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Improved Cultivars of Pearl Millet in Tamil Nadu : Adoption, Impact, and Returns to Research Investment

International Crops Research Institute for the Semi-Arid Tropics

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Abstract

Improved cultivars of pearl millet have been widely adopted in Tamil Nadu State of India, with both public and private sectors playing a significant role in making them available to farmers. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) made early breakthroughs in pearl millet breeding, which provided a strong base for further research. Farmers prefer improved cultivars because of their high yield, good grain size, pest and disease tolerance, and short duration.

The increased production on account of adoption of improved cultivars largely goes to the animal feed industry for use as raw material. However, consumption of pearl millet has sharply declined in Tamil Nadu. Research investment on pearl millet breeding has a high payoff. An analysis of farm-level efficiency of pearl millet production shows some degree of inefficiency. Strengthening extension education in precise application of inputs for pearl millet production is important.

Résumé

Cultivars améliorés de mil au Tamil Nadu : adoption, impact, et rentabilités des investissement en recherches. Les cultivars améliorés du mil ont été largement adoptés dans l'état de Tamil Nadu en Inde grâce aux secteurs public et privé qui ont joué un rôle important pour les rendre disponibles aux paysans. L'Institut international de recherche agricole dans les zones tropicales semi-arides (ICRISAT) a pu faire des percées très tôt dans son programme de sélection entraînant ainsi des recherches plus avancées. Les paysans préfèrent des cultivars améliorés en raison de leurs rendements plus élevés, de la bonne taille des grains, de leur tolérance aux ravageurs et aux maladies, et de leur cycle court.

La production accrue résultant de l'adoption des cultivars améliorés est principalement destinée à l'industrie fourragère qui l'utilise comme matière première. Cependant, la consommation du mil a connu une baisse sensible au Tamil Nadu. Les investissements dans la recherche sur la sélection du mil rapportent beaucoup. Une analyse faite au milieu réel montre qu'il y existe un certain degré d'inefficacité dans la production du mil. Il est ainsi important de renforcer les activités de vulgarisation pour préciser les moyens d'application des intrants afin de l'améliorer.

Improved Cultivars of Pearl Millet in Tamil Nadu: Adoption, Impact, and Returns to Research Investment

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Background

Pearl millet is an important cereal in Tamil Nadu, next only to rice and sorghum. It is grown over 236 000 ha and its production was estimated at 338 0001 in 1993 (Directorate of Agriculture 1994). It is widely grown in 16 of the 22 districts of the state, indicating its adaptability not only across physiogeographic but also socioeconomic environments (Fig. 1). An indication of pearl millet's proven resilience under the whole range of agroclimatic conditions can be had from its presence in Thoothukudi district with the least quantum of rainfall (660 mm) and in Kadalur district where there is high (1100 mm) rainfall. Its outstanding adaptation to varied environments has been well documented (Bidinger et al. 1982; ICRISAT 1996). Compared to the leading pearl millet-growing states in India which have a negligible 5% of the crop area under irrigation, Tamil Nadu irrigates about 15%.

Shrinking frontier

Temporally, the area sown to pearl millet in Tamil Nadu has shown a decline. Between the triennia ending 1972 and 1993, it lost nearly half its area from 451 000 ha to 217 000 ha (Appendix 1 and Fig. 2). This can be ascribed to two reasons: (1) the changing food habits of the people, primarily made possible by the supply of subsidized rice and wheat (superior cereals) under the Public Distribution System, which shifted the demand curve for pearl millet to the far left; and (2) the competitiveness of more profitable crops such as groundnut, pulses, sunflower, and maize. One redeeming feature, however, is that productivity almost doubled during this period (Appendix 1 and Fig. 3). This helped to maintain the production of pearl millet at the same level as in the earlier period. Given the limited scope for increasing the net cropped area in Tamil Nadu and competition from other crops, the area sown to pearl millet is likely to remain at its present level or may even decline further. What then are the alternatives?

