction and exchange of knowledge and materials among members. Thus, an agricultural research network is a group of individuals or institutions linked together because of a commitment to collaborate in solving or addressing a common agricultural problem or set of problems, and to use the existing resources more effectively.

ICRISAT provides direct technical oversight and backstopping to CLAN and five networks in Africa: VVCASRN for sorghum in West and Central Africa, ROCAFREMI for pearl millet in West and Central Africa, SMINET for sorghum and pearl millet in Southern Africa; the East and Central Africa Regional Sorghum and Millet Network (ECARSAMN) for sorghum and millets in Eastern and Central Africa and the Soil and Water Management Research Network for Eastern and Central Africa (SWMnet). ICRISAT's role in these networks along with some important achievements are given in Table 37.

The purpose of the network(s) is to enhance collaboration between NARS and ICRISAT, and among different NARS, which will help meet the common elements of the mission of both NARS and ICRISAT, especially in capacity building. True partnership, shared responsibility and joint ownership are the pillars of network operations. The success and impact of a network depends on joint responsibility and action among members and sponsors.

The scope and mission of these networks are described in brief in the following sections.

Cereals and Legumes Asia Network (CLAN)

The Cereals and Legumes Asia Network is a collaborative research and technology exchange network. It was formally launched in 1992 by merging the Asian Grain Legumes Network (1986) and the Cooperative Cereals Research Network (1988). CLAN activities are currently concentrated in 13 Asian countries (Bangladesh, China, Iran, India, Indonesia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam and Yemen). ICRISAT provides the coordination unit and the technical and backup support lor ICRISAT's mandate crops and related natural resource management activities.

The overall objective of this network is to increase productivity and production of coarse grains (sorghum and pearl millet) and grain legumes (groundnut, chickpea and pigeonpea) in the participating countries through an upgraded and intensified collaborative research and development network to achieve the goal of improving food availability, better nutrition and increased income to small farmers in rainfed areas.

Major activities

- Conducting collaborative in-country research based on the capability and needs of the national programs, targeted towards generating technologies to be adopted by farmers
- Strengthening crop improvement programs through the exchange of germplasm and breeding material to build viable breeding programs in XARS
- Conducting farmer-participatory on-farm adaptive research to enhance technology adoption
- Sharing information and knowledge among member countries
- Capacity building of NARS research and development programs through tailored learning-by-doing programs

Table 37. Description of networks in Asia and Africa coordinated/supported by ICRISAT.

Networks	Region and countries	Year set up	ICRISAT's role	Major source of funding	Some achievements
CLAN	13 Asian countries	1992	Coordination unit at ICRISAT-Patancheru; ICRISAT provides technical and backup support	Asian Development Bank	221 varieties released
WCAMRN, ROCAFREMI	14 WCA countries	1991	Coordination unit at ICRISAT-Niamey; ICRISAT provides technical and administrative support	Swiss Development Cooperation	Coordinated research projects where research activities are shared among NARS scientists; 29 varieties released
WCASRN, ROCARS	16 sorghum-producing countries of WCA	1992	Coordination unit at ICRISAT-Bamako; ICRISAT provides technical and administrative support	USAID	Coordinated research projects where research activities are shared among NARS scientist, 45 varieties released
SMIP	12SADC countries	1983	ICRISAT-Bulawayo coordinates research and training activities	USAID/CIDA/ GTZ	46 varieties released and about 900 staff trained
SMINET	12SADC countries	1999	Coordination unit at ICRISAT- Bulawavo; ICRISAT provides technical and administrative support	USAID	Contributed to the achievements of SMIP
SWMnet	10 East African countries including Madagascar	2002	ICRISAT-Nairobi is a scientific partner and provides a coordination unit; ASARECA is an implementing agency	EU	Newly established
ECARSAMN	10 East African countries including Madagascar	2002	ICRISAT-Nairobi is a scientific partner and provides a coordination unit; ASARECA is an implementing agency	EU	Newly established

- Organizing regional workshops and meetings to exchange research results and information and developing collaborative research plans
- Setting up working groups (or consortia) to address high priority regional production constraints, such as bacterial wilt of groundnut, botrytis gray mold of chickpea, aflatoxin management in groundnut, nitrogen-fixing legumes in Asia and groundnut viruses in the Asia-Pacific region
- Exchange of scientists' visits between ICRISAT and NARS and among NARS to enhance interaction, information exchange and research collaboration
- Supporting the execution of special bilateral and multilateral R&D projects in Asian countries, such as the Sri Lanka-ADB-ICRISAT Pigeonpea project, UNDP/FAO Asian Grain Legumes On-farm Research Project and several ADB-funded multilateral R&D projects
- The exchange of germplasm and breeding material, which enables NARS to have access to improved germplasm and breeding material from ICRISAT and other member countries. ICRISAT supplied 52,172 germplasm accessions, 62,306 breeding lines, 1410 trials and 1799 nurseries to member countries. The network member countries have also released 221 varieties (36 of sorghum, 53 of pearl millet, 59 of chickpea, 26 of pigeonpea and 47 of groundnut) using germplasm and breeding

material provided by ICRISAT (CLL Gowda. personal communication 2003).

Exchange of scientists between ICRISAT and NARS and among NARS enhances professional interactions, exchange of information and research collaboration. This would facilitate and strengthen ongoing research in member countries and ensure that improved technologies are adapted and adopted by the farmers. Five hundred and twenty two scientists from ICRISAT have made 406 visits to Asian countries (other than India) and spent 5836 days assisting NARS scientists. Six hundred and forty NARS scientists made 310 visits to ICRISAT or ICRISAT-supported meetings and workshops and spent 5648 person days on R&D activities (CLL Gowda, personal communication 2003).

West and Central Africa Millet Research Network (WCAMRN, ROCAFREMI)

The West and Central Africa Millet Research Network, better known by its French acronym ROCAFREMI, was set up in 1991 with its coordinating office at ICRISAT-Niamey (Niger). Its mission is to catalyze millet production and the sustainability of millet-based cropping systems. ROCAFREMI is funded by the Swiss Development Corporation (SDC).

An initiative of NARS, the Institute of Sahel (INSAH), ICRISAT and the Semi-Arid Food Grain Research and Development (SAFGRAD), ROCA-FREMI is a tool, and not an institution, of regional cooperation for improving millet production and utilization in 14 WCA countries (Benin, Burkina Faso, Cameroon, Chad, Ivory Coast, Gambia, Ghana, Guinea-Bissau, Mali, Mauritania, Niger, Nigeria, Senegal and Togo). INTSORMIL and a few NGOs too participate in the network.

Since 1991, ICRISAT has presided logistical and technical support to ROCAFREMI. One of the objectives of this network is capacity building, involving the training of scientists, technicians, farming communities, extension agents and small entrepreneurs, especially women.

The network translates its vision into concrete action through network projects carried out by member countries in collaboration with partner institutions. The following four research projects were developed in 1991:

- Supply of suitable varieties and seeds to farmers
- Research on the bioecology of panicle pests and the development of control methods for farmers, the important pests being stem borer and head miner
- Improvement in the control of downy mildew, one of the most devastating diseases of millet
- Improvement of millet-based cropping systems.

In 1997, the first three projects were terminated but were modified and translated into the following three activities:

- Promotion of millet through investment in processing technologies
- Integrated pest and disease management
- Development of improved varieties and seed production with farmer participation.

A few countries with a lead center conduct research on each project of ROCAFREMI. The results are shared among the participating countries. Capacity building among the participating countries and NARS is an integral part of each project.

West and Central Africa Sorghum Research Network (WCASRN, ROCARS)

In 1990, a joint initiative was launched by INSAH and the Special Program on African Agricultural Research (SPAAR), in an effort to develop a NARS-driven system for regional co-operation. This led to the creation of a regional sorghum 'pole' in 1992; by member countries of CILSS. This did not include all the sorghum-producing countries of WCA. At a regional workshop in March 1995, the membership of the 'pole' was expanded to include all sorghum-producing countries of WCA. The 'pole' concept was replaced by a collaborative research network - the West and Central Africa Sorghum Research Network, often referred to by its French acronym ROCARS. The network office is based at ICRISAT's research station at Samanko near Bamako. ICRISAT provides the network with technical and administrative support. Scientists from ICRISAT and national programs actively plan and execute the activities of this network, which is financially supported by USAID.

The network's overall objective is to improve sorghum production, productivity and marketing, thereby contributing to general food security and economic well-being in sorghum-producing countries of this region.

To achieve these objectives, the network involves itself in four main activities, including human capacity building. Though it relies on national research programs lor its activities, a majority of them do not have sufficient human and financial resources to enable them to face the constraints to sorghum production. For example in 1999, 55 NARS scientists were trained at ICRISAT-Bamako in the areas of on-farm testing, experimental design and data analysis, seed systems analysis and participatory evaluation of new varieties.

The other activities taken up by the network include:

Varietal adaptation trial. This activity makes promising materials developed by NARS and collaborative institutions available to network members through a regional adaptation trial.

On-farm evaluation of promising varieties. The purpose of this activity is to evaluate on-farm, advanced and improved sorghum varieties developed by ICRISAT and NARS, thereby promoting technology exchange among farmers.

Identification of partners for seed production and distribution. A weak link in sorghum improvement is the lack of effective production and distribution of seed of new sorghum varieties or hybrids. The objective of this activity is to develop new partnerships with farmers, NGOs and development investors for effective and sustainable seed production of new sorghum varieties. Participatorsy seed production projects were initiated in six countries with farmers' associations and women groups. Participants were imparted training in producing good quality seeds and their conservation. In Mali, produced seeds are stored in a village seed bank to be made available to more farmers during the following cropping season.

Enhancement of market-driven opportunities. Lack of opportunities for processing and value addition are contributing to poor sorghum utilization. There is a need to explore utilization and marketing options in order to create new income-generating opportunities for the poor. The objectives of this activity are: a) to transfer sorghum-based products and processing technologies to end-users and b) generate new sorghum-based products. Seven projects on sorghum utilization were initiated across the sub-region. New sorghum-based products were developed and diffused in Chad and Togo. Sorghum-based biscuit was produced and introduced into markets in Mali. Suitable sorghum varieties for end-uses such as bread, biscuits, *confectioneries,* malting *and* local food have been characterized in Ghana and Mali.

