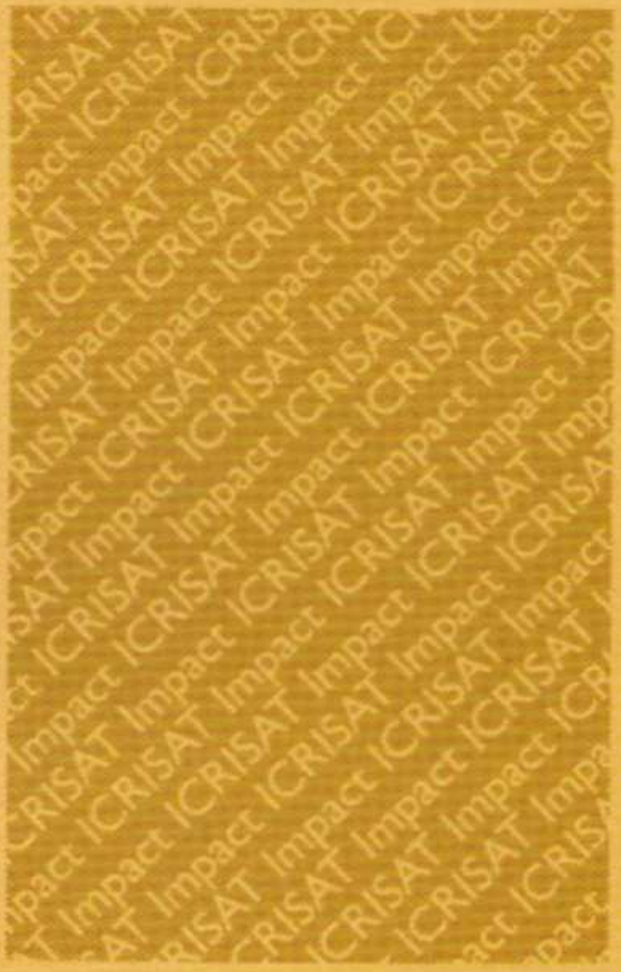
Impact Series no. 1

Returns to Research and Diffusion Investments

ON WILT RESISTANCE IN PIGEONPEA



International Crops Research Institute for the Semi-Arid Tropics

Returns to Research and Diffusion Investments on Wilt Resistance in Pigeonpea

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Introduction

Fusarium wilt caused by *Fusarium udum* Butler is one of the most widespread and destructive diseases of pigeonpea *(Cajanus cajan* (L.) Millsp.) in Asia and Africa. An international survey of pigeonpea diseases in Asia, Africa, and the Americas (Kannaiyan et al. 1981), initiated in 1975, showed that the disease occurred in almost all pigeonpea-growing areas on these continents. Subsequent monitoring surveys in 11 major pigeonpea-producing states in India reported high wilt incidence in three states - Maharashtra (23%), Bihar (18%), and Uttar Pradesh (15%) (Kannaiyan et al. 1984). Surveys in Africa found that wilt was the only major pigeonpea disease in Malawi, Tanzania, and Kenya. Other studies suggested that wilt caused yield reductions of up to 50% (Ryan 1981). Wilt-related production losses in 1977/78 were estimated to be 97 000 t (worth US$ 36.4 million) in India and 14 000 t (worth US$ 5.2 million) in Kenya, Malawi, and Tanzania.

Largely on the basis of these survey results, ICRISAT set a high priority for fusarium wilt research in pigeonpea. The research program aimed primarily at identifying resistant lines, conducting multilocational screening for resistance, and developing resistant cultivars. A combination of genetic resistance and cultural practices (crop rotation and mixed- or intercropping) was expected to offer farmers a cost-effective method of controlling the disease.

This work, conducted in collaboration with ICRISAT's NARS partners in different countries, has led to the release of four wilt-resistant cultivars in different regions

- ICP 8863 (Maruti) - released in 1986 for cultivation in Karnataka, India
- ICP 9145 (Nandolo wa nswana) - released in Malawi, in 1988
- ICPL 85063 - likely to be released in 1996; suitable for postrainy-season cultivation in Andhra Pradesh, India
- ICPL 87119 (Asha) - wilt- and sterility mosaic resistant; released in 1993 for central and southern India.

ICRISAT's Socioeconomics and Policy Division is planning a series of studies to track the spread and impact of these cultivars in farmers' fields, and thereby to demonstrate, in quantitative terms, the benefits that flow from research investment in genetic resources, genetic enhancement, pathology, and technology transfer. This publication reports results for ICP 8863 (Maruti), the first wilt-resistant, medium-duration pigeonpea cultivar to be released. Studies on the other three cultivars are planned or already under way, and will be reported in subsequent publications in this series.

Background

In order to breed resistant cultivars, it is essential that stable, broad-based sources of resistance be available. By the mid 1980s, several sources of wilt resistance had been identified at ICRISAT Asia Center (IAC). Of more than 11 000 accessions screened in wilt-sick plots at IAC during the 1977/78 cropping season onwards, 33 showed resistance to wilt (Nene and Kannaiyan 1982). Seeds collected from the resistant plants were resown in wilt-sick plots for further purification. Seeds of these resistant lines were then provided to breeders in national programs for further work. At about the same time, a few resistant/tolerant lines and cultivars were also being reported from other research stations in India, including the ICAR (Indian Council of Agricultural Research) stations at Pusa, Kanpur, and Badnapur.

Between 1978 and 1983, multilocational screening was carried out in India to identify genotypes with broad-based wilt resistance. This collaborative screening program, known as the ICAR/ICRISAT Uniform Trial for Pigeonpea Wilt Resistance (IIUTPWR), involved a number of institutions - ICRISAT, Marathwada Agricultural University (Badnapur, Maharashtra), Rajendra Agricultural University (Dholi, Bihar), the Agricultural Research Station of the University of Agricultural Sciences (Gulbarga, Karnataka), C S Azad University of Agriculture and Technology (Kanpur, Uttar Pradesh), J N Krishi Viswa Vidyalaya (Jabalpur, Madhya Pradesh), Pulses and Oilseeds Research Station (Berhampore, West Bengal), Agricultural College (Ranchi, Bihar), and the Indian Agricultural Research Institute (New Delhi). The trial was coordinated by ICRISAT and conducted by pathologists from ICAR and ICRISAT.

Sixty-one pigeonpea germplasm and breeding lines were evaluated at 15 wilt-endemic locations in India. A genotype was considered to be resistant if less than 20% of plants in all seasons of testing at a particular location wilted. Fifty-one such genotypes were identified at IAC, and other 10 by the Marathwada Agricultural University. All were medium- or long-duration types with a non-determinate flowering pattern. All except ICP 9168 (which is from Kenya) originated from India; most were germplasm accessions from the ICRISAT genebank.

This multilocational screening helped to identify - for the first time - wilt-resistant, true-breeding lines and cultivars that maintained their resistance across wilt-endemic locations and across years. Five pigeonpea lines (ICPs 4769, 8863, 9168, 10958, 11299) and two cultivars (C 11 and BDN 1) were resistant to wilt across a wide range of locations and seasons, indicating stable and broad-based resistance. These seven genotypes were later

included as long-term resistant controls in IIUTPWR, and remained resistant in subsequent years. The best performer in these trials was ICP 8863, which had maintained its resistance since 1977, and also exhibited high yield potential. It was developed by selection from ICP 7626 (P-15-3-3), a landrace from Badnapur in Maharashtra state, India.

Meanwhile, in the early 1980s, farmers in northern Karnataka, particularly in Gulbarga and Bidar districts, began reporting growing incidence of fusarium wilt. Production losses mounted, and farmers sought wilt-resistant materials from the Gulbarga Agricultural Research Station of the University of Agricultural Sciences. Scientists from this station approached ICRISAT, which by this time was recognized as the main source of disease-resistant pigeonpea lines.

The first set of multilocational trials was under way at that time, and preliminary results indicated the strong potential of ICP 8863. This was the only available pigeonpea variety that combined a high level of wilt resistance with broad-based resistance and a high degree of purity. It also matured slightly earlier than the medium-duration cultivars being grown in peninsular India. The yield advantage of ICP 8863, both in wilt-sick plots and in multilocational trials, was so apparent that it was selected by the Gulbarga scientists. On-station and on-farm adaptation trials at Gulbarga then began in earnest. Subsequently, the University conducted several large-scale demonstrations on their research stations, and front-line demonstrations on farmers' fields. The scientists' motivation was clear - they needed urgently to find a way to control wilt in northern Karnataka. In 1986, ICP 8863 was released in Karnataka under the name Maruti, and helped to stem the growing production losses. Its release was greatly facilitated by scientists and research managers from the University and the Karnataka State Department of Agriculture.