Bright spots

While the demand for pearl millet as a foodgrain has sharply diminished, demand for it as a raw material in the poultry and animal feed industry and to a lesser extent in the food-processing industry has increased. Therefore, if pearl millet is to retain its status as an important grain crop in Tamil Nadu, its production must be oriented toward industrial uses. The situation sends a clear message to agriculture planners and pearl millet researchers on what they must do to sustain

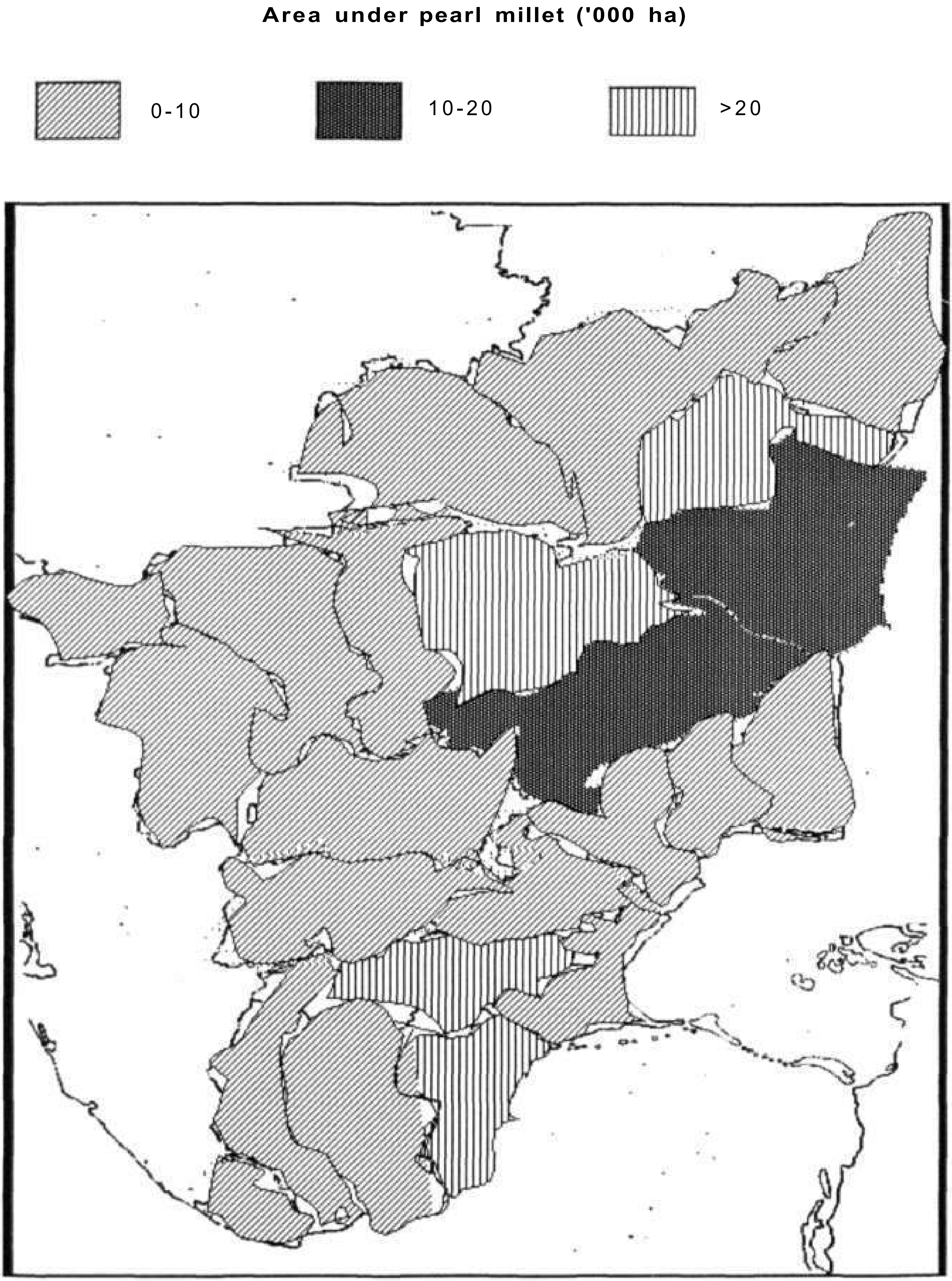

Figure 1. Pearl millet cultivation in Tamil Nadu.