The Sorghum and Millet Improvement Program (SMIP) for Southern Africa

The Sorghum and Millet Improvement Program was launched in 1983 under the auspices of SACCAR. Its main purpose was to improve food security in drought-prone areas of the SADC region by increasing the productivity of sorghum and pearl millet grown by resource-poor farmers, and to foster the efficient utilization and conservation of natural resources. It is a good example of a regional consortium conceived, facilitated and supported by ICRISAT to address the commonly shared problems of sorghum and millet improvement in the SADC region. SMIP was conceived as a four-phase program. Phase I (1983-1988) focused on germplasm collection and exchange, variety development, training for national scientists and technicians and infrastructure development. In Phase II (1988-1993), activities were expanded to include economics and policy studies and food technology research. This research agenda was modified in Phase III (1993-1998) with greater emphasis being placed on technology exchange and collaboration with a wider range of partners including NGOs and the private sector. This change was made to enhance the delivery of research products. These efforts continued in Phase IV (1999-2003) with the establishment of the regional Sorghum and Millet Improvement Network (SMINET).

Some of SMIP's major outputs till 1999 before SMINET was set up, included:

- Development of infrastructure suitable for crop research at its centers and at a number of NARS research stations in the SADC region.
- Supporting the training of NARS scientists. Ninety-six (34 Ph.D., 53 M.Sc. and 9 B.Sc.) scientists from nine SADC countries were assisted in undertaking advanced degrees. Many more have participated in the in-service training courses at ICRISAT-Patancheru and Matopos Research Station, Zimbabwe.
- Collection, evaluation and characterization of local germplasm. 1769 sorghum samples and 2345 pearl millet samples were collected between 1983 and 1992.
- Evaluation of over 4075 sorghum and pearl millet cultivars for 15 grain quality traits which indicate their suitability for use in food, malting, feed and milling into flour.
- Development of improved sorghum and pearl millet varieties in collaboration with national programs. Until 1999, new sorghum (27) and pearl millet (17) varieties were released by 8 SADC countries.
- Facilitation and promotion of networking, and the regional and global dissemination of information on sorghum and pearl millet.

SMIP Phase IV's agenda builds on past successes in varietal development. The main areas of emphasis during this phase are seed delivery, crop management, grain marketing and commercialization. During this phase, a greater share of SMIP's resources is targeted to Botswana, Mozambique, Tanzania and Zimbabwe, countries in the region most dependent on sorghum and pearl millet. Research results from the pilot countries are expected to spill over to other SADC countries through networking activities.

Sorghum and Millet Improvement Network (SMINET)

The Sorghum and Millet Improvement Network provides a platform for sharing technologies across the region, further broadening the range of partners, improving the access of regional researchers and

Others to the global knowledge base and germplasm resources for sorghum and pearl millet and facilitating technology spillovers across countries. The work in Phase IV goes beyond crop improvement in that it also addresses the issue of improving crop management and linking farmers to improved marketing opportunities.

The objective of SMINET is to engage a broad range of partners in a regional approach in order to develop and promote the adoption of sustainable production, productivity, processing, utilization and marketing of sorghum, pearl millet and other high value crops fitting into the production system of the SAT in Southern Africa. Capacity building is one of its major activities.

The network publishes a bi-annual newsletter to increase the flow of information on sorghum and pearl millet research and development. Its first issue was published in Feb 2000 and the second one in Dec 2001.

Training plans in SMIP Phase IV are linked with the implementation of project work plans. Priorities are set and ranked in terms of their contribution to achieving impact, such as the training workshop on G x E (Genotype x Environment interaction) and GIS applications.

The network supports seed strategy workshops, where participants discuss current national seed strategies, public and private seed supply and distribution and problems constraining further development of the seed system. The ultimate aim of the Seed Action Plans developed by the participating countries is to build a sustainable system for producing and distributing quality seed of improved varieties. The plan should eventually shift the national seed system away from a dependence on seed imports and emergency seed distribution to a commercially-based program.

Soil and Water Management Research Network for Eastern and Central Africa (SWMnet)

ASARECA is an organization of the National Agricultural Research Institutes (NARIs) of ten countries (Burundi, Democratic Republic of Congo, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania and Uganda). It carries out its activities through 19 regional networks, programs or projects (NPPs), of which SWMnet is one. The network is supported by the European Union (EU). Many of the networks have a CG center as scientific partner to provide the necessary technical backstopping. ICR1SAT was identified by ASARECA to host SWMnet. In 1996, the working group for ASARECA's strategic plan identified 19 priority research areas with significant potential for sustaining agriculture in the region. Among them, soil-water and soil-fertility were ranked as priority 5 and 6, respectively. Further, in the agrosystems/commodity matrix, soil-water and soil-fertility were the only research themes identified as priority areas by all the countries and for all agrosystems. Based on this analysis, the ASARECA Committee of Directors initiated the process of developing a network that enables the region to harness and benefit from collaboration on issues related to soil-fertility and soil-water management.

The first planning meeting for the proposed network was held in Entebbe, Uganda, in June 1998. On ASARECA's request, ICRISAT participated in the meeting and contributed to the drafting of a proposal to establish SWMnet. ICRISAT was identified as the IARC to backstop the network. It was designated as the implementing agency for the proposed network. The proposal was later discussed in detail at various national and regional meetings. All the ASARECA members agreed to participate in the network. This was followed by a Strategic Planning Workshop held at Arusha, Tanzania, in June 2001, at which the network's structure was finalized. While ICRISAT continues to be its implementing agency (it has now-been redesignated as the scientific partner) and supports the network administration, the International Water Management Institute (IWMI) and ICRISAT were identified for technical backstopping. The proposal later received financial support from the EU. The network coordinator, who has recently joined, is based at ICRISAT-Nairobi.

SWMnet's objectives are to (Hatibu et al. 2002):

- Provide a mechanism for avoiding duplication by fostering collaboration, partnership and coordination across countries, programs, projects, individual researchers and other stakeholders
- Provide economies of scale and scope, especially by fully exploiting the opportunities made possible by-advances in information technology
- Increase the impact of research by sharing experiences and the demonstration of successful technologies between scientists, with farmers and between networks, while recognizing the benefits to participating countries with limited capacity
- Assist in capacity building of NARS in the participating countries by identifying, enlisting and training capable researchers, improving the sharing of information and expertise within and between NARS, improving the utilization of existing human resources and increasing the interactions between stakeholders
- Enhance the effectiveness of other international and regional efforts by creating an environment that is conducive to productive collaboration, by-improving access to information, enhancing the dissemination of new ideas and technology and increasing scientific exchanges and collaborative projects

- Promote the wide dissemination and utilization of research findings by ensuring drat good research findings in SWMnet are not lost, connecting researchers to potential users of technologies and information from research and expanding the range of environments for technology testing.

Using its previous experience with network coordination, ICRISAT is to support the network in:

- Establishing and running the network's coordination unit
- Promoting collaboration and partnership between various stakeholders to increase the impact of soil and water management research
- Promoting the wide dissemination and utilization of its own research findings as well as those from other CG centers and NARS
- Building NARS capacity to manage the soil and water resources in the participating countries.

East and Central Africa Regional Sorghum and Millet Network (ECARSAMN)

The East and Central Africa Regional Sorghum and Millet Network was started in October 2002. The network is one of the recent additions in the list of networking activities supported by ICRISAT. The network coordinator, who joined in 2003, is based at ICRISAT-Nairobi. The detailed activities and program of ECARSAMN are being completed. Its goal is to improve the incomes and food security of small-scale farmers and other stakeholders through increased productivity and commercialization of sorghum and millets. Its implementing agency is ASARECA. A scientific partner in the project, ICRISAT manages the network's routine activities, ensuring the monitoring of all activities under the work program. Capacity building is one of the five tasks envisaged in this network. Initially the network covered eight countries (Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda) but it is expected to gradually expand activities to all the 10 member countries of ASARECA.

The expected outputs from the network include strengthening NARS linkages through exchange of information and germplasm, developing collaborative research projects among participating countries and facilitating technology transfer through training of scientists and technicians.

10. Summing Up and Implications for Enhancing Research Impacts

Over the last three decades, a number of important inter-regional spillovers have been achieved through various means such as networking, capacity development within national programs and south-south collaboration. Assessing the potential for the realization of spillovers across countries and regions can aid the development of strategies for NARS and IARCs in establishing their comparative advantages in terms of achieving desired impacts. It could also help determine the scale and scope of planned research programs in specific regions. Impact studies in the past have not explicitly captured the spillover benefits of new technologies across sub-national and national boundaries. Even inter-state spillovers (in a large country like India) have not been systematically documented. In this study, we have examined with the help of selected examples from ICRISAT's research the extent of spillovers, facilitating mechanisms and constraints, and drawn useful lessons and insights for future research. These lessons will also contribute to enhancing the spillover impacts of ICRISAT/NARS technologies in ecoregions where such unexploited potential exists. Several candidates for a more comprehensive and in-depth spillover assessment have also been identified.

The lessons indicate that ICRISAT, with its wide agroecological mandate, has played a major role in enhancing spillovers by generating technologies with potential for wider adaptation across eco-regions. The documented technology transfers include inter-regional technology transfers involving international, inter-continental and inter-state spillovers within a large NARS like India. Inter-regional technology transfer is significant not only in the spillover of finished products like crop varieties but also NRM technologies, methods and some tacit research products like new concepts and increased stock of knowledge for improving the productivity of SAT agriculture. A summary of the major spillovers of ICRISAT/NARS research products for the five mandate crops and NRM is given in Table 38. The Table shows the direction and process of technology movement within each region, across regions and the actors and factors that facilitate spillovers.

Experience shows that in addition to agroecological similarity, factors such as economic conditions, local food habits and preferences, historical and cultural ties between countries, geographic proximity and institutional capacity regulate the process and extent of spillovers. ICRISAT's role as a bridge, broker, catalyst and facilitator in fostering collaboration among the developing country scientists in the areas of commodity improvement, natural resources management, human resource development and capacity enhancement steered and accelerated the process of inter-regional technology transfer. Over the years, a number of research networks in Africa and Asia have been created and hosted. Such networks are now part of larger regional organizations such as APARI, ASARECA. SACCAR, CORAF, CILSS and ECOWAS. These networks are very useful in defining regional research priorities and for ex-ante assessment of' the potential for spillovers within and across the respective regions.

This study shows that there has been a spillover of technologies in all ICRISAT's mandate crops from ICRISAT-Patancheru to Asian and African countries. The spillover of technologies from ICRISAT's African programs to Asia has been largely limited to the use of germplasm collections as valuable sources of resistance in breeding programs. There has also been limited spillover of ICRISAT crop technologies between WCA and ESA regions, indicating that the eco-regions are very distinct and that the potential for inter-regional spillover is limited. These findings have important implications for technology design and organization of ICRISAT research and need further investigation.

Despite the diverse experiences across innovations, research spillover has occurred between Africa and Asia and within the continents for many of the crops, NRM and socioeconomics research. Perhaps one of the most important spillovers from ICRISAT's work is the global utilization of its germplasm collections from Africa, Asia and other parts of the world. Table 39 summarizes the global distribution of ICRISAT's germplasm collection (a total of 109 thousand accessions from around the world). A little less than half of the collection originated from Africa. The majority of sorghum, pearl millet and finger millet accessions originate from Africa. In contrast, the majority of chickpea and pigeonpea collections originate from India and other Asian countries. Germplasm-related spillovers need to be fully documented.