Research evaluation framework and zones of adoption

The welfare gains from fusarium wilt research were estimated using a simple non-traded goods framework based on the economic surplus model. Two adoption regimes were defined, to reflect

- the target zone of adoption
- the zones of diffusion.

Returns to investment on both base level research and extension were calculated for the target zone of adoption. Benefits in the zones of diffusion (i.e., wilt-endemic areas not directly targeted by the varietal release in 1986) were calculated as net additional incomes over the base level of investment.

Target zone

Northern Karnataka, where the ICP 8863 release was primarily targeted, is considered the target zone of adoption. Wilt-related losses were particularly severe in northern Karnataka, and it was farmers from this region (specifically, Gulbarga district) whose demand for wilt-resistant cultivars catalyzed the fast-track development and release of ICP 8863. Northern Karnataka has been called India's pigeonpea granary; about 118 000 t are produced each year from 301 000 ha (1988-90 average). The area has a favorable adoption environment, largely because the state seed agency ensures relatively good seed availability. It is also serviced by a good extension network operated by the State Department of Agriculture, which helped popularize ICP 8863 through minikit trials and a training and visit system. Once ICP 8863 was formally released in Karnataka in 1986, seed production was taken up almost immediately by the Karnataka State Seeds Corporation (KSSC).

Zones of diffusion

Wilt is also endemic in parts of Maharashtra, Andhra Pradesh, and Madhya Pradesh. Pigeonpea is grown on 930 000 ha in these regions, and annual production is over 550 000 t. However, since ICP 8863 has not been officially released except in Karnataka, efforts to popularize its use have received no support from the formal seed sector or from extension agencies in the other states. This study defines the possible zones of diffusion for ICP 8863 as

- districts in Andhra Pradesh and Maharashtra that border Karnataka - pigeonpea area 226 000 ha, annual production 66 000 t
- pigeonpea tracts in eastern Maharashtra and Madhya Pradesh - pigeonpea area 700 000 ha, production 493 000 t.

Figure 1 shows the distribution of pigeonpea throughout India, and highlights regions where the crop occupies a relatively high percentage of gross cropped area. Figure 2 shows the wilt-endemic areas in central India identified during the 1975-80 international survey of pigeonpea diseases.

Research process

It is important to document the time frame for research, development, and extension because this is an important input for the economic assessment discussed in this paper.

Table 1. Steps in the research process leading to the release of ICP 8863.

1975/76	Selection from landrace
1977	Original collection sown in a wilt-sick plot at IAC; seeds collected from resistant plants resown in wilt-sick plots for further purification
1978-83	Multilocational screening under the collaborative ICAR/ICRISAT trials (IIUTPWR); further purification
Early 1980s	In response to farmers' demands for a solution to the growing wilt problem, Agricultural Research Station in Gulbarga obtains wilt-resistant lines from ICRISAT
1984-85	On-station and on-farm adaptation trials
1986	ICP 8863 released in Karnataka under the name Maruti

The total research lag (i.e., the time taken from selection to release) for ICP 8863 was about 11 years. Table 1 gives a chronological account of the various steps in this process. Scientists at the Gulbarga Agricultural Research Station, who initiated the release of the cultivar, estimate that the ready availability of ICP 8863 material from ICRISAT essentially shortened their R&D lag by 50% (personal communication 1994). Another 4 years were added to the research lag to account for seed multiplication and front-line demonstrations conducted by institutions in Karnataka from 1986 to 1989.

Adoption - tracking the spread of ICP 8863

After almost 20 years of research on fusarium wilt - from problem identification to product development and dissemination - it is of prime interest to determine the extent to which products emerging from this research are utilized. This section discusses patterns and levels of adoption of the first research product - ICP 8863, both in the target zone of northern Karnataka and in the diffusion zones in other states of India.

Survey design and methodology

Pigeonpea is generally grown in highly variable semi-arid tropical environments, where adoption is expected to be non-uniform. A systematic tracking approach was therefore developed. Information from several sources was pieced together to form a composite

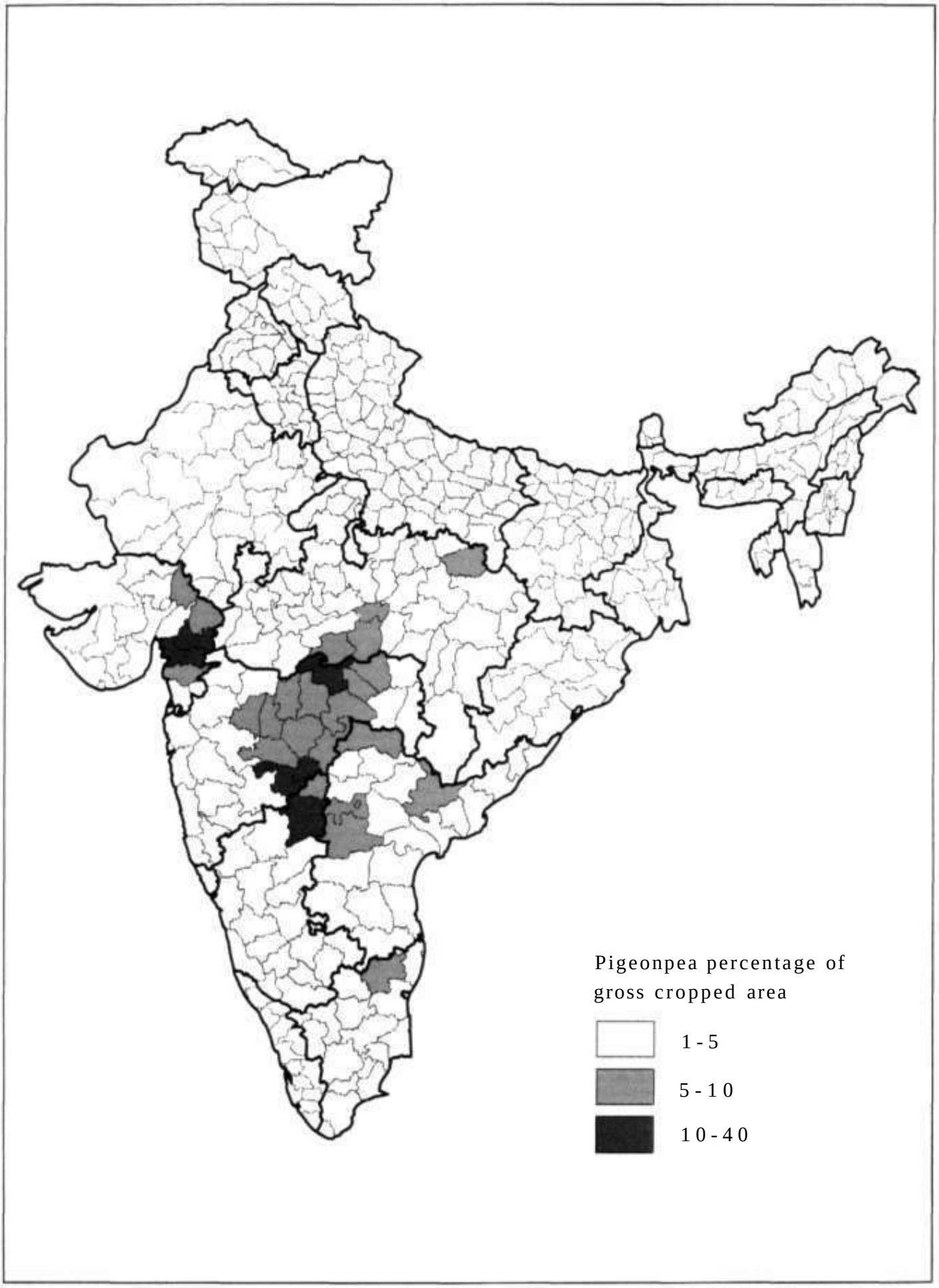


Figure 1. Distribution ofpigeonpea in India.