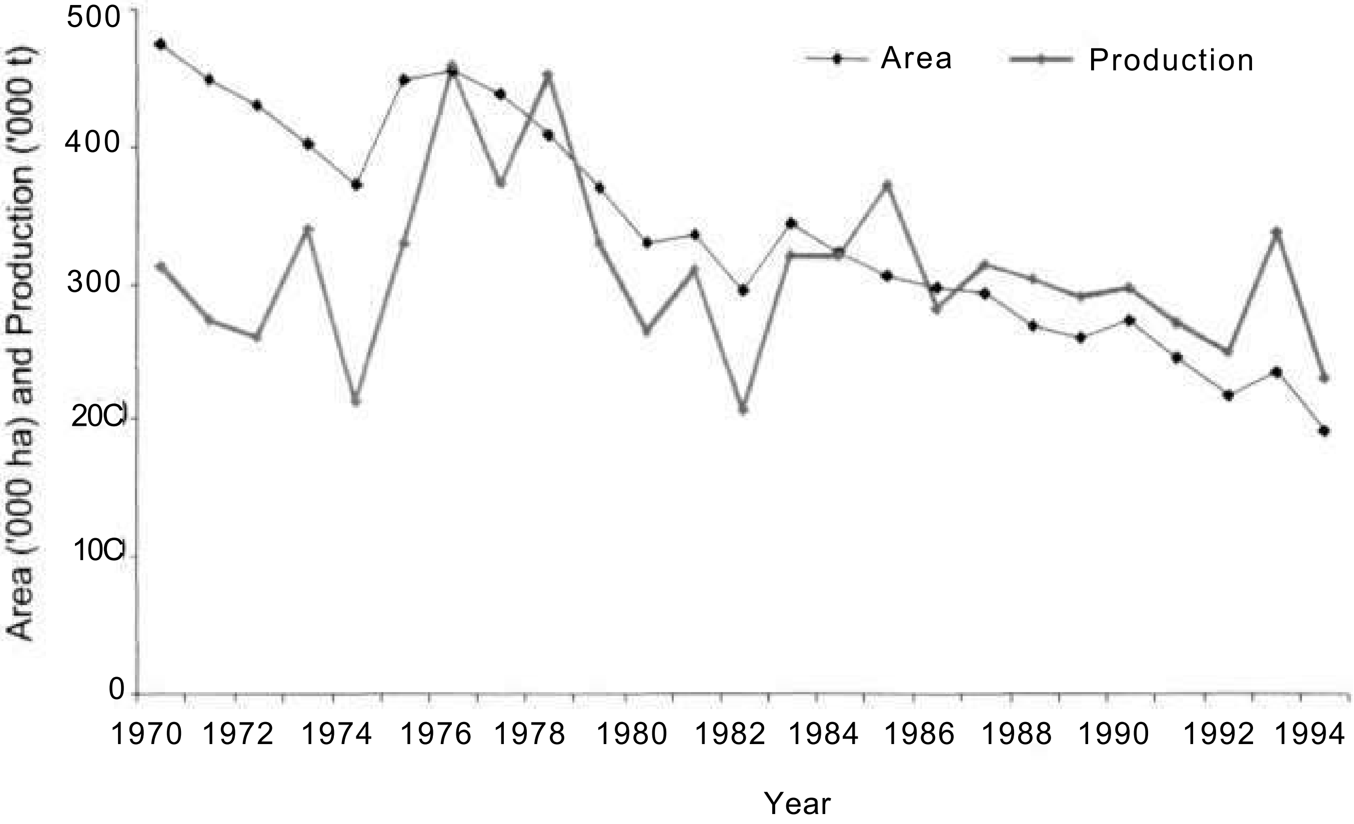

Figure 2. Area and production of pearl millet in Tamil Nadu, 1970-1994.