The OPVs constitute major technology spillovers from Asia to some African countries. This is an important achievement from the generation of IPGs from the Institute's crop improvement work. ICRISAT-Patancheru-bred sorghum and groundnut varieties have been adopted in some countries across Africa. The adoption of sorghum varieties developed at Patancheru has been limited in WCA mainly because many of these technologies are early-maturing varieties not suitable to most of the sorghum-growing

Table 38. Selected examples of spillovers and some characteristics of ICRISAT/NARES technologies.

Technology	Where developed?	Where spilled over?	Who links to spillover?	Why/how spillover happened?
Sorghum				
S 35	ICRISAT-Patancheru	Cameroon, Chad	Cameroon, Chad NARES and ICRISAT	Need for early-maturing and high yielding genotypes. Spillover through NARES, ONDR (extension) and NGO.
ICSV 111	ICRISAT-Patancheru	Nigeria, Ghana, Benin	Respective NARES, NGOs, ROCARS and ICRISAT	Escape from terminal drought, high yield in Nigeria. Spillover through SG 2000, SACDP (local NGOs) and extension services.
ICSV 112	ICRISAT-Patancheru	Zimbabwe. Malawi. Kenya, Mozambique, Swaziland, Mexico, Nicaragua	ICRISAT and respective NARES	Need for early-matunng and high yielding genotypes. Spillover through NARS and extension.
SV 2	ICRISAT-Patancheru	Zimbabwe	National program of Zimbabwe	Need for early-maturing and high yielding genotypes. Spillover through demonstrations by extension.
Macia	ICRISAT-Bulawayo	Mozambique, Botswana, Namibia, Tanzania, Zimbabwe	ICRISAT-Bulawayo and respective NARES	Need for early-maturing and high yielding genotypes and grain yield and grain quality in the field at harvest. Spillover through demonstrations by extension and NARS.
Pearl Millet				
Okashana I	ICRISAT. Patancheru	Namibia Botswana, Malawi	ICRISAT-Patancheru ICRISAT-Bulawayo, respective NARES and NGOs	Extra early maturing, high yield under drought and resistant to downy mildew. Spillover to Namibia through demonstrations by Rossing Foundation (NGO).
SOSAT-C88	ICRISAT-Niamev/Malian NARES	Mali, Chad, Burkina Faso, Nigeria, Cameroon, Mauritania	ICRISAT programs in WCA, respective NARES, ROCAFREMI, NGOs (such as SG 2000 and SACDP in Nigeria)	Downy mildew resistant, high again yield, early maturing, thick stem. Spillover through demonstration by extension, SACDP. SG 2000 (NGOs) and seed companies in Nigeria.
G8 8735	ICRISAT-Niamey/NARES	Nigeria, Chad, Benin, Mauritania	Same as for SOSAT-C88	Extra-early maturing, high yield-high nodal tillering, bold grains. Spillover as for SOSAT-C88.
PMV 2	ICRISAT-Bulawayo	Botswana, Zimbabwe	Botswana NARES with ICRISAT-Bulawayo	Medium maturing, high yielding. Spillover through national extension service.
Groundnut				
CG 7	ICRISAT-Patancheru	Malawi, Zambia Uganda	ICRISAT-Lilongwe and respective NARES	High yield, large seeds and suitability for confectionery trade Spillover through extension and NGOs.
ICGV 87157	ICRISAT-Patancheru	Mali	ICRISAT-Bamako, Malian NARES and NGOs	High yield, resistance to foliar diseases, good food taste. Spillover through extension and NGOs.

Continued...

Table 38. *Continued.*

Technology	Where developed?	Where spilled over?	Who links to spillover?	Why/how spillover happened?
ICGV-SM 90704	ICRISAT-Lilongwe	Uganda, Malawi	Ugandan NARES, ICRISAT-Lilongwe and NGOs	Need for rosette-resistant variety. Spillover through extension and NGOs.
ICGV 86015	ICRISAT-Patancheru	Pakistan, Vietnam, Nepal	ICRISAT and respective NARES	Need for early maturing and high yielding varieties. Spillover through NARS and extension.
Pigeonpea				
ICPL 88039	ICRISAT-Patancheru	Indo-Gangetic Plains	Rice-Wheat Consortium	Need for crop diversification in cereal intensive system.
ICPL 87	ICRISAT-Patancheru	Sri Lanka	Sri Lankan NARES with ICRISAT	Need for additional pulses replacing low-yielding cowpeas and mung bean in rainfed uplands.
ICPL 87091	ICRISAT-Patancheru	China	ICRISAT, Chinese scientists and farmers	Need for erosion control in hilly areas. Protects soils and used as vegetable. Strong demand from farmers.
ICPL 87091	ICRISAT-Patancheru	Kenya	ICRISAT scientists with NARES	Vegetable pigeonpea needs.
ICP 9145	ICRISAT-Parancheru	Malawi, Kenya	ICRISAT with NARES	Will resistance needs.
Chickpea				
ICCV 2	ICRISAT-Patancheru	Andhra Pradesh, Myanmar	ANGRAU and farmers	Wilt resistance, short duration need to utilize residual soil moisture during the fallow period.
Mariye	ICRISAT-Patancheru	Ethiopia	Ethiopian NARES and Farmers	High fertilizer prices, need for traditional cereal-legume rotations and suitability for highlands.
ICCV 10	ICRISAT - Patancheru	Bangladesh	BARI and ICRISAT	Need for short-duration legumes on rice fallows.
Myles	ICRISAT-Patancheru	USA/Canada	Respective NARES	Higher market demand, international trade and higher returns to developed country farmers.
NRM				
Watersheds	ICRISAT/ NARES	Thailand. Vietnam, Ethiopia, Burkina Paso, Niger	NARES, ICRISAT and NGOs	Risk management, environmental protection, sustainability needs in drought-prone areas.
Vertisol technology	ICRISAT-Patancheru	Ethiopia	Ethiopian NARES/ILRI	The potential for more sustainable production and suitability to utilize otherwise underutilized heavy soils higher yields to manage soils.
Cropping systems	NARES-ICRISAT and Mali	Nigeria, Niger	ICRISAT and NARES	Need for scientific basis for improvement of dryland cropping/intercropping systems.
Soil management	ICRISAT	Niger, Burkina Faso, Mali	Respective NARES	Need for low-cost soil and water conservation technologies in marginal an
Animal-drawn implements	ICRISAT	Ethiopia, Mali	NARES and ICRISAT	Labor shortages and the need for intensification of production.
Modeling	ARI and ICRISAT	Niger, Zimbabwe	ICRISAT and NARES	Need for ex-ante technology evaluation and exploring opportunities for scaling up and out.

Table 39. The germplasm collection at ICRISAT-Patancheru and its worldwide distribution.

	Collection					Distribution				
Crop	India	Asia	Africa	Others	Total	ICRISAT	Asia	Africa	Others	Total
Sorghum	6,201	4,107 (23)[a]	23,011 (40)	2,906	36,225	206,603	138,330	69,721	38,950	247,001
Pearl millet	6,771	59 (7)	12,588 (34)	301	20,258	41,712	60,417	23,630	4,309	88,356
Chickpea	6,930	6,965(15)	1,479 (11)	1,598	16,972	166,623	106,805	2,393	8,433	117,631
Pigeonpea	9,126	572(14)	1,310 (22)	926	11,934	70,973	*48,870*	10,051	6,219	65,140
Groundnut	3,754	1,172(21)	4,548 (41)	5,831	15,305	73,183	58,919	28,795	3,337	91,051
Finger millet	1,338	771 (4)	2,819 (12)	85	5,013	390	20,415	7,558	360	28,333
Foxtail millet	974	449(12)	22 (6)	89	1,534		8,046	932	1,651	10,629
Proso millet	69	318(13)	2 (2)	452	841		3,686	488	1,098	5,272
Kodo millet	656	2 (1)			658		1,727	219	95	2,041
Little millet	459	4 (3)	3 (1)		466		1,203	468	324	1,995
Barnyard millet	447	193 (4)	6 (4)	97	743		1,753	249	428	2,430
Total	36,725	15,151(28)	45,788 (47)	12,285	109,949	559,484	450,171	144,504	65,204	659,879

a. Figures in parentheses are, the number of countries.

Source: ICRISAT Gene Bank

areas in the region. Pearl millet varieties bred at ICRISAT-Patancheru were highly susceptible to downy mildew in WCA; therefore the desired level of spillover did not occur. Some pearl millet varieties with parental lines originating in West Africa have been adopted in ESA. These important experiences show the need to further strengthen sorghum and pearl millet research in these two regions since the potential for inter-regional spillover does not seem to be promising. Further, the information reviewed here indicates that a few varieties of sorghum (Macia, S 35, ICSV 111, SV 2 and ICSV 112) and pearl millet (SOSAT-C 88, PMV 2, GB 8735 and Okashana 1) have been widely adopted by farmers in Africa. The overall impact of these varieties and lessons on the process and enabling conditions need to be carefully investigated. Although several groundnut varieties developed at Patancheru have been released in African countries, there is a need to develop locally adaptable varieties considering the pressures from rosette, other diseases and pests. Chickpea spillover has been limited to a few countries in Eastern Africa. Given the concentration of chickpea research in Asia, the limiting factors and the potential for expansion of chickpea cultivation need to be explored to increase food production and cash incomes of the poor in ESA.

Much of the information available indicates that improved varieties and germplasm represent a significant share of technology movement across borders and inter-regional spillovers. Such a widespread transfer of technologies has not been observed for other non-crop related research products. ICRISAT is however well positioned to promote the sharing of products such as knowledge, policy instruments methods, principles, decision and diagnostic tools, etc, from its NRM and socioeconomic and policy research across national and regional borders. It is important to explore new opportunities and mechanisms to enhance and maximize the delivery of such research products to policymakers, analysts, development agencies, NARS and to the ultimate beneficiaries, ie, the small-holder farmer and the poor of the SAT

This study also led to the following observations:

- The ways and means to enhance spillovers and mechanisms for facilitating inter-country collaboration need to be identified with care. It seems that technology spillover was enhanced when ICRISAT scientists were closely associated with the receiving *NARS,* as exemplified by chickpea in Bangladesh, pigeonpea in Sri Lanka and East Africa and cropping systems in Africa. These experiences also indicate that human resource development and networking played key roles in enhancing spillovers and south-south collaboration.
- The comparative advantages and roles of international and national research systems are evident but vary greatly by region and type of research. Careful coordination and team- and network-based R&D activities seem to have facilitated and enhanced the spillovers. However, given the varying capabilities and strategies of different NARS in Africa and Asia, ICRISAT's role in enhancing spillovers and technology exchange within and between regions needs further analysis.
- Spillovers to the developed world may have complicating effects on developing country agriculture, especially for small chickpea farmers in the SAT. The market opportunities and comparative advantages of the new technologies that drive the spillovers to developed countries (eg, chickpea in Australia and Canada) may have undesirable effects on the poor by lowering producer prices. This indicates how inter-regional spillovers interact with price spillovers to generate differential impacts on producers and consumers across regions. The productivity gains to developing country fanners

could be wiped out by highly subsidized chickpea exports from developed countries and low world market prices. This requires detailed investigation.