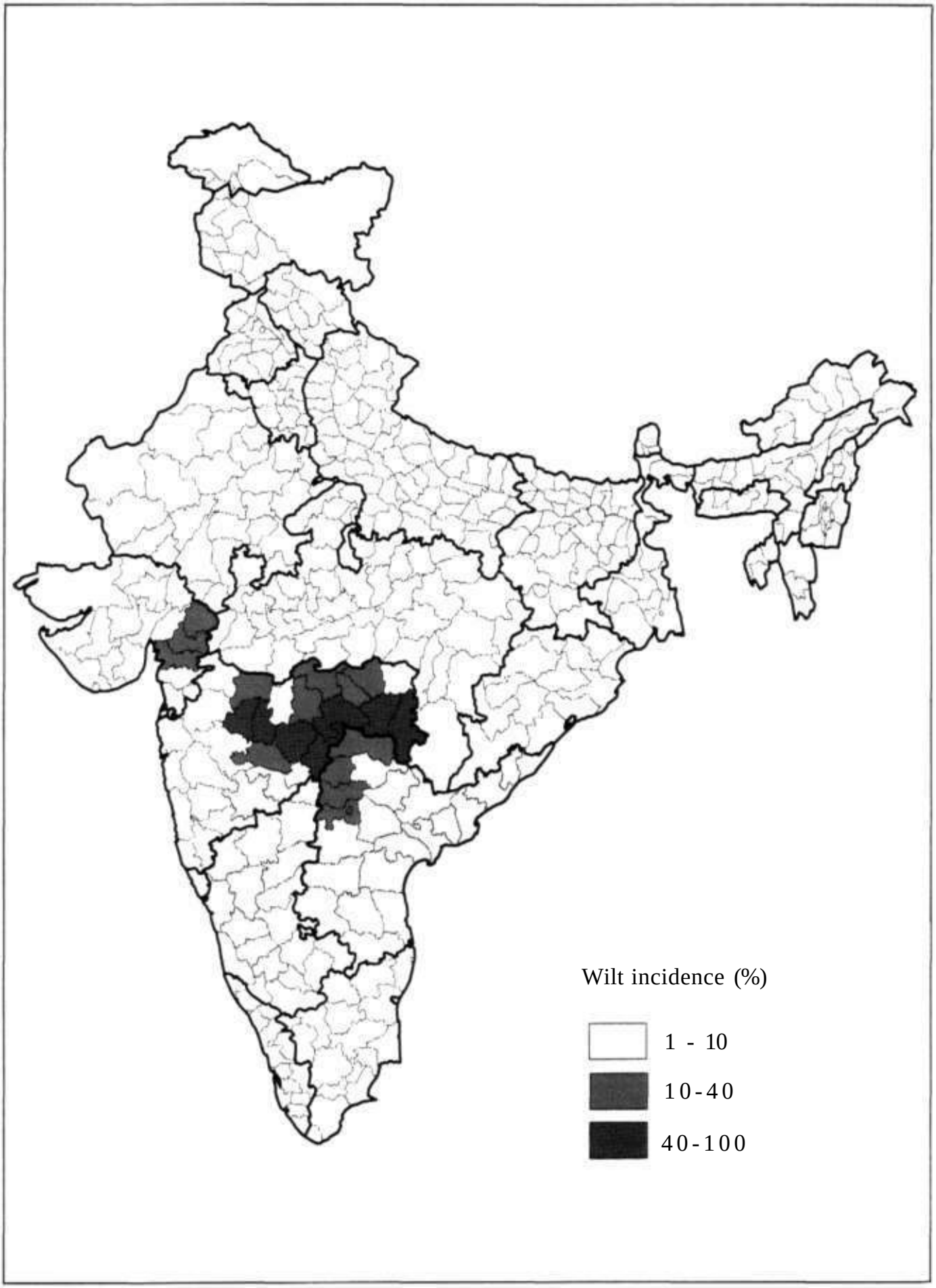


Figure 2. Incidence of fusarium wilt of pigeonpea in India, 1975-80.

picture of the spread of ICP 8863. Seed sector sales, area estimates by subject matter specialists appointed by the Department of Agriculture and Extension, farm-level reconnaissance, formal surveys, all provided data. The strategy used to track adoption and impact (and thereby estimate the benefits from R&D investments) is a two-pronged approach.

- NARS, government agencies, and private and public seed companies were visited to elicit information on ICP 8863 area/production, and seed production, multiplication, and distribution
- on-farm surveys were conducted to determine the extent and rate of adoption and the impact of improved cultivars in farmers' fields.

Selection of samples for the adoption survey was carefully designed to ensure that the sample derived was representative of the two adoption regimes, i.e., the target zone and the diffusion zones. The selection of survey sites was based primarily on secondary district-level data and a reconnaissance survey of pigeonpea-growing districts. Field observations and interviews with research and extension staff pointed to specific regions and districts where pigeonpea is important. Sample districts were identified by analyzing district-level data trends in area, production, and yield, and growth rates within and across regions and years. Table 2 shows pigeonpea area and production in the regions covered by the study.

Stratified multi-stage sampling was used to select a sample of farmer respondents. Once the pigeonpea-growing districts in the study area were identified, blocks (the next administrative level) were classified under two strata according to the intensity of pigeonpea cultivation. Block level data on pigeonpea area were obtained from the offices of the Department of Agriculture in each identified pigeonpea growing district. One block was then randomly selected from each strata, providing a representative sample of two blocks from each district. Sample villages were randomly selected from each block; and based on a sampling frame of village-level data obtained from each sample block, a random sample of farmers was taken from each selected village.

A survey questionnaire and modules were developed to obtain structured information on basic farmholding characteristics, land use/cropping system, adoption of wilt-resistant ICP 8863, farm cost structure, postharvest practices, and seed utilization.

Table 2. Pigeonpea area and production in three adoption regions: northern Karnataka, border districts in Andhra Pradesh and Maharashtra, and eastern Maharashtra and Madhya Pradesh, 1980-90.

Area ('000 ha)	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Average 1988–90
Northern Karnataka	198.0	218.1	140.7	232.1	240.3	243.6	259.2	279.6	298.1	302.0	302.4	301
Border districts in Andhra Pradesh and Maharashtra	168.5	171.3	167.3	172.2	170.8	170.9	166.2	185.1	213.1	231.3	232.9	226
Eastern Maharashtra and Madhya Pradesh	500.2	505.7	522.2	537.2	572.2	577.1	576.0	579.3	657.8	699.4	743.6	700
Total	866.7	895.1	830.2	941.5	983.3	991.6	1001.4	1044.0	1169.0	1232.7	1278.9	1227

Production ('000 t)	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Average 1988–90
Northern Karnataka	55.2	112.0	67.4	88.4	127.3	123.6	110.3	141.4	111.1	127.2	115.5	118
Border districts in Andhra Pradesh and Maharashtra	46.7	60.3	52.7	76.0	70.8	57.9	33.2	75.8	49.3	100.9	47.3	66
Eastern Maharashtra and Madhya Pradesh	285.6	342.5	349.2	381.9	391.6	393.3	333.7	431.3	528.5	587.3	363.1	493
Total	387.5	514.8	469.3	546.3	589.7	574.8	477.2	648.5	688.9	815.4	525.9	677

Patterns of adoption

Results from the adoption surveys confirmed the large-scale adoption of ICP 8863 (Maruti) in the target zone of adoption (Table 3, column 2). Adoption in northern Karnataka steadily increased from 5% in 1987 to 55% in 1991, peaking at almost 60% in 1992/93. It is expected that the ceiling level of adoption will hold at this value because the formal seed sector (KSSC and the private sector) maintains seed supply to meet 15% of total seed demand (KSSC, personal communication). Much of the demand will continue to be met by informal farmer-to-farmer seed channels.

The zones of diffusion for ICP 8863 are the pigeonpea-growing regions in the states of Andhra Pradesh, Maharashtra, and Madhya Pradesh. In particular, this includes eight pigeonpea-growing districts in Andhra Pradesh and Maharashtra, near the borders of northern Karnataka; and pigeonpea tracts in eastern Maharashtra and southern Madhya Pradesh.

These diffusion zones were delineated from the target zone in order to study the spread of ICP 8863 across states into areas where, because it has not been released, its spread depends solely on informal channels that may have evolved.

Table 3. Adoption of ICP 8863 (as a percentage of total pigeonpea area) in Karnataka, Maharashtra, and Andhra Pradesh, 1987-93.