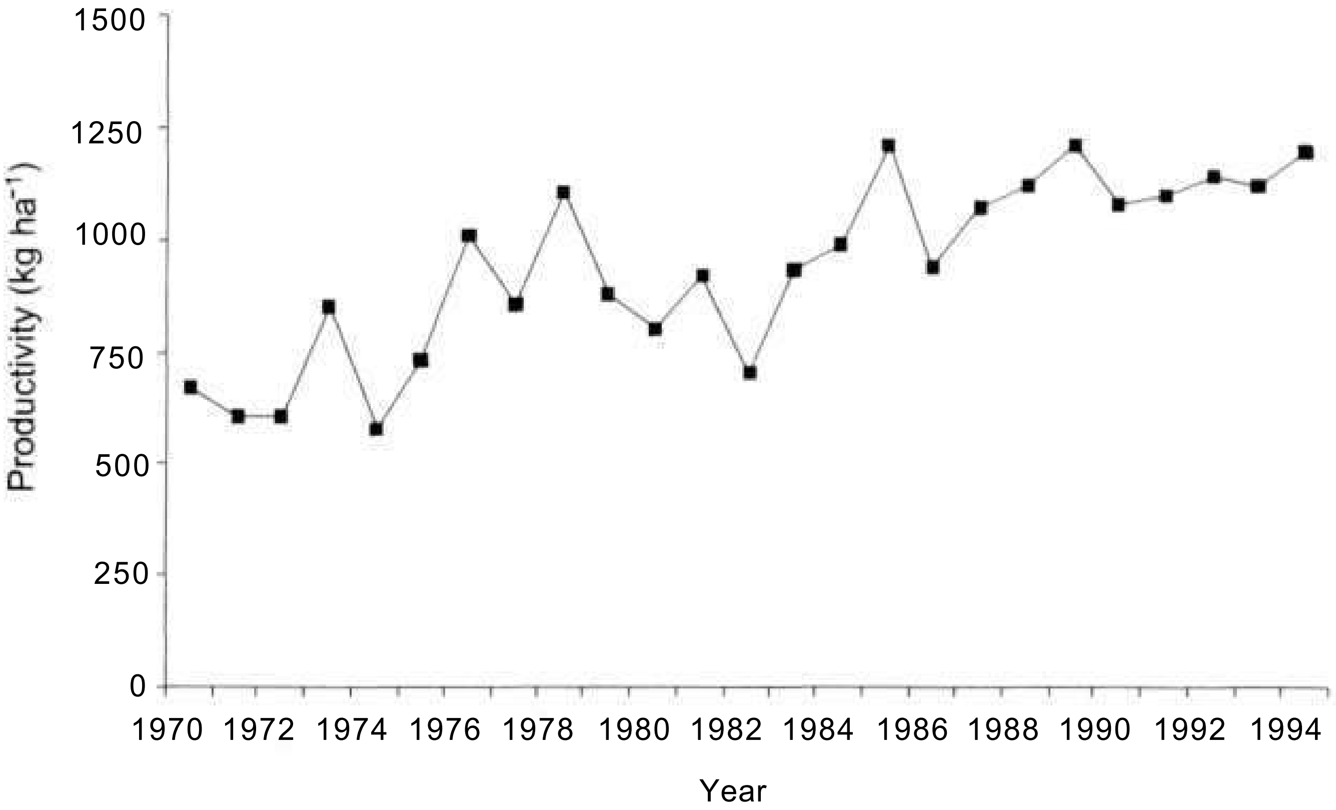

Figure 3. Productivity of pearl millet in Tamil Nadu, 1970-1994.

the production of this cereal. Another bright spot certainly is the emergence of distinctly improved pearl millet cultivars during the past 15 years. Such productivity enhancements have enabled pearl millet to be competitive in terms of profitability. The higher productivity of improved cultivars (ICs) has minimized the production loss. But for the benefits derived from ICs, the area under pearl millet would have shrunk further. New cultivars with more desirable traits and associated management technologies will likely remain the source of progress toward higher pearl millet production.

Improved cultivars: A brief history

Pearl millet breeding research in Tamil Nadu dates back to the late 1930s. The first improved variety, CO 1, was released in 1939 (Table 1).