- In addition to inter-regional spillovers, cross-commodity spillovers have also occurred. For example, the BBF technology originally developed for vertisol watershed management, found niches in improved groundnut production in both vertisols and alfisols.
- While complete adoption of some technologies (eg, finished products like new varieties) was observed, small farmers also adopted components of some technology packages, as was the case with vertisol technologies in India. There is a need to identity' and develop appropriate indicators for impact evaluation, particularly for NRM and socio-economics research wherein direct benefits may be delayed or attribution to desired outcomes may be difficult to establish. Natural resource investments may generate higher social benefits while private benefits remain low (due to the public goods nature of many such benefits). This may lower incentives for private investments and the potential for inter-regional technology transfer.
- Impact studies that exclude spillovers are likely to understate research benefits. Likewise, NARS may overstate the benefits from their own R&D investments when spill-in benefits from ICRISAT (or other) research are ignored. Therefore, there is a need for future ICRISAT impact studies to include spillover benefits to the extent that the existing methods allow. The traditional "what" and Where" factors of economic and environment impacts need to be combined with the "who" and "how" aspects of all the actors and institutions involved to understand the process and track patterns of spillovers.
- Spillovers occur due to the joint efforts of many partners and stakeholders. A systematic understanding of the research, development, adaptation and adoption processes requires good databases, which will allow systematic analysis of the extent of spillovers and the limiting factors. The institutional memories and lessons learnt from ongoing and completed projects should be documented at regular intervals. ICRISAT may play an important role in assisting NARS and various networks in developing and maintaining such databases.

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Appendices

Appendix 1a. List of released sorghum varieties and hybrids developed at ICRISAT locations in collaboration with NARS and used in other countries.

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
Within Asia						
ICSV 735	(ICSV 197 × SPV 351)-9-1-1-2-6	Patancheru	1996	Myanmar	YEZIN 6	Midge resistant, high grain yield
ICSV 758	(ICSV 197 × A 13108)-1-2-1-1-1	Patancheru	1996	Myanmar	YEZIN 7	Midge resistant, high grain yield
ICSV 804	(ICSV 197 × SPV 351)-3-1-1-1-1	Patancheru	1996	Myanmar	YEZIN 5	Midge resistant, high grain yield
ICSV 107	(SC 108-3 × CSV 4)-19-1	Patancheru	1991	Pakistan	PARC-SS 1	High yielding, good grain quality
ICSV 126	[(SC 108-3 × Swarna) × E 35-1] 6-2	Patancheru	1994	Philippines	IES Sor 4 (PSB SG 94-02)	Dual purpose, good grain quality
M 90906	Sel. from (TAM 428 × E 35-1)-4	Patancheru	1984	Myanmar	YEZIN 1 (Schwe phyu 1)	High yielding, good grain quality
M 36248	Sel. from [(WABC × SC 108-3)-1-1 × IS 9327] 1-2-2	Patancheru	1984	Myanmar	YEZIN 2	High yielding, good grain quality
M 36335	Segregating progeny	Patancheru	1984	Myanmar	YEZIN 3	High yielding, good grain quality
M 36172	[(SC 108-3 × E 35-1)-5-1 × CSV 4 derivative] 3-4-2-1	Patancheru	1984	Myanmar	YEZIN 4	High yielding, good grain quality
IS 8965	Germplasm***	Kenya	1980	Myanmar	Shwe-ni 1	Brown colored grain
IS 2940	Germplasm	USA	1981	Myanmar	Shwe-ni 2	High yielding, shoot fly resistant
A 3681	(FLR 101 × IS 1082)-4-5-3	Patancheru/ China	1982	China	YUAN 1-98	High yielding, good grain quality
A 3872	Bulk Y -398-69-1	Patancheru/ China	1982	China	YUAN 1-28	High yielding, good grain quality
A 3895	Bulk Y -398-1045-2-3-1	Patancheru/ China	1982	China	YUAN 1-505	High yielding, good grain quality
A 6072	Indian synthetic 600	Patancheru/ China	1882	China	YUAN 1-54	High yielding, good grain quality
**	ICRISAT line	Patancheru	1993	Philippines	IES Sor 1 (PSB SG 93-20)	-*

Continued...

Appendix 1a. *Continued.*

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
**	Diallel 346-1 (SPL 132 A)	Patancheru/ China	1988	China	Liao 4	High yielding, female parent from ICRISAT
**	ICRISAT line (SPL 132 A)	Patancheru/ China	1995	China	Liao Za 4	High yielding, female parent from ICRISAT
**	ICRISAT line (SPL 132 A)	Patancheru/ China	1996	China	Liao 5	High yielding, female parent from ICRISAT
**	ICRISAT line (SPL 132 A)	Patancheru/ China	1996	China	Liao Za 6	High yielding, female parent from ICRISAT
**	ICRISAT line (SPL 132 A)	Patancheru/ China	1996	China	Liao Za 7	High yielding, female parent from ICRISAT
**	ICRISAT line (SPL 132 A)	China	1996	China	Jinza 94	High yielding, female parent from ICRISAT
**	ICRISAT line	Patancheru/ Thailand	1996	Thailand	Suphanburi 1	Red colored grains, average grain yield
Asia (or via Patancheru) to Africa						
M 91019-6	[(SPV 35 × E 35-1) CS 3541]-8-1-1	Patancheru/ Samaru	1986 1989	Cameroon Chad	S 35 S 35	Early maturing, dwarf, white grain
ICSV 111	[(SPV 35 × E 35-1) × (CSV 4)]-8-1	Patancheru	1997 1996 1999	Ghana Nigeria Benin	Kapala ICSV 111 ICSV 111	Early maturing, white grain, good food quality
ICSV 400	ICSV 112 × (IS 12611 × SC 108-3)	Patancheru	1996	Nigeria	ICSV 400	Early maturing, preferred for malt, white grain
ICSV 401	[(SC 108-3 × CSV 4)-16-3 × MR 801 × R 2751] –4-22	Patancheru	1994	Mali	ICSV 401	High grain yield
ICSV 1 (SPV 351)	Derived from (SC 108-3 × CSV 4)	Patancheru	1993 1988 1984	Malawi Ethiopia India	PIRIRA 1 Dinkmash CSV 11	High grain yield, medium maturing, suitable for intercropping
ICSV 2	(SC 108-4-8 × CSV 4)-88	Patancheru	1983	Zambia	ZSV 1	High grain yield
ICSV 112 (SPV 475)	[IS 12622C × 555] × [(IS 13612C × 2219B) × E 35-1)]	Patancheru	1993 1987 1988 1993 1992 1987	Malawi Zimbabwe Kenya Mozambique Swaziland India	PIRIRA 2 SV 1 ICSV 112 Chokwe MRS 12 CSV 13	Medium maturing, medium-tall, resistant to most leaf diseases, creamy-white grain
A 6460	IS 24704 × IS 10558	Patancheru	1987	Zimbabwe	SV 2	Early maturing, white grain, medium tall plants
ICSV 210	SPV 350 × SPV 475	Patancheru	2000	Eritrea	Bushuka	High grain yield, drought tolerant
SRN 39	Derived from (GPR 148 × Framida)	Patancheru	1991 1993	Sudan Niger	SRN 39 SRN 39	Resistant to *Striga*

Continued...

Appendix 1a. *Continued.*

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
M 90393	[(GPR 148 × E 35-1)-4-1 × CSV 4]-5-4-2	Patancheru	1992	Sudan	INGAZI	High yielding
M 90038	Segregating progeny	Patancheru	1993	Niger	SEPON 82	High yielding
IS 29415	Germplasm	Lesotho	2000	Eritrea	Shiketi	High yielding, adapted to dry mid-highlands
IS 25395	Germplasm	Kenya	2001	Rwanda	IS 25395	Brown, high yielding, best for brewing as adjunct, early maturing
IS 21219	Germplasm	Kenya	2001	Rwanda	IS 21219	Brown, high yielding, best for brewing as adjunct, early maturing
IS 8193	Germplasm	Uganda	2001	Rwanda	IS 8193	Brown, high yielding, good for brewing, medium maturing
IS 9302	Germplasm	South Africa	1984	Ethiopia	ESIP 11	-
IS 9323	Germplasm	South Africa	1984	Ethiopia	ESIP 12	-
IS 9830	Germplasm	Sudan	1991	Sudan	Mugawim Buda 2	*Striga* resistant
IS 13444	Germplasm	Zimbabwe	2000	Sudan	Arous el Rimal	Late maturing, average grain yield
IS 8193	Germplasm	Uganda	2001	Kenya	KARI MATAMA 2	High yielding, semi-dwarf/tall, excellent Uji and Ugali composite flour quality
IS 8571	Germplasm	Tanzania	1989	Mozambique	Mamonhe	White grain
IS 23520	Germplasm	Ethiopia	1989	Zambia	Sima	High yielding, tall, medium maturing, bold grains
IS 15401	Germplasm	Cameroon	2001	Mali	Soumalemba	-
IS 76	Germplasm	Mexico	1980 2001	Ethiopia Kenya	76 T1 #23	High yielding
**	PP 290 INTSORMIL	Patancheru/ Eritrea	2000	Eritrea	Shambuko	Earliness, white grain
**	89 MW 5003	Patancheru/ Eritrea	2000	Eritrea	Shieb	Very high yielding, semi-tall, medium maturing, good grain quality
**	89 MW 5056	Patancheru/ Eritrea	2000	Eritrea	Laba	Very high yielding, semi-tall, medium maturing, good grain quality
**	Diallel pop. 7-682	Patancheru	1988	Ethiopia	Melkamash	High yielding
Within Africa						
SDS 3220 (M 91057 derivative)	[(GPR 148 × E 35-1) × CS 3541]-1-1	Bulawayo (initial cross at Patancheru)	1989 1994 1998 1998 1999	Mozambique Botswana Namibia Zimbabwe Tanzania	Macia Phofu Macia Macia Macia	Early to medium maturing, good grain yield, stay-green, broad leaves with juicy thick stem, good quality crop residue
SDS 2293-6	Selection from germplasm (IS 23496 from Ethiopia)	Bulawayo	1995	Tanzania	Pato	White grain

Continued...