		Districts bordering Karnataka		
Year	Karnataka	Rangareddy (Andhra Pradesh)	Osmanabad (Maharashtra)	Maharashtra
1987	4.8	0.0	0.0	0.0
1988	8.8	0.0	12.9	0.0
1989	8.6	3.5	24.3	2.2
1990	18.0	10.2	18.6	2.0
1991	55.1	34.3	36.6	4.0
1992	59.4	48.9	40.6	13.2
1993	58.9	51.8	58.7	17.2

The districts bordering northern Karnataka were considered first because farmers in these areas have indirect access to reliable sources of seed even though the variety has not been officially released. Interactions with local government officials, seed dealers, and farmers in northern Karnataka (near the state borders) indicated that demand for ICP 8863 was increasing in the neighboring districts in Andhra Pradesh and Maharashtra. Adoption trends in these border districts are interesting (Table 3, columns 3 and 4). While wilt occurs every year in this area and yield losses ranging from 10% to 30% have been reported, it took almost 2 years before adoption of the first wilt-resistant variety took place. However, once farmers became aware of the durable wilt resistance in ICP 8863, adoption picked up rapidly. Certified seed was available from the neighboring district of Gulbarga, which is the main seed production center in Karnataka. ICP 8863 is now very popular among farmers in this diffusion zone; on-farm surveys showed that adoption has reached 100% in some villages.

In Maharashtra, the demand for ICP 8863 has been growing, especially in the wilt-endemic areas of eastern Maharashtra. Farmers essentially depend on a few progressive farmers who produce seed, and on seed dealers who obtain only limited amounts of certified seed from KSSC for multiplication and sale. One private seed agency, Mahesh Seeds, began ICP 8863 seed production in 1990 and claims to be able to supply only about 1% of total demand in the districts of Yeotmal, Akola, and Amravati in eastern Maharashtra. The agency sells Maruti seed to farmers for double the KSSC market price.

The wilt-endemic areas of eastern Maharashtra clearly represent a constrained adoption scenario. Farmers in this area report that wilt is an annual occurrence; incidence of up to 69% has been reported in some districts (Kannaiyan et al. 1984, Nene et al. 1989). However, farmers do not have ready access to ICP 8863 through the formal seed sector, and are severely constrained by the inadequacy of informal seed channels, which have evolved rather slowly due to limited access to breeder and certified seed from KSSC (whose priority clientele is in Karnataka). The survey results reflect the consequences - a 2-year adoption lag and slow adoption, reaching less than 18% after 7 years. It is expected that farmer-to-farmer seed distribution will remain the major source of adoption unless government agencies facilitate the release of Maruti in Maharashtra.

Complementary information on adoption

Information was gathered from various sources to complement the primary data obtained from the formal surveys. These sources include seed agencies, NARS scientists, and staff of the Department of Agriculture.

Seed production and distribution data from both public and private seed companies provided clues to the spread of the cultivar and helped define target areas. KSSC reports that between 1990 and 1994, sales of Maruti seed have increased in absolute terms from 49 t to 140 t, and as a proportion of KSSC's total sale of pigeonpea seed from 32% to 47%. Maruti now covers large tracts in several districts in Karnataka, including Gulbarga, Bidar, Bijapur, and Raichur. Based on seed sales data (Table 4), and using the farmers' average seed rate of 10 kg ha^{-1}, the area sown to Maruti in these districts is conservatively estimated at about 95 000 ha.

Table 4. Pigeonpea seed sales by the Karnataka State Seeds Corporation, 1988-94.

	Seed sales (t) in different years						
Variety	1988	1989	1990	1991	1992	1993	1994
ICPL 87	-	-	–	3.4	11.7	17.6	10.0
HY 3C	14.3	18.5	25.2	11.0	12.4	2.1	20.0
GS 1	53.4	52.6	46.9	-	32.6	21.0	30.0
TTB 7	-	13.9	9.9	38.4	35.8	36.0	40.0
PT 221	23.9	30.7	21.3	51.9	28.1	21.6	60.0
ICP 8863	12.6	16.2	49.0	98.8	82.5	79.4	140.0

KSSC began multiplying and distributing seed almost immediately after ICP 8863 was released in 1986. However, they estimate that they can meet only 15% of the annual demand (KSSC, personal communication). This figure was based on the estimate that farmers usually purchase and replace seed once in 3 years. KSSC seed is distributed to various districts and blocks on demand. The company procures seed from seed producers at Rs 13.75 kg^{-1} and sells certified seed at Rs 18 kg^{-1} (1993/94 prices).

Discussions with NARS scientists, extension personnel, and specialists and village assistants of the Department of Agriculture were equally helpful. They provided very useful directions for ground-truthing adoption levels. For example, reports by specialists of the Principal Agricultural Offices of the Department of Agriculture in Karnataka indicated that in 1994, Maruti occupied about 116 120 ha in the major pigeonpea-growing districts of Karnataka. Figure 3 shows that data obtained from subject matter specialists match closely with data collected during the on-farm surveys, especially in Bidar district.

Farm cost structure

Table 5 shows a cost analysis for ICP 8863 based on input and output data from on-farm surveys. Yield and input use are compared between ICP 8863 and the best cultivar used by farmers before this variety became available.

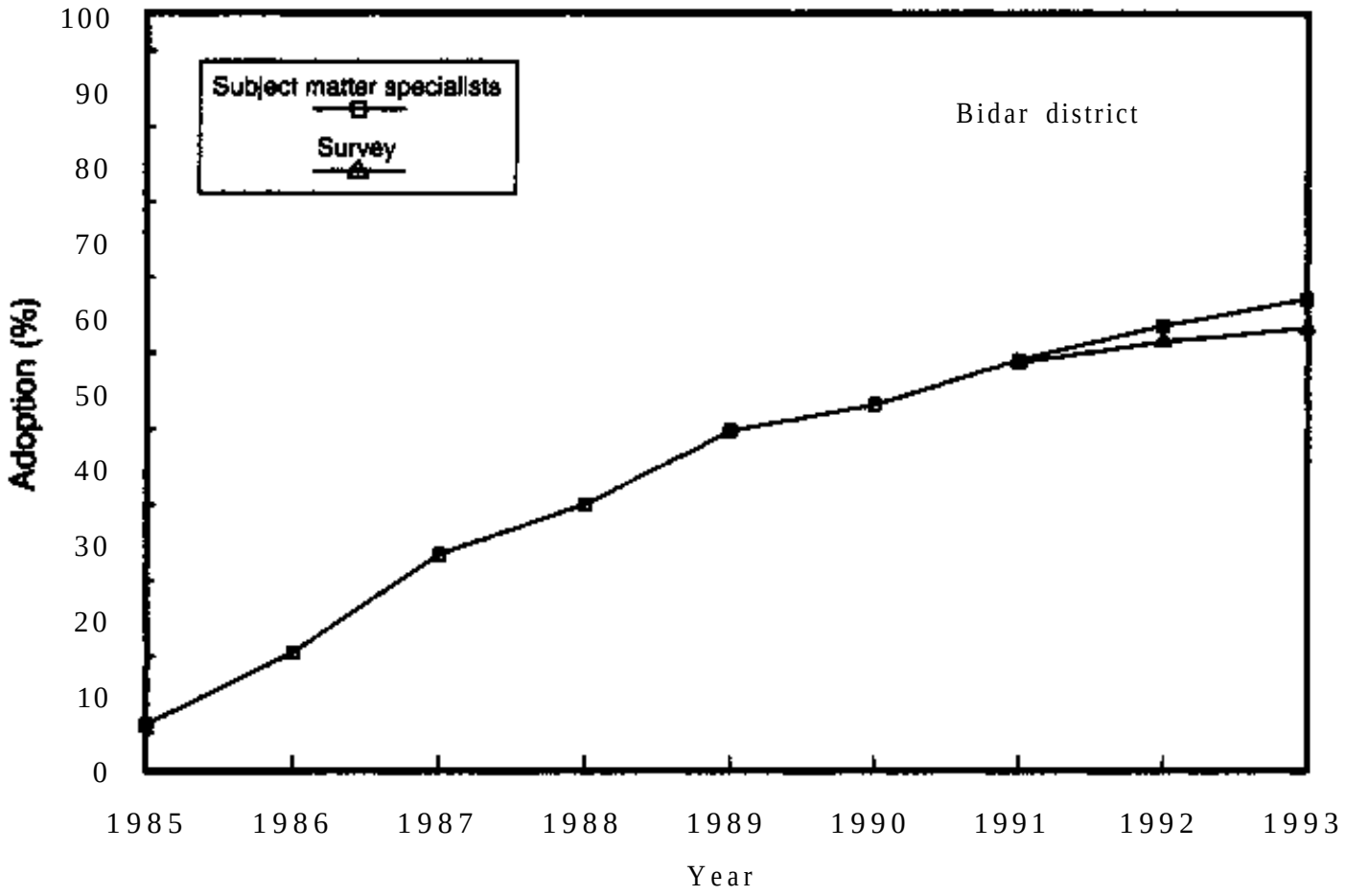
Research costs

The costs of wilt-resistance research at ICRISAT and its partner institutions in the NARS were estimated from annual budgets (Table 6). Historical budget records disaggregated by research program are very difficult to reconstruct for research conducted at ICRISAT during the early years. Thus, for the purposes of this study, expenditure on fusarium wilt research was estimated with guidance from scientists who were part of ICRISAT's wilt research team during those years, and administrative officers in charge of budgets. The breakdown of research costs was made on the basis of the research team's salaries, and the proportion of each scientist's time spent on fusarium wilt. Operating costs were estimated from the total operating costs for the Legumes Pathology program, which focused on three major research activities during that period - pigeonpea fusarium wilt, pigeonpea sterility mosaic, and chickpea wilt complex. Similar imputations were made for the NARS counterpart funds.