Table 1. Cultivars released by Tamil Nadu Agricultural University[1].

Cultivar	Year of release	Research lag (years)
CO 1	1939	7
CO 2	1940	7
CO 3	1942	7
X 1	1950	9
X 2	1951	9
CO 4	1953	7
CO 5	1954	7
X 3	1957	9
CO 6	1976	NA[2]
X 4	1980	9
X 5	1984	9
CO 7	1986	7
X 6	1993	9

1. COs are composites and Xs are hybrids.
2. NA = Not available.

Since then, 12 more cultivars have been released by the Tamil Nadu Agricultural University (TNAU)[1]. In addition, the Department of Agriculture of the Government of Tamil Nadu released two single-cross hybrid cultivars originally developed by the Indian Agricultural Research Institute (IARI): KM $_1$ (BJ 104) and KM 2 (BK 560). In addition, some new cultivars developed in the rest of India, both in the public and private sectors, also made a solid impact on pearl millet production in Tamil Nadu. As regards breeding research in India, the earlier focus was on improvement of open-pollinated cultivars. Much of the earlier work concentrated on mass selection of locally adapted landraces. Some amount of hybridization between landraces or between landraces and inbred lines followed by progeny selection also took place (Krishnaswamy 1962). These cultivars, however, did not make much of an impact on increasing yields (Bidinger and Rao 1988). The next phase of pearl millet breeding research was characterized by the advent of the cytoplasmic/genetic male sterility line Tift 23A which was used to produce F_1 hybrids (Anand Kumar and Andrews 1984). Grain yields of the hybrids were substantially higher, which led to their rapid adoption by farmers, to the extent of 20% of the pearl millet area in India. However, unexpected outbreaks of downy mildew epidemics caused the collapse of many hybrids such as HB 1, HB 2, and HB 4 (Walker 1989). Consequently, the trend of adoption of hybrids rapidly slowed down. A further contributing factor to the low rate of adoption of hybrids in Tamil Nadu has been the limited availability of high-yielding hybrids with problem-free seed multiplication as many hybrid seed plots produced on male-steriles LIIIA and PT 732A would not have met seed certification standards due to their high pollen shedder frequency.

The occurrence of downy mildew epidemics resulted in a reorganization of pearl millet breeding with the major thrust shifting to building downy mildew resistance in hybrid parents and breeding of open-pollinated cultivars (Bidinger and Rao 1988). The establishment of ICRISAT in 1972, the activities of ICAR under the All India Coordinated Pearl Millet Improvement Programme (AICPMIP), and the efforts of state agricultural universities (SAUs) in the late 1970s and 1980s strengthened pearl millet breeding research through introduction of new materials with resistance to downy mildew (e.g., genetic materials from Africa introduced to India by ICRISAT), development of several male-sterile lines, and diversification of hybrid parents. By the mid 1980s, a new generation of pearl millet cultivars had found their way into farmers' fields in India (Dave 1987). In the late 1980s and early 1990s, the private sector came

1. Prior to 1972, TNAU was known as the Agricultural College and Research Institute.

out with a number of new hybrids challenging the cultivars originating from the National Agricultural Research System (NARS) and the International Agricultural Research Centers (IARCs). Very recently, biotechnology has opened up new opportunities of breeding cultivars with desired traits. Clearly, hybrids with enough heterogeneity for durable resistance and sufficient uniformity of agronomic characters will soon be in the field. The first field evaluations of these new hybrids will begin very soon (ICRISAT 1996).

Issues and objectives

Tamil Nadu is one of the more agriculturally progressive states in India, and is in the forefront of adoption of improved technologies of crop production. This state has over the years built up a good agricultural extension system that has consistently helped farmers adopt ICs. Hybrids such as HB 1, HB 2, and HB 3 were adopted in the early 1970s but had to be discontinued later due to incidence of downy mildew. The other ICs grown in the state are listed in Table 2. Recent decades have witnessed a large-scale cultivation of ICs of pearl millet spanning the entire state.