Appendix 1a. *Continued.*

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
SDS 2583	Selection from germplasm (IS 3923 from USA)	Bulawayo	1994	Botswana	Mahube	Earliness, high yield
SDSV 1513	Selection from germplasm (IS 2391 from South Africa)	Bulawayo	1990	Swaziland	MRS 13	High yielding, medium maturing
SDSV 1594-1	Selection from germplasm (IS 3693 from USA)	Bulawayo	1990	Swaziland	MRS 94	High yielding, medium-long duration
IS 18758 (E 35-1)	Germplasm	Ethiopia	1983 1990 1980	Burkina Faso Burundi Ethiopia	E 35-1 Gambella 1107	Donor for anthracnose resistance, dual purpose
SDSH 48	Hybrid	Bulawayo	1994	Botswana	BSH 1	High-yielding hybrid
ICSV 1007 BF	Synthetic variety	Kamboinse	1991	Sudan	Mugawim Buda 1	-
ICSV 1063 BF	Synthetic variety	Kamboinse	2000 1993	Ivory Coast Mali	- -	-
ICSV 1079 BF	(Framida × E 35-1)	Kamboinse	2001	Mali	Yagare	-
**	KAT 83/369	ICRISAT-Kenya	1994	Kenya	KARI MATAMA 1	High yielding, semi-dwarf, white grain for food, medium maturing
**	PGRC/E216740	ICRISAT-Kenya	2001	Kenya	KARI MATAMA 3	High yielding, semi-tall, large red grains, medium maturing
**	5 D × 160	ICRISAT-Tanzania	1980 1989	Rwanda Burundi	5 D x 160	High yielding, brown, excellent for brewing, medium maturing
**	2k × 17	ICRISAT-Tanzania	1988 1995	Tanzania Uganda	Tegemeo Equripur	High yielding, white, good for brewing as adjunct/malt
**	MR 4/4606 T11 (WSV 387)	Patancheru/ Zambia	1989	Zambia	Kuyuma	Semi-dwarf, medium maturing, high yielding
**	ICRISAT line	Patancheru/ Zambia	1987	Zambia	WSH 287	Hybrid, no more in circulation
**	ICRISAT line	Patancheru/ Zambia	1990	Zambia	MMSH 413	Hybrid, brown, high yielding, medium/late maturing
**	(SEPON 82 × S 34)	Togo	1998	Togo	SORVATO 1	-
**	(Framida × S 34)	Togo	1998	Togo	SORVATO 28	-
Africa to Asia						
IS 30468	Germplasm	Ethiopia	1990	A.P., India	NTJ 2	Zera zera landrace
***	Germplasm - IRAT 408	Mali	1991	Pakistan	PARC-SS 2	-
Spillover to other regions (Patancheru to Latin America and within Latin America)						
ICSV 112	[IS 12622C × 555] × [(IS 13612C × 2219B) × E 35-1)]	Patancheru	1987 1990 1990	Mexico Mexico Nicaragua	UANL 1-87 Pacifico 301 Pinollnero 1	Medium maturing, medium-tall, resistant to most leaf diseases, creamy-white grain

Continued...

Appendix 1a. *Continued.*

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
ISIAP DORADO (M 91057)	Derived from (GPR 148 × E 35-1) × CS 3541	Patancheru/Mexico	1981 1986 1991 1991 Grown by farmers	El Salvador Mexico Mexico Panama Paraguay Honduras Egypt	ISTMENNO Blnaco 86 ISIAP DORADO Alanje Blanquito - - -	Drought tolerance, photoperiod insensitive, open-pollinated variety, bold, hard and white grain
M 90362	Segregating progeny	Patancheru	1987	Mexico	UANL-1-287	Whit grain
M 90362	Male parent used in hybrid	Patancheru	1987	El Salvador	Agroconsa-1	High-yielding hybrid
M 62641	(SC108-3 × CS 3541) × E15-5	Patancheru	1989	Mexico	COSTENO 201	Early maturing, white grain
M 90812	IS 12611 × (Bulk 'Y' × GPR 165)	Patancheru	1991	Mexico	Tropical 401	Late maturing, white grain
M 90975	(GPR 168 × SC 170)	Patancheru	1985	Guatemala	ICTA MILTAN 85	Medium height, white grain
M 90361		Patancheru	1987	El Salvador	Centa Oriental	Late maturing, white grain
M 62650	(SC 423 × CS 3541) × E 35-1	Patancheru	1985	Honduras	SURENO	Grain mold resistant, white grain
SEPON 77	(SC 108-3 × CS 3541)-29-1	Patancheru	1985	Nicaragua	NICA-SOR (T43)	Tall, white grain
A 3895	Bulk Y 398-1045	Patancheru	1992	Colombia	Icayanuba	-
IS 9468	Germplasm	South Africa	2000	Mexico	Maravilla No. SOF0430201092	-
IS 18484	Germplasm (CS 3541)	India	1984	Honduras	TORTILLERO 1	-
Hybrid	AT × 623 × TORTILLERO	ICRISAT-Mexico	1984	Honduras	Catracho	High-yielding hybrid
ICSV-LM 90502	(M 36285 × 77 CS -1)-bk-5-1-2-3-1-bk	ICRISAT-Mexico	1996	El Salvador	Soberano	White grain and high yielding
ICSV-LM 90503	(M 35585 × CS 3541 crosses 31)-bk-5-2-2-3-1-1-1-bk	ICRISAT-Mexico	1996	El Salvador	R.C.V.	White grain and high yielding
ICSV-LM 90508	(PP 290 × 852-2235) bk-46-3-1-bk	ICRISAT-Mexico	1997	El Salvador	Jocoro	White grain and high yielding
ICSV-LM 90501		ICRISAT-Mexico	1993	Dominion Rep.	SURENNA -1	White grain and high yielding
**		Colombia	1992	Colombia	Sorghica PH 302	-
**				Colombia	HE 241	-
**		Costa Rica	1991	Costa Rica	ESCAMEKA	White grain and high yielding

a Data not available.

* ICRISAT locations: Patancheru (India), Bulawayo (Zimbabwe), Nairobi (Kenya), Kano/Samaru (Nigeria), Bamako (Mali), and Mexico.

** Varieties developed by national programs based on ICRISAT lines.

*** ICRISAT collected, conserved and facilitated the exchange of germplasm.

Appendix Ib. Sources of resistance for different biotic stresses in sorghum.

Traits	Resistance source	Origin	Traits	Resistance source	Origin
Grain mold	IS 14384	Zimbabwe	Shoot fly	IS 1054	India
	IS 14388	Swaziland		IS 1071	India
	IS 7173	Tanzania		IS 2394	South Africa
	IS 23773	Malawi		IS 5484	India
	IS 23783	Malawi		IS 18368	India
	IS 34219	India			
			Midge	DJ 6514	India
Downy mildew	QL-3	Australia		IS 10712	USA
	SC 414-12	USA		IS 7005	Sudan
	IS 20450	Niger		IS 8891	Uganda
	IS 20468	Niger			
	IS 20478	Niger	Stem borer	IS 7224	Nigeria
				IS 18573	Nigeria
Anlhracnose	SC 326-6	USA		IS 2291	Sudan
	SC 599-11E	USA		IS 13674	Uganda
				IS 18551	Ethiopia
Leaf blight	87 BL 2598			IS 9608	Pakistan
Sooty stripe	IS 23818	Yemen		IS 23962	Yemen
	E 35-1	Ethiopia		IS 12308	Zimbabwe
Ergot	ETS 2454	Ethiopia			
	ETS 3135	Ethiopia			
	ETS 3147	Ethiopia			
Rust	IS 2300	Sudan			
	IS 3443	Sudan			
	IS 31446	Uganda			
	IS 18758	Ethiopia			

Appendix 2a. List of released pearl millet varieties and hybrids developed at ICRISAT locations in collaboration with NARS and released in other countries.

ICRISAT Code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
Within Asia						
ICMS 7704	Synthetic variety	Patancheru	1991	Pakistan	PARC-MS2	Early maturing, dual purpose
**	81 A × ***	Korea/Patancheru	-[a]	Korea	Suwon-6	Forage yield, virus resistance
**	81 A × ***	Korea/Patancheru	-	Korea	Suwon-7	Forage yield, virus resistance
Asia to Africa						
WC-C75 (ICMV 1)	7 full-sibs of World Composite	Patancheru	1987 1982	Zambia India	ZPMV 871 WC-C75	Medium maturing, resistant to downy mildew
ICMV 82132	5 S_1 progenies of Smut Resistant Composite	Patancheru	1989	Zambia	Kaufela	Medium maturing, smut resistant
LBC	Late Backup Composite	Patancheru	1991	Zambia	Lubasi	Late maturing suitable for parts of Africa
ICTP 8203	5 S_2 progenies from Togo population	Patancheru via Bulawayo	1989 1988	Namibia India	Okashana 1 PCB 138	Bold grain, early maturing
ICMV 88908	BSEC × ICMV 87901	Patancheru via Bulawayo	1990 1998 1996	Namibia Botswana Malawi	Okashana 1 Bontle Nyankhombo	Replaced original Okashana 1, higher yield
ICMV 221 (ICMV 88904)	124 S_1 progenies of BSEC	Patancheru	2001 2001 1993	Kenya Eritrea India	Kat/PM 3 Kona ICMV 221	Bold grain, early maturing
¾ Hk-B78	Derived from HK population from Niger	Patancheru	1995 1987	Mauritania Senegal	- IBMV 8401	d_2 dwarf variety with long panicles
Within Africa						
SOSAT-C88	Derived from (Sauna × Sanio crosses)	Mali/Niamey	1992 1996 1997 1997 2000 2000	Mali Burkina Faso Chad Cameroon Nigeria Mauritania	SOSAT-C88 SOSAT-C88 SOSAT-C88 SOSAT-C88 LCIC-MV 1 SOSAT-C88	Downy mildew resistant, high grain yield, early maturing (90-95 days), medium plant height, thick stem, low tillering, moderately susceptible to stem borer
GB 8735	Iniadi × Souna	Niamey	1998 1990 1999 1994	Nigeria Chad Benin Mauritania	GB 8735 GB 8735 GB 8735 GB 8735	Extra early maturing (70 to 75 days), high tillering, bold grains, good grain yield, nodal tillers moderately susceptible to downy mildew
ICMV-IS 88102	Recombination of 14 lines from IP 6426 Mali-ICRISAT/IER in 1988	Kamboinse	1994 1994	Mali Burkina Faso	Benkadi Nio ICMV-IS 88102	Medium-late maturing, high yield, tolerant to smut, downy mildew and head miner

Continued...