Two budget scenarios (low and high) are discussed. This range in budget allocations reflects the variation in estimates made by different staff members. The lower budget scenario is also a way to simulate the effect of marginal budget reductions on the net benefits flowing from the research.

Assessment of benefits from technology adoption

This section discusses quantitative indicators of the benefits from the use of ICP 8863. Results are analyzed to draw important lessons for research and extension policy and



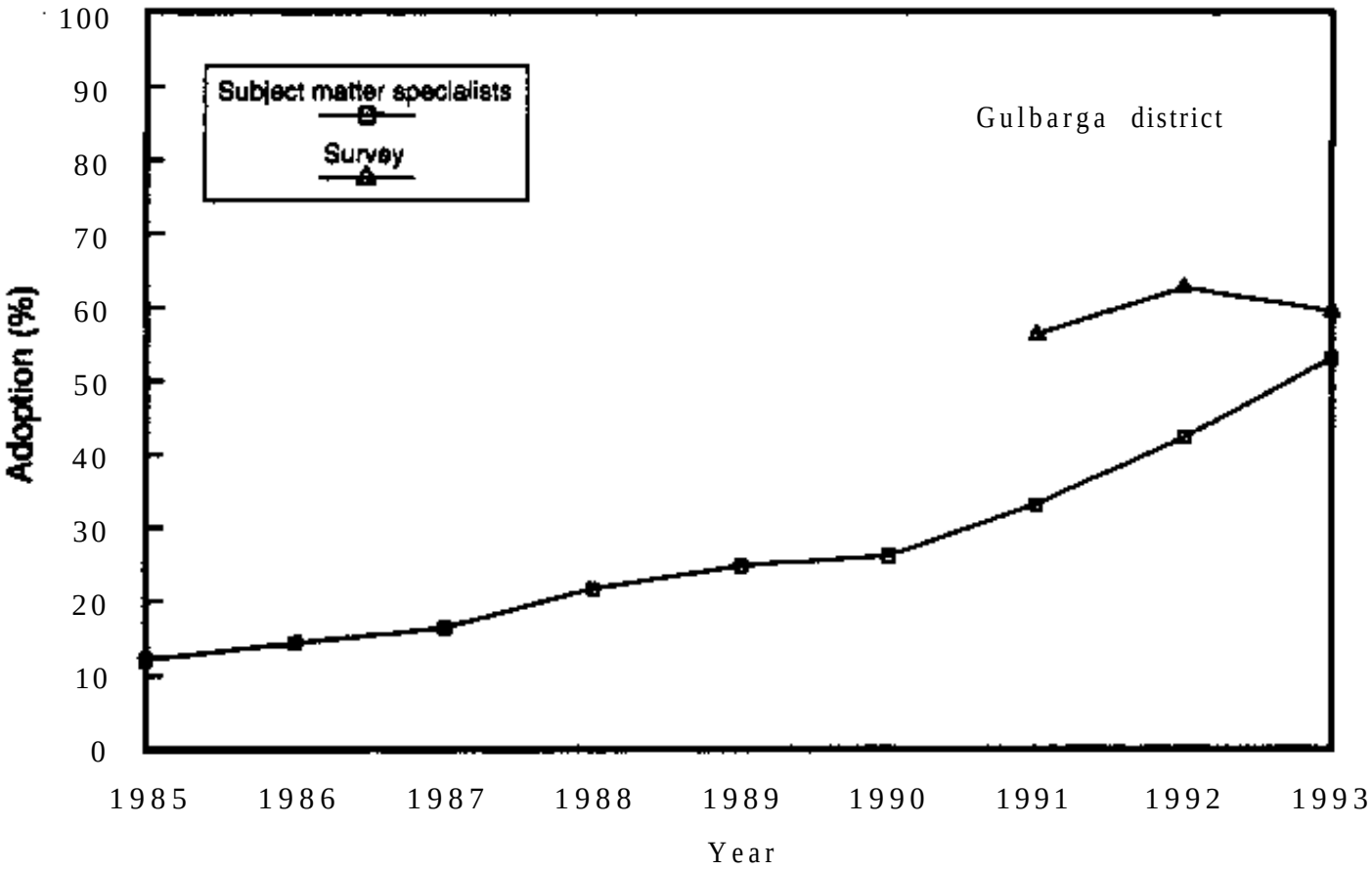


Figure 3. Adoption ofICP 8863 (Maruti) as indicated by Subject Matter Specialists and survey data.

Table 5. Cost analysis of research impact of ICP 8863.

	Unit	Unit price (Rs)	Best cultivar used before ICP 8863		ICP 8863	
			Quantity	Cost (Rs)	Quantity	Cost (Rs)
Variable costs[1]						
Male labor						
Land preparation	days	20.00	7.00	140.00	8.00	160.00
FYM application	days	20.00	2.47	49.40	0.64	12.80
Sowing	days	30.00	1.85	55.50	1.25	37.50
Weeding	days	20.00	0.82	16.40	-	-
Fertilizer application	days	20.00	0.41	8.20	-	-
Inter culture	days	20.00	4.00	80.00	5.40	108.00
Irrigation	days	20.00	1.24	24.80	3.00	60.00
Spraying	days	25.00	6.00	150.00	7.00	175.00
Harvesting	days	25.00	5.35	133.75	7.00	175.00
Threshing	days	25.00	6.18	154.50	3.82	95.50
Female labor						
Land preparation	days	12.00	6.00	72.00	8.00	96.00
FYM application	days	12.00	3.29	39.48	0.55	6.60
Sowing	days	13.50	2.00	27.00	3.35	45.23
Weeding	days	13.50	17.00	229.50	17.40	234.90
Fertilizer application	days	12.00	1.44	17.28	2.71	32.52
Harvesting	days	13.50	3.29	44.42	1.10	14.85
Threshing	days	13.50	12.30	166.05	11.25	151.88
Bullock labor						
Land preparation	days	50.00	6.00	300.00	6.00	300.00
FYM application	days	50.00	3.00	150.00	0.46	23.00
Sowing	days	65.00	1.65	107.25	1.18	76.70
Inter culture	days	50.00	2.00	100.00	4.00	200.00
Spraying	days	50.00	-	-	0.46	23.00
Threshing	days	60.00	0.82	49.20	1.14	68.40
Seed	kg	15.00	12.35	185.25	9.50	171.00 @ Rs 18 kg^{-1}
Farmyard manure	kg	0.15	5269.00	790.35	823.00	123.45

1. Costs expressed in ha^{-1} $year^{-1}$

Continued...

Table 5. ***Continued.***

	Unit	Unit price (Rs)	Best cultivar used before ICP 8863 Quantity	Best cultivar used before ICP 8863 Cost (Rs)	ICP 8863 Quantity	ICP 8863 Cost (Rs)
Fertilizer						
Urea	kg	2.70	-	-	36.36	98.17
DAP	kg	6.50	70.00	455.00	53.06	344.89
SSP	kg	3.00	-	-	3.43	10.29
20:20:0	kg	5.40	-	-	30.87	166.70
15:15:15	kg	5.20	20.58	107.02	-	-
Pesticides	1	240.00	1.65	396.00	1.70	408.00
Equipment						
Land preparation	days	800.00	-	-	0.07	56.00
Irrigation	days	16.00	1.03	16.48	2.15	34.40
Miscellaneous				203.24		175.49
Total variable costs[1]			4268.06		3685.26	
Fixed costs[1]						
Tax on owned land				60.00		60.00
Tax on land				1200.00		1200.00
Depreciation and interest on capital			810.00		810.00	
Total fixed costs[1]				2070.00		2070.00
Total cost[1]				6338.06		5755.26
Output[2]						
Grain	kg	5.47	700.00	3829.00	1099.61	5465.06 @ Rs 4.97 kg^{-1}
By-product	kg	1.20	500.00	600.00	725.00	870.00 @ Rs 1.20 kg^{-1}
Stalk	kg	0.20	1500.00	300.00	1900.00	380.00 @ Rs 0.20 kg^{-1}
Total value of output[2]	Rs			4729.00		6715.06
Unit cost assessment						
Variable cost	Rs t^{-1}			6097.23		3351.42
Fixed cost	Rs t^{-1}			2957.14		1882.49
Total cost	Rs t^{-1}			9054.37		5233.91
Unit cost reduction						
Variable cost	Rs t^{-1}					2745.81
Fixed cost	Rs t^{-1}					1074.66
Total cost	Rs t^{-1}					3820.47

1. Costs expressed in ha^{-1} $year^{-1}$. 2. Output expressed in ha^{-1} $year^{-1}$

Table 6a. Annual costs (US $) for fusarium wilt research conducted by ICRISAT and the NARS.