But concurrently certain issues have also emerged that need detailed scrutiny. Despite a wide consensus on adoption of ICs, no scientifically based results are available indicating the precise measurement of their adoption and composition. Secondly, adoption rates and varietal composition considerably vary across production environments (such as agroclimatic zones), which may cause differential impacts on income distribution. Thirdly, the area under pearl millet in Tamil Nadu is showing a secular decline. Fourthly, research products from the private sector appear to be overtaking those of the public sector. This has implications for agricultural research investment and prioritization.

Table 2. Improved pearl millet cultivars grown in Tamil Nadu.

Agency	Cultivar	Year of release	Research lag (years)
NARS-Public	HB 1	1965	NA[1]
	HB 3	1968	NA
	KM 2	1979	NA
	KM 3	1977	NA
NARS-Private	Eknath 101	1988	NA
	Eknath 301, Eknath 302, Eknath 303	1992	NA
	MAHYCO 151	1995	NA
	PBH 13, PBH 19, PBH 37, PBH 38	1996	NA
	Pioneer	1987	NA
	Pioneer 7602	1995	NA
	Pioneer 7686	1996	NA
	Plantgene	1988	NA
ICRISAT	WC-C 75	1982	7
	ICMS 7703	1985	8
	ICTP 8203	1988	6
	ICMV 155	1991	6
	ICMV 221	1993	5

1. NA = Not available.

Sources: For NARS-Public: TNAU and Analytical report on varietal release, Directorate of Agriculture, Government of Tamil Nadu, Chennai; and for NARS Private : Rapid rural appraisal conducted as part of the study.

Lastly, the available ICs do not seem to have totally met the requirements of pearl millet growers in Tamil Nadu. These issues unambiguously warrant a scientific investigation to understand the problems with better perspectives and more insights. This study is an attempt in this direction. Its focused objectives are:

- To measure the scale of adoption and varietal composition of ICs of pearl millet in Tamil Nadu;

- To identify the determinants of adoption of ICs of pearl millet and to quantify their influence;
- To determine the magnitude of lags (time from development to adoption) in the adoption of ICs;
- To study the perceptions of farmers on the constraints that inhibit increased adoption of ICs; and
- To assess the impact of ICs in terms of efficiency, equity, and sustainability.

Methodology

Sampling

This study is based on a household survey of pearl millet producers spread over 28 villages spanning seven districts of Tamil Nadu (Appendix 2 and Fig. 4). The sample districts, blocks, and villages were selected on the basis of pearl millet acreage data from 1991 to 1993 (Appendix 3). The survey sample consisted of 336 cultivator households, 84 agricultural labor households, and 28 nonagricultural labor households. The sample distribution was uniform across all the villages. The sample farmers represent all the production environments under which pearl millet is cultivated in Tamil Nadu. Information relating to household characteristics, cropping pattern, adoption pattern, seed source, reasons for adoption, and cost of cultivation were collected using a structured questionnaire. This was supported by a detailed discussion with leading farmers, agricultural extension personnel, researchers, seed producers, and agricultural policy-makers in the state. In addition, secondary data relating to area, production, seed distribution, etc. were obtained from the offices of the joint director of agriculture, located at the district level.

Analytical framework

Often, research attempts to quantify the adoption of ICs as a single variable aggregating all the cultivars. Realizing the importance of determining the scale of adoption of each cultivar (or a group of cultivars), a disaggregated analysis was attempted. Farmers adopt pearl millet ICs bred by various agencies: (1) Public sector agencies in the NARS, which includes in the Indian context, the Indian Council of Agricultural Research (ICAR) and the SAUs; (2) Private sector bodies