Appendix 2a. *Continued.*

ICRISAT Code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
ICMV-IS 89305	Recurrent selection (cross: 3/4 HK B-78, SOUNA and CIVT) in 1989	Niamey	1998 1995 1995 1995	Niger Senegal Benin Cameroon	ICMV-IS 89305 " " "	Early maturing, high yield, tolerant to stem borer and downy mildew
ITMV 8001	Mass selection from INMG-1	Tarna	1985 1992	Niger Chad	ITMV 8001 ITMV 8001	Early maturing, tolerant to smut and downy mildew
IBMV 8001	Synthetic variety (700516, Serere 2 A and Cassady)	Bambey	1988 1985	Mali Senegal	IBV 8001 IBV 8001	Early maturing, compact heads, downy mildew resistance
ICMV-IS 85333	Recombination of 8 S1 lines from ITMV 8001	Niamey	1990	Mali	ICMV-IS 85333	Early maturing, high yield, tolerant to smut, downy mildew and hear miner
IKMV 8201	Recombination of S1 lines from Mali germplasm P449/ICRISAT/INERA	Kamboinse	1988 1992	Mali Burkina Faso	IKMV 8201 IKMV 8201	Medium- late maturing, high yield, tolerant to smut, downy mildew and head insects
Serere Composite 2	Composite	Uganda via Wad Medani	1981	Sudan	Ugandi	Early, bold grain, bristles
SDMV 93032	SDGP 1514, ICMV 87901, and ICMV 88908	Bulawayo	1996 1998 2000	Zimbabwe Namibia Sudan	- Okashana 2 Ashana	Early maturing, drought resistant
SDMV 89004	Variety from Short Cycle Composite	Bulawayo	1992 1998	Zimbabwe Botswana	PMV 2 Legakwe	Medium maturing, high yielding, good panicle
SDMV 92040	2 accessions and 4 progenies from White Grain Composite	Bulawayo	1998 1998	Zimbabwe Namibia	PMV 3 Kangara	Early maturing, bold white grain
SDMV 89005	Synthetic	Bulawayo	2000 1996	Mozambique Malawi	Kuphanjala 1 Tupatupa	Early maturing
SDMV 90031	Composed of 5 early-maturing varieties	Bulawayo	2000	Mozambique	Changara	Early maturing
SDMV 91018	Developed from 7 Nigerian lines	Bulawayo	2000	Mozambique	Kuphanjala-2	Medium maturing
TSPM 91001	Selection from Buruma population from Tanzania	Bulawayo/ Tanzania	1994	Tanzania	Shibe	Medium maturing
TSPM 91018	Halale germplasm from Zimbabwe	Bulawayo/ Tanzania	1994	Tanzania	Okoa	Drought resistant
Africa to Asia via Patancheru						
Serere Composite 2	Composite developed at Serere, Uganda	Uganda via Patancheru	1991	Pakistan	PARC-MS1	Bold grain, early, bristles

a Data not available.

* ICRISAT locations: Patancheru (India), Bambey (Senegal), Niamey and Tarna (Niger), Kamboinse (Burkina Faso), Bulawayo (Zimbabwe), Wad Medani (Sudan) and Nairobi (Kenya).

** Hybrids developed by national program based on ICRISAT female parent.

*** A male parent of hybrid used by national program (confidential).

Appendix 2b. Non-varietal technologies developed for pearl millet.

Technology	Where developed	Year developed	Spillover to country	Year of spillover	Additional remarks on the technology and process of spillover
Screening technique	Patancheru	1977	Countries in WCA/F.urope	1985	Infector row technique for screening for downy mildew resistance
Screening technique	Patancheru	1985	Countries in WCA/Europe	1991	Greenhouse potted seedlings for screening for downy mildew resistance

Appendix 3a. List of released groundnut varieties developed at ICRISAT locations in collaboration with NARS and released in other countries.

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
Within Asia						
ICGV 86072	(ICGS 22 × TG 2E)	Patancheru	1999	Bangladesh	BARI GR 6	High yielding, early maturing
ICGV 86021	(RMP 91 × (DHT 200)	Patancheru	1998	Indonesia	Jerapah	Drought tolerant, resistant to foliar diseases
ICGV 87358	(OG 69-6-1 × NC Ac 17090)	Patancheru	2001	Indonesia	Turangga	Moderately resistant to bacterial wilt, rust, LLS, *Aspergillus flavus* and drought
ICGV 86031	(F 334 A-B-14 × NC Ac 2214)	Patancheru	2001	Indonesia	Kancil	Resistant to bacterial wilt, tolerant to rust, LLS, *Aspergillus flavus* and chlorotic symptom
ICGV 87127 (ICGS 35)	Selection from natural hybrid from Robut 33-1	Patancheru	1987	S. Korea	Jinpungtangkong	Early maturing, wild adaptability, high yielding
ICGV 86326	(ICGS 21 × G 201)	Patancheru	1996	S. Korea	Jeokwangtangkong	High yielding
ICGV 87160	(Ah 65 × NC Ac 17090)	Patancheru	1993	Myanmar	Sinpadetha 5	High yielding, resistant to rust, tolerant to LLS
ICGV 93382	(ICGV 86068 x Chico)	Patancheru	1998	Myanmar	Sinpadetha 7	High yielding, short duration
ICGV 86015	(ICGS 44 × TG 2E)	Patancheru	1996 1994 1992	Nepal Pakistan Vietnam	Jayanti BARD 92 HL 25	Early maturing, high yielding
Bulk seed of two varieties	(ICGS 44 + ICGS 37)	Patancheru	1989	Pakistan	BARD 699	High yielding
ICGV 86564	(Ah 114 c NC Ac 1107)	Patancheru	1994	Sri Lanka	Walawe	Bold seeded
ICGV 87123	Selection from natural hybrid from Robut 33-1	Patancheru	1994 1986	Sri Lanka India	Indi ICGS 11	High yielding, tolerant to BND and end-of-season drought
ICGV 86143	[ICGS 44 × (Robut 33-1 × NC Ac 2821)]	Patancheru	2000 1994	Vietnam India	LO5 BSR-1	Early maturing, high yielding
Asia to Africa						
ICGMS 42 (ICGV-SM 83708)	(USA 20 × TMV 10)	Patancheru	1999 1990 1990	Uganda Malawi Zambia	Serenut 1R CG 7 MGV 4	High yielding, large seeds and wide adaptability, red skin, suitable for confectionery trade

Continued...

Appendix 3a. *Continued.*

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
ICGS 31	(Shulamit × Robut 33-1)	Patancheru	2000	Botswana	–a	High yielding, early maturing
ICGV 86143	[ICGS 44 × (Robut 33-1 × NC Ac 2821)]	Patancheru	1999	Zambia	MGS 2	Early maturing, high yielding
ICGV 93207	(ICGV 86594 × ICGV 86672)	Patancheru	1997	Mauritius	Sylvia	High yielding
ICGV 87853	(Robut 33-1 × CS 9)	Patancheru	1997	Mauritius	Venus	High yielding, resistant to foliar diseases, suitable for intercropping
ICGV 93437	(ICGV 86063 × ICGV 86065)	Patancheru	1999	Zimbabwe	Nyanda	High yielding, early maturing
ICGS (E) 104	(Colorado Manfredi × L No 95-A)	Patancheru	2001	Burkina Faso	ICGS (E) 104	High yielding, early maturing
ICGS (E) 27	(JH 89 × Chico)	Patancheru	1990	Congo		High yielding, early maturing
ICGS 114	(GAUG 1 × NC Ac 17090)	Patancheru	1989	Ghana	Sinkarzei	Early maturing, higher shelling % and 100-seed mass than local
ICGV 86105	[NC Ac 537]	Patancheru	1992	Guinea-Conakry	VP 20	Early maturing, high yielding
ICGV 88023	(Faizpur 1-4 × UF 71513-1)	Patancheru	2001	Guinea-Conakry	No local name given	High yielding, early maturing
ICGV 86065	(Var 2-5 × Robut 33-1)	Patancheru	2000	Mali	ICGS (E) 34	High yielding, early maturing
ICG 7878	Germplasm	USA via Patancheru	2001	Mali	Waliyar tiga	Resistant to foliar diseases
ICGV 87157 [ICG (FDRS) 4]	(Argentine × PI 259747)	Patancheru	2001	Mali	ICG (FDRS) 4 in the official catalog	High yielding, resistant to foliar diseases and good food taste
ICGV 87160 ICG (FDRS) 10	Ah 65 × Nc Ac 17090	Patancheru	2002 Diffusion year 1998	Mali	ICG (FDRS)10 in the official catalog	High yielding, resistant to foliar diseases, particularly ELS and LLS
ICG 12991	-		2001	Malawi	Baka	Early maturing, rosette resistant
Asia to other regions						
ICGV 89214	(ICGV 87123 × ICG 6150)	Patancheru	1995	Cyprus	Kouklia	Bold seeded, tolerant of lime-induced iron chlorosis

Continued...

Appendix 3a. *Continued.*

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
ICGV 88438	[GP NC 343 × (NC 17367)]	Patancheru	1995	Cyprus	Nikoklia	Bold seeded, tolerant of lime-induced iron chlorosis
ICGV 91098	*(ICGV 86564 × ICGV 87152)*	*Patancheru*	*1995*	*Cyprus*	*Gigas*	Bold seeded, tolerant of lime-induced iron chlorosis
Within Africa						
ICGV-SM 86715	Interspecific derivative	Lilongwe	1992	Mauritius	Veronica	Resistant to rust, LLS and pepper spot
ICGV-SM 85048	[(Goldin 1 × Faizpur1-5) × (Manfredi × M 13)]	Lilongwe	1992	Mauritius	Stella	Suitable for cultivation both in sugarcane inter-rows and pure stand, resistant to web blotch
ICGV-SM 90704	(RG 1 × Mani Pintar)	Lilongwe	1999 2000	Uganda Malawi	Serenut 2R Nsinjiro	Rosette resistant, high yielding Rosette resistant
ICGV-SM 93530	(ICGV-SM 85027 × RG 1)	Lilongwe	2000	Uganda	Serenut 3R	Rosette resistant, high yielding
ICGV-SM 83005	ICGMS 5	Lilongwe	1995	Zambia	Chipego	High yielding, for low and medium altitude areas
ICGV-SM 86068	[(Goldin 1 × Faizpur1-5) × (Manfredi × M 13)]	Lilongwe	1999	Zimbabwe	Jesa	High yielding, early maturing
ICGV-IS 96894	ICGV-SM 85048 × RG 1	Kano	2001	Nigeria	SAMNUT 23	High yielding, early maturing, rosette resistant

a Data not available.
* ICRISAT locations: Patancheru (India), Lilongwe (Malawi) and Kano (Nigeria).