Year	Research expenditure by ICRISAT	Research expenditure by NARS	Objective
1975/76	-	845	Selection from landrace
1977	5 070	845	Original collection sown in wilt-sick plot at IAC
1978-80	42 250	845	Further purification
1981-83	42 250	845	Multinational screening for resistance
1984/85	-	1267.5	On-station and on-farm adaptation trials
1986-89	-	2535	Seed multiplication and extension after release

Basis for ICRISAT's annual research cost (US $).

Staff member	Cost for entire year	Proportion (%) of time spent on fusarium wilt	Budget allocation
1 Principal Scientist	80 000	18	14 400
1 National Scientist	8 000	100	8 000
1 Research Associate	2 400	100	2 400
1 Field assistant	1 200	100	1 200
3 Field laborers	1 250	100	1 250
Operating expenses			15 000
Total			42 250

Table 6b. Annual costs (US $) for fusarium wilt research conducted by ICRISAT and the NARS (low-range funding scenario).

Year	Research expenditure by ICRISAT	Research expenditure by NARS	Objective
1975/76		662	Selection from landrace
1977	3 309	662	Original collection sown in wilt-sick plot at IAC
1978-80	33 091	662	Further purification
1981-83	33 091	662	Multilocational screening for resistance
1984/85		993	On-station and on-farm adaptation trials
1986-89		1985	Seed multiplication and extension after release

Continued...

Table 6b. ***Continued.***

Basis for calculating ICRISAT's annual research cost (US $).

Staff member	Full cost	Proportion (%) of time spent on fusarium wilt	Budget allocation
1 Principal Scientist	80 000	9	7 241
1 National Scientist	8 000	75	6 000
1 Research Associate	2 400	100	2 400
1 Field assistant	1 200	100	1 200
3 Field laborers	1 250	100	1 250
Operating expenses			15 000
Total			33 091

help guide future research priorities. Tables 7 and 8 present a summary of data reported in previous sections, and show the basic information needed to assess research benefits (for the target region). The net present value of the stream of benefits from fusarium wilt research is obtained by analyzing the following information:

- production levels in the study area
- cost structures based on on-farm surveys
- varying adoption levels in different adoption regimes
- possible input variation across regions
- research costs.

The internal rate of return to research investment is also presented.

The base-case analysis uses parameter estimates based on on-farm survey data on inputs, outputs, and costs involved in the production of ICP 8863 and a wilt-susceptible local variety used by farmers in the study area.

The survey data show that ICP 8863 provides considerable yield gains over the next best cultivar - 57% gain in grain yield, 45% in fodder, 27% in stalk yield. These yield benefits due to the utilization of wilt-resistant ICP 8863 has expanded production levels as yield gains translate to lower per unit production costs and improved profitability levels.

A cost analysis based on on-farm survey data (Table 5) indicates that the use of ICP 8863 reduces unit cost by as much as 42%, or Rs 3820.47 per tonne. The major differences in

Table 7. Background information: wilt-endemic regions in central and peninsular India.

Year	Total pigeonpea area ('000 ha)	Total production ('000 t)		
		Karnataka	Andhra Pradesh and Maharashtra borders	Maharashtra and Madhya Pradesh
1970	732.48	74.21	45.80	237.43
1971	649.19	50.48	29.67	223.62
1972	640.37	20.76	23.54	192.45
1973	758.72	50.32	42.37	281.38
1974	746.98	80.13	43.08	310.37
1975	795.73	131.01	54.62	327.50
1976	751.57	78.39	37.54	216.61
1977	769.19	116.84	38.05	259.05
1978	807.41	115.71	51.90	297.16
1979	799.30	137.35	57.35	320.57
1980	866.76	55.25	46.65	285.57
1981	895.05	112.00	60.30	342.47
1982	830.17	67.38	52.69	349.16
1983	941.55	88.42	76.01	381.85
1984	983.28	127.34	70.79	391.61
1985	991.56	123.57	57.92	393.28
1986	1001.31	110.30	33.15	333.68
1987	1044.00	141.40	75.75	431.25
1988	1168.95	111.11	49.25	528.54
1989	1232.69	127.24	100.90	587.27
1990	1278.92	115.46	47.29	363.14

Source: Indian Agricultural Statistics, Agricultural Situation in India.

Table 8. Summary data for benefit assessment of ICP 8863 for the target region.

Base level of annual (1986-88 average) production	120 935 t
Base price level (1986-88 average)	Rs 5468 t^{-1}
Supply elasticity	0.2
Demand elasticity	-0.5
Discount rate used for benefit assessment	0.08
Unit cost reduction	Rs. 3820.47 t^{-1}
Slope of supply curve	4.423015
Slope of demand curve	11.05754
Exchange rate (1 US$)	Rs 30.9

input use between ICP 8863 and the local variety are in seed rate and use of farmyard manure. Farmers use higher seed rates for the local variety, for two reasons: Maruti seed is more expensive, and wilt losses in the local variety have to be compensated for. Farmers also tend to use more farmyard manure on the local variety.

Given the research costs presented in Table 6, the base price of Rs 5468 (US$ 177) per tonne, a discount rate of 8%, supply elasticity of 0.2, demand elasticity of -0.5, and the estimated adoption rates depicted in Figure 4, the net present value of benefits accruing to the primary target area of northern Karnataka alone is US$ 25.5 million (Table 9). Additional benefits worth about US$ 36.4 million flow to the diffusion zones in Andhra Pradesh, Maharashtra, and Madhya Pradesh (Tables 10 and 11). Thus, the total net present value of benefits from fusarium wilt research is approximately US$ 61.7 million. This represents an internal rate of return of 65% resulting from the benefits accruing to the various regions covered in the study.

Farmers were interviewed to discover their perceptions of the benefits from the use of ICP 8863. They described several benefits

- greater disease resistance
- shorter duration (160 days) than other available medium-duration varieties
- suitability for sowing both in the rainy season and in the early part of the postrainy season
- suitability for either sole- or intercropping
- efficiency in input use, i.e., good response to irrigation and a plant height that is ideal for plant protection operations.

Follow-up monitoring in the regions covered by the study also provided feedback on impact. For example, Raju (1993) reported after a monitoring tour of Gulbarga that wilt incidence in farmers' fields in the area was low, and that farmers attributed this improvement primarily to the widespread cultivation of ICP 8863.

In Maharashtra, where ICP 8863 has not been released, the strong evidence of high demand for ICP 8863 (Bantilan and Joshi 1995) led to two positive policy actions. First, the management of the Maharashtra State Seeds Corporation, the main public seed agency in the state, was convinced of the need to produce substantial quantities to meet the fast-growing demand. Starting 1995, the Corporation bought breeder seed from KSSC to initiate their own ICP 8863 seed multiplication and distribution program. They have also contracted seed growers across Maharashtra to produce certified and truthfully labeled seed.