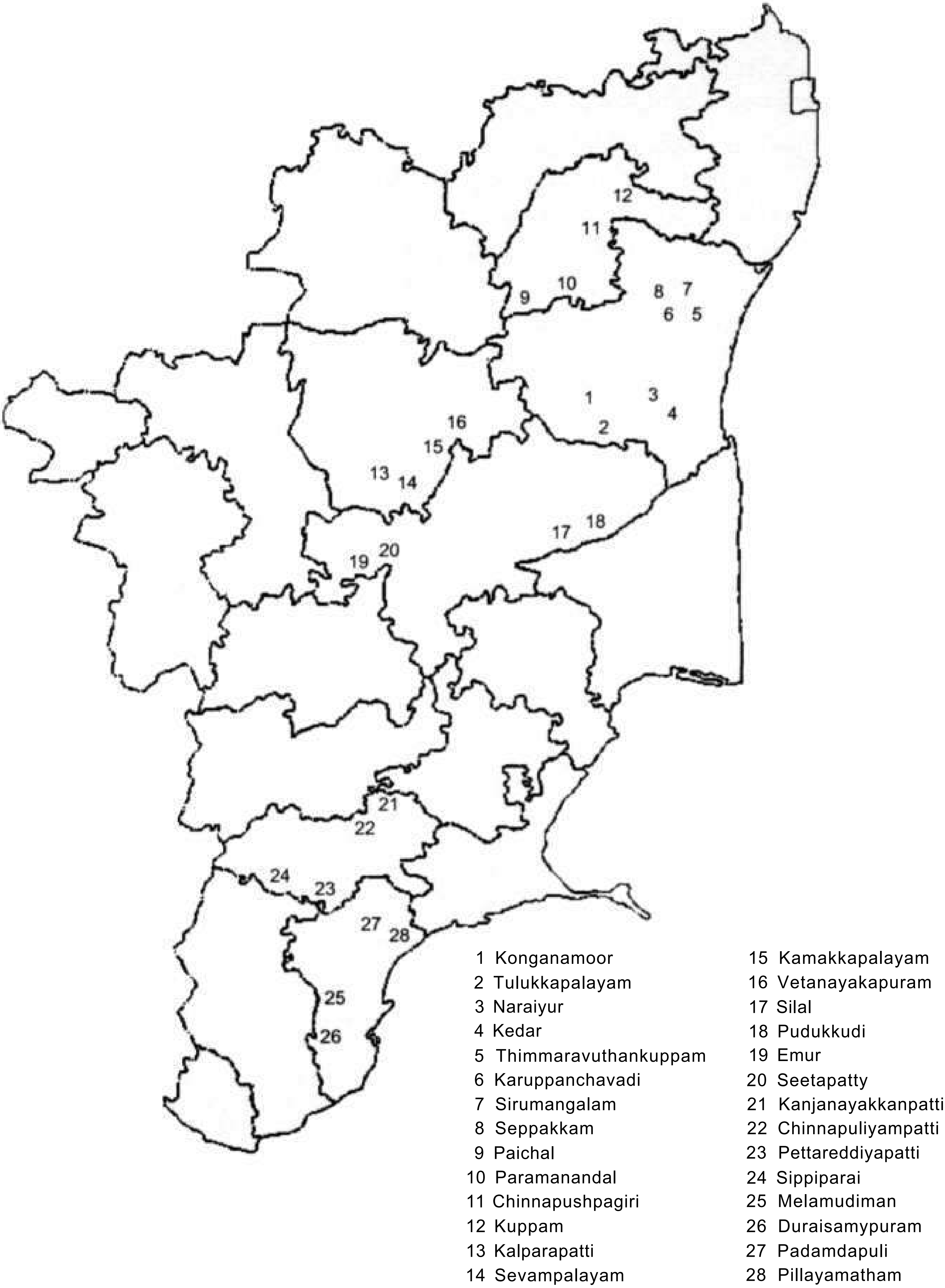

Figure 4. Location of sample villages.

in the NARS such as seed production companies with their own R&D; and (3) IARCs, e.g., ICRISAT in the present case. A disaggregated analysis would provide the varietal contribution of each agency.

This analysis also looks at the temporal adoption pattern of cultivars of each agency from 1989/90 to 1994/95, without leaving out the adoption of individual cultivars under each agency. As the study covered seven districts of Tamil Nadu, it facilitated the spatial comparison of adoption of improved pearl millet cultivars. An analysis of the performance of varietal groups in each district is also attempted in the study. Further, adoption of a cultivar is a dynamic process. Farmers have to decide: (1) when to replace the seed used; (2) where to buy it from (seed source); (3) where to get information on the new seed; and (4) when to replace a variety once adopted. Farmers are basically economic decision units. Unless they are convinced about a cultivar/technology, they will not adopt it. Several factors and their interactions influence their adoption decisions. This analytical framework attempts to understand the farmers' perception of factors that convinced them to go in for new cultivars.