Appendix 3b. Non-varietal technologies developed for groundnut.

Technology	Where developed	Spillover to country	Additional remarks on the technology and process of spillover
Screening technique	Patancheru, India	Mali Burkina Faso	Infector row technique for rust or late leaf spot
Screening technique	Chitedze, Malawi	Nigeria Burkina Faso	Infector row technique used for screening for resistance to rosette disease
EUSA Test	Patancheru, India	Many groundnut-producing countries in Africa	Low-cost Aflatoxin detection kit using ELISA technique

Appendix 3c. Sources of resistance for different biotic stresses in groundnut.[a]

Traits resistance source	Alternate identity	Origin	Traits/ resistanance source	Alternate identity	Origin
Aspergillus flavus			Rust		
ICG 1326	J 11	India	ICG 1697	NC Ac 17090	Peru
ICG 3263	U4-47-7	Uganda	ICG 4747	PI 259747	Argentina
ICG 3700	AH 7223	Nigeria	ICG 10881	BZC 372 red	Bolivia
ICG 4749	PI 337394 F	Argentina	ICG 10890	SPA 406 red	Peru
ICG 4888	AH 7827	China	ICG 6902	NC Ac 17894	USA
ICG 7633	UF 71513	USA	Early leaf spot		
ICG 9407	61-40	Senegal	ICG 11476	PI 274194	Argentina
Late leaf spot			ICG 8298	NC Ac 18045	USA
ICG 4747	PI 259747	Argentina	91 PA 150	Breeding line	USA, NCSU
ICG 2716	EC 76446 (292)	Uganda	91 PA 131	Breeding line	USA, NCSU

a. A more complete list of germplasm with resistance to different diseases is available (Bonny Neare, personal communication 2003).

Appendix 4a. List of released pigeonpea varieties and hybrids developed by ICRISAT in collaboration with NARS and used in other countries.

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
HUNT	Prabhat × Baigani × (QPL 1)	Patancheru	1983	Australia	Hunt	Short duration
			1987	Indonesia	Megha	
Quantum	T 21 × JA 277	Patancheru	1985	Australia	Quantum	Short duration
ICPL 87	T 21 × JA 277	Patancheru	1986	India	Pragati	Short duration, suitable for multiple harvest
			1990	Myanmar	ICPL 87	
ICPL 332	ICP 1903-E1-4EB	Patancheru	1989	India	Abhaya	Medium duration, pod borer tolerant
ICPL 151	ICP 6997 × Prabhat	Patancheru	1989	India	Jagriti	Short duration
ICPH 8	Hybrid	Patancheru	1991	India	ICPH 8	Short duration, hybrid, 30% more yield than variety
ICPL 87119	C11 × ICP 1-6	Patancheru	1993	India	Asha	Medium duration, sterility mosaic resistant, wilt resistant
ICPL 84031	ICPX 80543	Patancheru	1995	India	Durga	Short duration
ICPL 85010	ICPL 87 × DL 78-1	Patancheru	1996	India	Sarita	Early short duration, suitable for double cropping
ICPL 85063	BDN 1 × ICP × 73054	Patancheru	1997	India	Lakshmi	Medium duration, postrainy variety
ICPL 2	ICP 6971-83-3-5	Patancheru	1997	Sri Lanka	Prasada	Short duration, Maruca tolerant
ICPL 87091	ICP 8504 × ICP 7220 × ICPL 010-1 × ICP 8504	Patancheru	1997	Kenya	Komboa	Short duration, vegetable type
			1997	Tanzania	ICPL 87091	
			1997	Uganda	ICPL 8709	
			2000	Mozambique	ICPL 87091	
ICPL 90028	24C selection	Patancheru	2000	Sudan	-[a]	Short duration, grain type
ICEAP 00040	African line	Nairobi	2000	Malawi	-	Long duration, grain type
				Tanzania	Mali	
ICEAP 00068	African line	Nairobi	2003	Tanzania	ICEAP 00068	Medium duration, grain and vegetable type
ICPL 93027	-	Patancheru/ Nairobi	2003	Malawi	-	Short duration, high yielding and grain and vegetable type
ICPL 87105	-	Patancheru/ Nairobi	2003	Malawi	-	Short duration, high yielding and grain and vegetable type

Continued...

Appendix 4a. *Continued.*

ICRISAT code	Pedigree	Developed at*	Year of release	Country of release	Release name	Specific traits
Kat 60/8	African line	Nairobi/Kenya	2000	Kenya	Kat 60/8	Medium duration, vegetable type
				Uganda	-	
ICP 7035	Germplasm***	India	1984	Fiji	Kamica	Long duration
ICP 8863	Germplasm	India	1986	India	Maruti	Medium duration, wilt resistant
ICP 11384	Germplasm		1992	Nepal	Bageshwari	Long duration, sterility mosaic resistant
ICP 9145	Germplasm	Kenya/Nairobi	1987	Malawi	Nandolo Wansa Nswawa	Long duration, wilt resistant
**	Sel from S4 ICPL 88015	USA/Patancheru	1995	USA	MN 1	Early short duration
**	Sel from F5 ICPL 83004-1 × ICPL 85010	USA/Patancheru	1995	USA	MN 5	Early short duration
**	S4 sel from ICPL 83004 × ICPL 85010	USA/Patancheru	1995	USA	MN 8	Early short duration
**	Sel. from ICRISAT line	Patancheru/ Australia	1988	Australia	Quest	Short duration
**	ICPX 78120 Selection	Patancheru/India	1992	India	Birsa Arhar	Medium duration, wilt resistant
**	Sel. from ICP 6997 OP bulk	Patancheru/ Nepal	1992	Nepal	Rampur Rhar	Long duration, sterility mosaic resistant
**	ICRISAT line	India	1994	India	CoH 1	Short duration hybrid
**	ICRISAT line	India	1994	India	PPH 4	Short duration hybrid

a Data not available.

* ICRISAT locations: Patancheru (India) and Nairobi (Kenya).

** Varieties/hybrids developed by national programs using ICRISAT breeding materials.

*** ICRISAT collected, introduced, maintained and facilitated the exchange of germplasm accessions.

Appendix 4b. Sources of resistance for different biotic and abiotic stresses in pigeonpea.

Traits	Resistance source	Origin
Fusarium wilt	ICP 8863	Patancheru
	ICP 9145	Kenya
	ICP 9174	Kenya
	ICP 12745	Patancheru
	ICPL 333	Patancheru
	ICPL 8363	Patancheru
	ICPL 88047	Patancheru
	BWR 370	India
	DPPA 85-2	India
	DPPA 85-3	India
	DPPA 85-8	India
	DPPA 85-13	India
	DPPA 85-14	India
	Bandapalera	India
	ICP 4769	India
	ICP 9168	Kenya
	ICP 10958	India
	ICP 11299	Patancheru
	C11 (ICP 7118)	India
	BDN 1 (ICP 7182)	India
Sterility mosaic	Bahar	India
	DA 11	India
	DA 13	India
	ICP 999	India
	ICP 6997	India
	ICP 7035	India
	ICP 7197	India
	ICP 7234	India
	ICP 7353	India
	ICP 7867	India
	ICP 8094	India
	ICP 8109	India
	ICP 8129	India
	ICP 8862	India
	ICP 10976	India
	ICP 10977	India
Phytophthora blight	ICP 9252	India
	Hy 4	India
	ICPL 150	ICRISAT line
	ICPL 288	ICRISAT line
Phytophthora blight	ICPL 304	ICRISAT line
	KPBR 80-1-4	India
	KPBR 80-2-1	India
	KPBR 80-2-2	India
Cercospora leaf spot	UC 796/1	India
	UC 2113/1	ICRISAT
	UC 2515/2	ICRISAT
	UC 2568/1	ICRISAT
	ICP 8869	India
	ICP 12792	India
	ICP 12165	India
	ICP 657/1	India
	ALPL 6-2	India
	ALPL 66	India
	ALPL 666	India
Powder; mildew	ICP 7035	India
	ICP 9177	India
	ICP 9179	India
	ICP 9188	India
	ICP 9189	India
	ICP 9192	India
Alternaria blight	DA 2	India
	DA 11	India
	MA 128-1	India
	MA 20	India
Podfly	PDA 88-2E	India
	PDA 89-2E	India
	PDA 92-2E	India
	SL 21-93	India
	MA 2 (105)	India
Pod borer	ICPL 332	ICRISAT line
	ICPL 77303	ICRISAT line
	ICPL 87088	ICRISAT line
	ICPL 84060	ICRISAT line
	ICPL 87089	ICRISAT line
Drought	ICPL 88039	ICRISAT line
	ICPL 84023	ICRISAT line

Appendix 5a. List of released chickpea varieties developed at ICRISAT Patancheru in collaboration with NARS and used in other countries.

ICRISAT code	Pedigree	Developed at	Year of release	Country of release	Release name	Specific traits
ICCV 1	H 208 × T 3	Patancheru	1983 1987	India Nepal	ICCC 4 Sita	Basal branching, wide adaptation
ICCV 2	[(K 850 × GW 5/7) × P 458] × (L 550 × Guamuchil)	Patancheru	1989 1999 2000	India Sudan Myanmar	Swetha Wad Hamid Yezin 3	Extra early, wilt resistant, Kabuli
ICCV 3	[(K 850 × GW 5/7) × P 458] × (L 550 × Guamuchil)	Patancheru	2000	India	Chamatkar	Medium large seed, wilt resistant
ICCV 6	L 550 × L 2	Patancheru	1990	Nepal	Koselee	Wilt resistant, Kabuli
ICCV 10	P 1231 × P 1265	Patancheru	1992 1993	India Bangladesh	Bharati Barichhola 2	Erect type, wilt resistant, medium duration
ICCC 37	P 481 × (JG 62 × P 1630)	Patancheru	1989	India	Kranthi	Wilt resistant, short duration
ICCL 87207	K 850 × ICCL 80074	Patancheru	1995	India	Vishal	Large seeded, wilt resistant
ICCV 92311	(ICCV 2 × Surutato 77) × ICC 7344	Patancheru	1999	India	KAK 2 (PKV Kabuli 2)	Large seeded, wilt resistant, short-duration, Kabuli
ICCV 93958	ICCC 42 × ICC 12237	Patancheru	1999	India	CO 4	Large seeded, wilt resistant
ICCV 93954	(Phule G-5 × Narsingpur Bold) × ICCC 37	Patancheru	1999	India	JG 11	Large seeded, wilt resistant, suitable for irrigated and rainfed conditions
ICCV 91106	BEG 482 × BN 31	Patancheru	1999	India	Vaibhav	Wilt resistant, drought and high temperature tolerant, large seeded
ICCV 89314	ICCL 80074 × ICCC 30	Patancheru	2000	India	Dilaji	Wilt resistant
ICCV 90201	GL769 × P919	Patancheru	2003	India	Himachal Chana 2	Ascochyta blight resistant
ICCV 94954	ICCC 42 × BG 256	Patancheru	2000	India	JG 130	Large seeded, resistant to wilt
ICCV 96970	(ICCC 42 × ICCV 88506) × (KPG 59 × JG 74)	Patancheru	2001	India	JG 16	Multiple disease resistance (wilt, BGM, charcoal rot and stunt)

Continued...