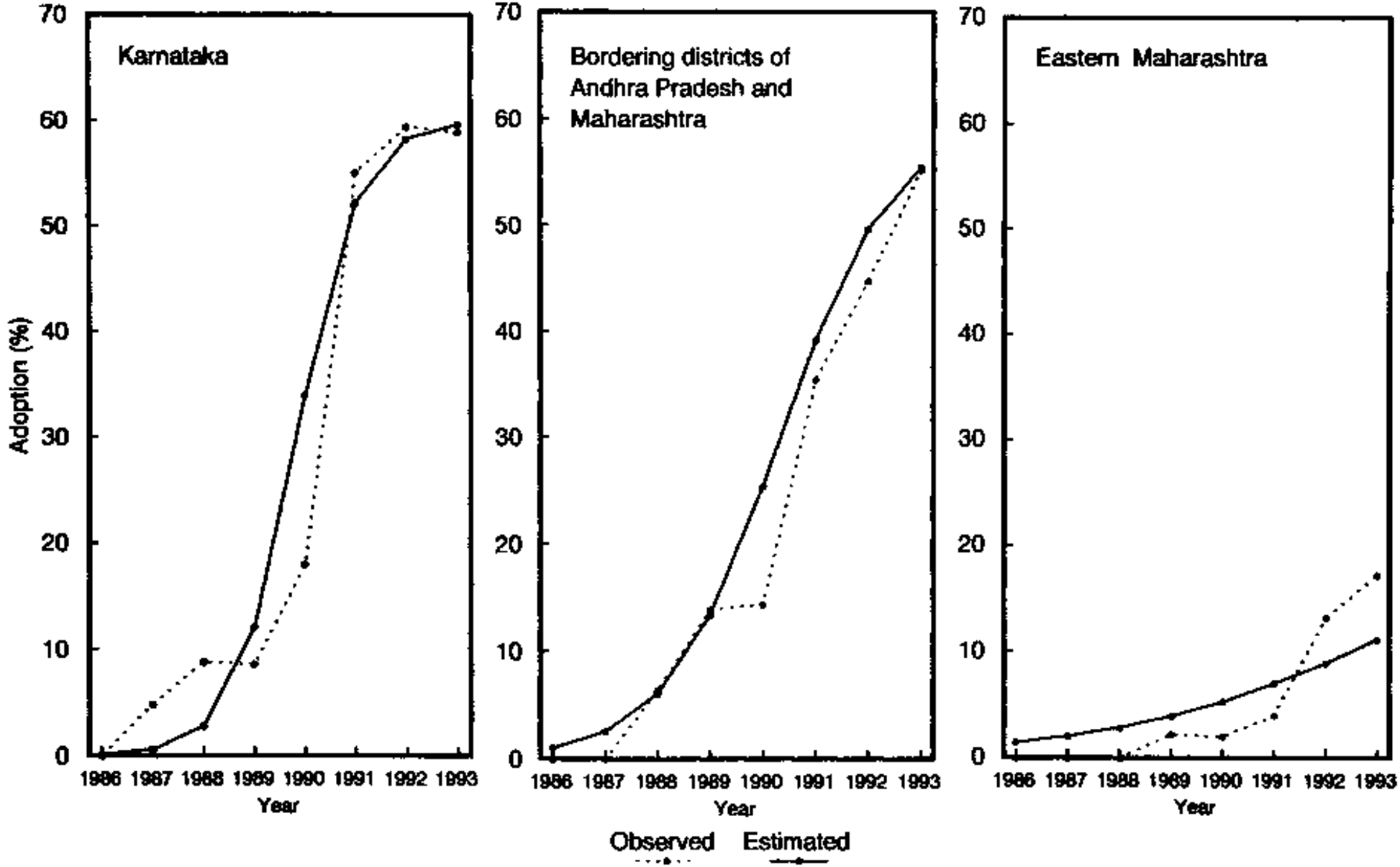


Figure 4. Observed and estimated adoption of ICP 8863 in Karnataka, Andhra Pradesh, and Maharashtra.

Table 9. Analysis of benefits from ICP 8863 research.

Year	Net benefits (US$)	Reseach costs (US$)			Research gains – Karnataka (US$)			Distribution of benefits			
		Total	ICRISAT	ICAR/other institutions	Total	Adoption level	Annual gains	Consumers US$	Consumers (%)	Producers US$	Producers (%)
Present value	61 736 978	169 099	158 403	10 696	25 466 357			7 276 102		18 190 255	
Total	375 510 560	279 273	257 725	21 458	147 514 346			42 146 956		105 367 390	
1975	(845)	845	0	845							
1976	(845)	845	0	845							
1977	(5 070)	5 070	4 225	845							
1978	(43 095)	43 095	42 250	845							
1979	(43 095)	43 095	42 250	845							
1980	(43 095)	43 095	42 250	845							
1981	(43 518)	43 518	42 250	1 268							
1982	(43 518)	43 518	42 250	1 268							
1983	(43 518)	43 518	42 250	1 268							
1984	(1 268)	1 268	0	1 268							
1985	(1 268)	1 268	0	1 268							
1986	87 374	2 535	0	2535	17 268	0.0011	15 698 527	4 934	28.57	12 335	71.43
1987	266 978	2 535	0	2535	87 912	0.0056	15 698 527	25 118	28.57	62 794	71.43
1988	909 668	2 535	0	2535	470 956	0.03	15 698 527	134 559	28.57	336 397	71.43
1989	4 014 807	2 535	0	2535	1 883 823	0.12	15 698 527	538 235	28.57	1 345 588	71.43
1990	8 245 404	0	0	0	5 337 499	0.34	15 698 527	1 525 000	28.57	3 812 499	71.43
1991	13 152 973	0	0	0	8 163 234	0.52	15 698 527	2 332 353	28.57	5 830 881	71.43
1992	19 764 218	0	0	0	9 105 145	0.58	15 698 527	2 601 470	28.57	6 503 675	71.43
1993	22 603 561	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
1994	23 091 754	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
1995	23 704 937	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
1996	24 318 120	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
1997	24 858 662	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
1998	25 399 205	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
1999	25 669 476	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
2000	25 939 748	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
2001	26 210 019	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
2002	26 480 290	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
2003	26 750 562	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
2004	27 020 833	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43
2005	27 291 104	0	0	0	9 419 116	0.60	15 698 527	2 691 176	28.57	6 727 940	71.43

Internal rate of return = 0.6480

Table 10. Analysis of benefits from ICP 8863 research flowing to districts of Andhra Pradesh and Maharashtra bordering Karnataka.

	Research gains (US$)			Distribution of benefits			
		Adoption	Annual	Consumers		Producers	
Year	Total	level	gains	(US$)	(%)	(US$)	(%)
Present value	11 237 164			3210618		8 026 546	
Total	65 993 759			18 855 360		47 138 399	
1975	0						
1976	0						
1977	0						
1978	0						
1979	0						
1980	0						
1981	0						
1982	0						
1983	0						
1984	0						
1985	0						
1986	72 640	0.010	7 264 035	20 754	28.57	51 886	71.43
1987	181 601	0.025	7 264 035	51 886	28.57	129 715	71.43
1988	435 842	0.06	7 264 035	124 526	28.57	311 316	71.43
1989	944 325	0.13	7 264 035	269 807	28.57	674 518	71.43
1990	1 816 009	0.25	7 264 035	518 860	28.57	1 297 149	71.43
1991	2 832 974	0.39	7 264 035	809 421	28.57	2 023 553	71.43
1992	3 632 018	0.50	7 264 035	1 037 719	28.57	2 594 298	71.43
1993	3 995 219	0.55	7 264 035	1 141 491	28.57	2 853 728	71.43
1994	4 213 140	0.58	7 264 035	1 203 754	28.57	3 009 386	71.43
1995	4 285 781	0.59	7 264 035	1 224 509	28.57	3 061 272	71.43
1996	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43
1997	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43
1998	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43
1999	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43
2000	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43
2001	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43
2002	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43
2003	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43
2004	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43
2005	4 358 421	0.60	7 264 035	1 245 263	28.57	3 113 158	71.43

Table 11. Analysis of benefits from ICP 8863 research flowing to the diffusion zone in eastern Maharashtra and southern Madhya Pradesh.