Appendix 5a. ***Continued.***

ICRISAT code	Pedigree	Developed at	Year of release	Country of release	Release name	Specific traits
ICCV 95418	(ICC 7676 × ICCC 32) × [(ICCC 49 × FLIP 82-1C) × ICCV 3)]	Patancheru	2001	India	Virat	Large seeded, wilt resistant, Kabuli
ICCV 95311	(ICCC 32 × ICCL 80004) × [(ICCC 49 × FLIP 82-1C) × ICCV 3]	Patancheru	2002	India	Vihar	Large seeded, wilt resistant, Kabuli
ICCV 92337	(ICCV 2 × Surutato 77) × ICC 7344	Patancheru	2002	India	JGK 1	Short duration, large seeded, resistant to wilt resistant
ICCL 83110	(K 850 × T 3) × (JG 62 × BEG 482)	Patancheru	1986	Kenya	ICCL 83110	Medium duration, wilt resistant
ICCV 88202	PRR 1 × ICCC 1	Patancheru	2000 1998	Myanmar Australia	Yezin 4 Sona	Short duration, early vigor, attractive seed
ICCL 82108	(JG 62 × WR 315) × (P 1363-1 × PRR 1)	Patancheru	1990	Nepal	Kalika	Double pod, wilt resistant, tolerant to botrytis gray mold
ICCL 79096	JG 62 × F 496	Patancheru	1993	Pakistan	DG 92	Medium duration, wilt resistant
ICCV 89509	(L 550 × Radhey) × (K 850 × H 208)	Patancheru	1999	Sudan	Atmor	Large seed, resistant to wilt and root rot, Kabuli
ICCV 91302	ICCC 32 × (K 4 × Chaffa)	Patancheru	1999	Sudan	Burgeig	Large seeded, resistant to wilt and root rot, Kabuli
ICCV 92318	(ICCV 2 × Surutato 77) × ICC 7344	Patancheru	1999	Sudan	Hawata	Medium size seed, resistant to wilt and root rot, Kabuli
ICCV 92809	(BDN 9-3 × K 1184) × ICP 87440	Patancheru	1994	USA	Myles	Ascochyta blight resistant
ICCL 81248	P 481 × (JG 62 × P 1630)	Patancheru	1987	Bangladesh	Nabin	Wide adaptation
ICCL 83105	(K 850 × T3) × (JG 62 × BEG 482)	Patancheru	1993	Bangladesh	Barichhola – 3	Large seeded, erect plant type, wilt resistant
ICCL 85222	HMS 10 × (P 436 × H 223)	Patancheru	1996	Bangladesh	Barichhola – 4	Double pod, medium tall
ICCL 83149	(G 130 × B 108) × (NP 34 × GW 5/7)	Patancheru	1996	Bangladesh	Barichhola – 6	Medium duration, wilt resistant

Continued...

Appendix 5a. *Continued.*

ICRISAT code	Pedigree	Developed at	Year of release	Country of release	Release name	Specific traits
ICCV 88003	(K 4 × Chaffa) × ICCL 81001	Patancheru	1999	Bangladesh	Barichhola – 8	Wilt resistant, Kabuli
ICCL 82104	(Annigeri × Chaffa) × (Rabat × F 378)	Patancheru	1993	Ethiopia	Worku Golden	Short duration, wilt resistant
ICCL 82106	(P 99 × NEC 108) × Radhey	Patancheru	1995	Ethiopia	Akaki	Short duration, wilt resistant
ICCV 93512	ICCC 33 × [L 144 × E 100 Y (M)]	Patancheru	2000	Ethiopia	Sasho	Large seeded, Kabuli
*	F 378 × F 496	Patancheru	1984	India	Anupam	Medium duration, wilt resistant
*	JG 62 × F 496	Patancheru	1984	India	RSG 44	Double pod, tolerant to drought and frost
*	L 550 × L 2	Patancheru	1985	India	GNG 149	Kabuli, long duration
*	JG 1258 × BDN 9-3	Patancheru	1998	India	GG 2	Short duration, attractive seed
*	GL 629 × ILC 202	Patancheru	1999	India	Himachal Chana 1	Ascochyta blight resistant
*	ICCC 32 × (Pant G-114 × GL 629)	Patancheru	1999	India	L 551	Wilt resistant, moderately resistant to ascochyta blight
*	ICCL 84224 × Annigeri	Patancheru	2000	India	GG4	Wilt resistant
*	K 850 × F 378	Patancheru	1986	Myanmar	Schwe Kyehmon	Short duration, large seeded, wilt resistant
*	K 850 × F 378	Patancheru	1985	Ethiopia	Mariye	Wilt resistant, semi erect, wide adaptation
*	*	Patancheru	1999	India	HPG 17	Ascochyta blight resistant
*	ICCV2 × Surutato 77	Patancheru	2003	India	HK 98-155	Medium tall, spreading plant type, Kabuli variety

* Segregating material supplied by ICRISAT from which selection was made by the national program.

Appendix 5b. Sources of resistance for different biotic and abiotic stresses in chickpea.

Traits	Resistance source	Origin
Fusarium Will	ICC 11311, ICC 11312, ICC 11313, ICC 11314, ICC 11315, ICC 11316, ICC 11317, ICC 11319, ICC 11320, ICC 11322, ICC 11323, ICC 11324, ICC 12233, ICC 12234, ICC 12235, ICC 12236, ICC 12237, ICC 12238, ICC 12239, ICC 12240, ICC 12249, ICC 12251, ICC 12252, ICC 12253, ICC 12256, ICC 12257, ICC 12259, ICC 12267, ICC 12268, ICC 12269, ICC 12275, ICC 12428, ICC 12431. ICC 12435, ICC 12437, ICC 12440, ICC 12444, ICC 12450, ICC 12452, ICC 12454, ICC 12460, ICC 12467, ICC 12470, ICC 12471, ICC 12472, ICC 14364, ICC 14365. ICC 14366, ICC 14367. ICC 14368, ICC 14369, ICC 14370, ICC 14371, ICC 14372. ICC 14373, ICC 14374	India
	ICC 11318, ICC 11321, ICC 12244, ICC 12245, ICC 12248, ICC 12247. ICC 12248, ICC 12250, ICC 12254, ICC 12255, ICC 12258, ICC 12270, ICC 12271, ICC 12272, ICC 12273, ICC 12274	Iran
	ICC 12241, ICC 12242, ICC 12243, ICC 12429	Mexico
	ICC 12430	Spain
	ICC 12432, ICC 12433, ICC 12434	Ethiopia
Dry root rot	ICC 11315, ICC 12237, ICC 12240, ICC 12257, ICC 12268, ICC 12269, ICC 12428, ICC 12435, ICC 12437, ICC 12440, ICC 12444, ICC 12450, ICC 12452, ICC 12454, ICC 12460, ICC 12467, ICC 12470, ICC 12471, ICC 12472, ICC 14374, ICC 14396, ICC 14440, ICC 14442	India
	ICC 12241	Mexico
	ICC 12270, ICC 12271. ICC 12273, ICC 14449	Iran
	ICC 12430	Spain
Black root rot	ICC 11313, ICC 11316, ICC 11317, ICC 11320, ICC 11324, ICC 12236, ICC 12237, ICC 12239, ICC 12249, ICC 12256, ICC 12259, ICC 12269, ICC 12275, ICC 14450, ICC 14451	India
	ICC 12242	Mexico
	ICC 12245. ICC 12255, ICC 12258, ICC 12270, ICC 12271, ICC 12274, ICC 14411, ICC 14425. ICC 14426. ICC 14449	Iran
	ICC 14444	Pakistan
Botrytis gray mold	ICC 1084, ICC 1093, ICC 1102, ICC 4014, ICC 4018, ICC 4055, ICC 4063, ICC 4065, ICC 4074, ICC 4075, ICC 6671	Iran
	ICC 3540	India
	ICC 1069	USSR
	ICC 7574	Morocco
	ICC 10302	Colombia
	ICC 12512	India
Ascochyta blight	ICC 1084. ICC 1093. ICC 1102. ICC 4014, ICC 4018. ICC 4055, ICC 4063, ICC 4065, ICC 4074. ICC 4075	Iran
	ICC 3540	India
	ICC 1069	USSR
	ICC 12512	India

Continued...

Appendix 5b. ***Continued.***

Traits	Resistance source	Origin
Helkoverpa pod borer	ICCV 7. ICCL 86102, ICCL 86103, ICCX 730041 -8- 1-B-BP. ICCV 10	ICRISAT
	ICC 506, ICC 1381, ICC 4935, ICC 5264, ICC 9526, ICC 10460, ICC 10619, ICC 10667	India
	ICC 2696, ICC 6663, ICC 7966	Iran
	ICC 10870	Afghanistan
Drought tolerance[a]	ICC 4958	India
Drought tolerance[b]	ICC 5680	India
Cold tolerance	ICCV 88503, ICCV 88506, ICCV 88510, ICCV 93929. ICCV 92504	ICRISAT
Early maturity	ICC 8923	Russia
	ICCV 96029, ICCV 96030, ICCV 89244. ICCV 92332	ICRISAT
	ICC 1398, ICC 2023, ICC 5810, ICC 8378, ICC 8931, ICC 10232, ICC 10629, ICC 10822, ICC 10926. ICC 10976, ICC 10981, ICC 1096, ICC 11021. ICC 11039, ICC 11040, ICC 11059, ICC 11160. ICC 11180, ICC 12424, ICC 14595, ICC 14648, ICC 16947	India
	ICC 1097, ICC 2859, ICC 6919	Iran
	ICC 2171	Mexico
	ICC 8618	Ethiopia
	ICC 16641, ICC 16644	Pakistan

a. Large root system, good initial growth vigor, rapid rate of grain filling.

b. Limited leaflets per leaf.

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political, international organization for science-based agricultural development. ICRISAT conducts research on sorghum, pearl millet, chickpea, pigeonpea and groundnut – crops that support the livelihoods of the poorest of the poor in the semi-arid tropics encompassing 48 countries. ICRISAT also shares information and knowledge through capacity building, publications and ICTs. Established in 1972, it is one of 15 Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

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