	Research gains (US$)			Distribution of benefits			
		Adoption	Annual	Consumers		Producers	
Year	Total	level	gains	US$	(%)	US$	(%)
Present value	25 202 557			7 200 730		18 001 826	
Total	162 281 728			46 366 208		115 915 520	
1975	0						
1976	0						
1977	0						
1978	0						
1979	0						
1980	0						
1981	0						
1982	0						
1983	0						
1984	0						
1985	0						
1986	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0
1988	5 405	0.0001	54 054 270	1 544	28.57	3 861	71.43
1989	1 189 194	0.0220	54 054 270	339 770	28.57	849 424	71.43
1990	1 091 896	0.0202	54 054 270	311 970	28.57	779 926	71.43
1991	2 156 765	0.0399	54 054 270	616219	28.57	1 540 547	71.43
1992	7 027 055	0.130	54 054 270	2 007 730	28.57	5 019 325	71.43
1993	9 189 226	0.170	54 054 270	2 625 493	28.57	6 563 733	71.43
1994	9 459 497	0.175	54 054 270	2 702 713	28.57	6 756 784	71.43
1995	10 000 040	0.185	54 054 270	2 857 154	28.57	7 142 886	71.43
1996	10 540 583	0.195	54 054 270	3 011 595	28.57	7 528 988	71.43
1997	11 081 125	0.205	54 054 270	3 166 036	28.57	7 915 089	71.43
1998	11 621 668	0.215	54 054 270	3 320 477	28.57	8 301 191	71.43
1999	11 891 939	0.220	54 054 270	3 397 697	28.57	8 494 242	71.43
2000	12 162211	0.225	54 054 270	3 474 917	28.57	8 687 293	71.43
2001	12 432 482	0.230	54 054 270	3 552 138	28.57	8 880 344	71.43
2002	12 702 753	0.235	54 054 270	3 629 358	28.57	9 073 395	71.43
2003	12 973 025	0.240	54 054 270	3 706 578	28.57	9 266 446	71.43
2004	13 243 296	0.245	54 054 270	3 783 799	28.57	9 259 497	71.43
2005	13 513 567	0.250	54 054 270	3 861 019	28.57	9 652 548	71.43

Table 12. Analysis for benefits from ICP 8863 (Maruti) research under favorable environment.

Year	Net benefits ($US)	Research costs (US 8)			Research gains (US$) - Karnataka		
		Total	ICRISAT	ICAR/other institutions	Total	Adoption level	Annual gains
Present value	79 776 211	169 099	158 403	10 696	25 466 357		
Total	517 673 289	279 273	257 725	21 548	147 514 346		
1975	(845)	845	0	845			
1976	(845)	845	0	845			
1977	(5 070)	5 070	4 225	845			
1978	(43 095)	43 095	42 250	845			
1979	(43 095)	43 095	42 250	845			
1980	(43 095)	43 095	42 250	845			
1981	(43 518)	43 518	42 250	1268			
1982	(43 518)	43 518	42 250	1 268			
1983	(43 518)	43 518	42 250	1 268			
1984	(1 268)	1268	0	1 268			
1985	(1 268)	1 268	0	1 268			
1986	87 374	2 535	0	2535	17 268	0.0011	15 698 527
1987	266 978	2 535	0	2535	87 912	0.0056	15 698 527
1988	909 668	2 535	0	2535	470 956	0.03	15 698 527
1989	4 014 807	2 535	0	2535	1 883 823	0.12	15 698 527
1990	8 245 404	0	0	0	5 337 499	0.34	15 698 527
1991	13 152 973	0	0	0	8 163 234	0.52	15 698 527
1992	19 764 218	0	0	0	9 105 145	0.58	15 698 527
1993	22 603 561	0	0	0	9 419 116	0.60	15 698 527
1994	24 443 110	0	0	0	9 419 116	0.60	15 698 527
1995	27 218 464	0	0	0	9 419 116	0.60	15 698 527
1996	29 993 818	0	0	0	9 419 116	0.60	15 698 527
1997	32 696 531	0	0	0	9 419 116	0.60	15 698 527
1998	35 399 245	0	0	0	9 419 116	0.60	15 698 527
1999	38 101 958	0	0	0	9 419 116	0.60	15 698 527
2000	40 804 672	0	0	0	9 419 116	0.60	15 698 527
2001	41 885 757	0	0	0	9 419 116	0.60	15 698 527
2002	42 966 843	0	0	0	9 419 116	0.60	15 698 527
2003	44 047 928	0	0	0	9 419 116	0.60	15 698 527
2004	45 129 013	0	0	0	9 419 116	0.60	15 698 527
2005	46 210 099	0	0	0	9 419 116	0.60	15 698 527

Internal rate of return = 0.6523

Continued.

Table 12. ***Continued.***

Year	Research gains (US $)					
	Andhra Pradesh and Maharashtra borders			Maharashtra and Madhya Pradesh		
	Total	Adoption level	Annual gains	Total	Adoption level	Annual gains
Present value	11 237 164			43 241 789		
Total	65 993 759			304 444 457		
1975	0			0		
1976	0			0		
1977	0			0		
1978	0			0		
1979	0			0		
1980	0			0		
1981	0			0		
1982	0			0		
1983	0			0		
1984	0			0		
1985	0			0		
1986	72 640	0.01	7 264 035	0	0	0
1987	181 601	0.025	7 264 035	0	0	0
1988	435 842	0.06	7 264 035	5 405	0.0001	54 054 270
1989	944 325	0.13	7 264 035	1 189 194	0.0220	54 054 270
1990	1 816 009	0.25	7 264 035	1 091 896	0.0202	54 054 270
1991	2 832 974	0.39	7 264 035	2 156 765	0.0399	54 054 270
1992	3 632 018	0.50	7 264 035	7 027 055	0.13	54 054 270
1993	3 995 219	0.55	7 264 035	9 189 226	0.17	54 054 270
1994	4 213 140	0.58	7 264 035	10 810 854	0.20	54 054 270
1995	4 285 781	0.59	7 264 035	13 513 567	0.25	54 054 270
1996	4 358 421	0.60	7 264 035	16 216 281	0.30	54 054 270
1997	4 358 421	0.60	7 264 035	18 918 994	0.35	54 054 270
1998	4 358 421	0.60	7 264 035	21 621 708	0.40	54 054 270
1999	4 358 421	0.60	7 264 035	24 324 421	0.45	54 054 270
2000	4 358 421	0.60	7 264 035	27 027 135	0.50	54 054 270
2001	4 358 421	0.60	7 264 035	28 108 220	0.52	54 054 270
2002	4 358 421	0.60	7 264 035	29 189 306	0.54	54 054 270
2003	4 358 421	0.60	7 264 035	30 270 391	0.56	54 054 270
2004	4 358 421	0.60	7 264 035	31 351 476	0.58	54 054 270
2005	4 358421	0.60	7 264 035	32 432 562	0.60	54 054 270

The second and perhaps more important policy consequence is the planned release of the variety in Maharashtra. The adoption data and feedback from farmers reported in this study were used to initiate procedures for its release. This policy action will help significantly to remove seed availability as a binding constraint to adoption, and is likely to raise the ceiling level of adoption. Assuming that the adoption ceiling will eventually reach 60% (the same level as in Karnataka), substantial potential benefits - of the order of US$ 79.8 million - are estimated (Table 12).

Summary and conclusions

The wilt-resistant pigeonpea variety ICP 8863 (Maruti) is a product of joint research and development by ICRISAT and the Indian NARS. It was selected and identified from P-15-3-3, a landrace from Badnapur, Maharashtra, and stored in the ICRISAT germplasm collection. Further purification was undertaken at ICRISAT Asia Center, and multilocational screening was conducted through the IIUTPWR cooperative trials involving ICRISAT and several NARS institutions. Scientists from the Agricultural Research Station in Gulbarga pushed aggressively for the release of ICP 8863 in Karnataka, where wilt incidence was growing progressively more severe.

The entire process, from selection to its release in Karnataka in 1986, involved a total of 11 years of applied and adaptive research conducted jointly by ICRISAT and the NARS. The Karnataka program invested another 4 years (1986-1989) for seed multiplication and extension.

A systematic tracking approach was developed, using complementary information from several sources. These include secondary district/block level data on area, production, and yield, seed sector sales, farm-level reconnaissance, and formal surveys. This information was pieced together to form a composite picture of the spread of ICP 8863.

The results of this study clearly demonstrate the significant impact of ICP 8863, which now dominates the pigeonpea tracts of northern Karnataka, considered the pigeonpea granary of South Asia. Diffusion to districts in the neighboring states of Andhra Pradesh, Maharashtra, and Madhya Pradesh also occurred. The cultivar occupies almost 60% of the pigeonpea area in the wilt-affected districts of northern Karnataka and the bordering districts of Andhra Pradesh and Maharashtra. Nonavailability of seed has constrained adoption in the wilt-endemic areas of eastern Maharashtra, but an informal sector has evolved to meet the demand for seed. The private sector in Maharashtra does produce ICP 8863 seed, but is constrained by limited availability of breeder seed from KSSC. It

Ryan, J.G. 1981. Estimation of the economic value of production losses due to diseases of pigeonpeas. Appendix V *in* International survey of pigeonpea diseases. Departmental progress report no. 12. Pulse pathology. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (Limited distribution.)

RA 00306

About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 16 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR).The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank.

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