To understand the adoption decision, an econometric model (Tobit) was estimated. For measuring efficiency in the production of local and improved cultivars, a stochastic frontier production function was estimated along with the conventional costs and return analysis. Equity and sustainability issues are examined with a simple descriptive analysis.

Tobit model

It is critical to precisely measure the degree of influence of the variables that determine adoption decisions. The literature on adoption lists many such variables: farm size, quantity of family labor, proximity to market, human resources, capital availability, input prices, agricultural information, production uncertainty, and risk (Adesina and Zinnah 1993; Shakya and Flinn 1985; Rauniyar and Goode 1996). One of the key purposes of the present study is to measure the extent of adoption of improved pearl millet cultivars by farmers in Tamil Nadu and to identify and quantify the effects of the variables which influence that adoption. Econometrics provides ample scope to study the adoption behavior of new technologies. Fedar et al. (1985) provide an excellent review of adoption models. In particular, limited dependent variable models provide a good framework to study technology adoption behavior in agriculture. Some of the most appropriate ones among them are Probit, Logit, and Tobit.

For the present study, the Tobit model (Tobin 1958) was considered appropriate as it measures not only the probability that a pearl millet farmer will adopt a new variety but also the intensity of use of the technology once adopted. The functional form is as follows:

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

$$\text{(or)} \quad = 0 \quad \text{if} \quad i^* = X_i\beta + \mu_i < T \quad \text{...........(1)}$$

where,

Y. is the probability of adoption (and the intensity of use of improved cultivars);

i* is a nonobservable latent variable;

T is a nonobserved threshold level; and

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

This equation is a simultaneous and stochastic decision model. If the nonobserved latent variable i* is greater than T, the observed qualitative variable Y that indexes adoption becomes a continuous function of the explanatory variables, and zero otherwise. In the present case, there are large numbers of farmers who have completely adopted the technology. Hence a two-limit Tobit proposed by Rosett and Nelson (1975) has been followed. The Tobit model uses a maximum-likelihood method to estimate the coefficients of the equation. The regression coefficients are asymptotically efficient, nonbiased, and normally distributed.

The total effect of an explanatory variable can be decomposed using the McDonald and Moffitt (1980) procedure. The two effects of a given change in a variable are adoption probability and intensity of adoption. The effects are discerned by computing elasticities using model results (Adesina and Zinnah 1993).

The empirical model assumes that the dependent variable, the proportion of area under ICs in the total area under pearl millet, depends on the following variables: education, nonfarm income, farm size, irrigation, market distance, existence of NARS-private companies, and district representation. The adoption behavioral model (Leagnes 1979) suggests that education (a personal variable), farm size (a socioeconomic variable), and irrigation (a biophysical variable), all in the farmer's primary environment, would affect the adoption of a technology. Nonfarm income was also hypothesized to be positively related to adoption as the farmer would then have adequate resources to invest in modern technology.

Similarly, distance to factor and product market was expected to negatively affect adoption. As the data showed that NARS-private agencies were capturing a greater share of the area over the years, it was hypothesized that presence of private companies through their sales network would push up the adoption rate. District dummies were included to determine whether the spatial changes in adoption could be attributed to region-specific agroclimatic characteristics (soil, temperature, rainfall, etc.). The explanation of independent variables along with their units of measurement is given in Table 3.

Table 3. Independent variables considered in the Tobit model.

Education	:	Farmer's education, measured in years
Nonfarm income	:	Annual income earned from sources other than agriculture, measured as a binary variable: 1 if the farmer has nonagricultural income, 0 otherwise
Farm size	:	Farm size, measured in hectares
Irrigation		Binary variable: 1 if the farmer irrigates pearl millet, 0 otherwise
Market distance	:	Distance to factor and product markets, measured in kilometers.
Presence of private seed sector	:	Presence of private seed sector, identified with the use of private sector seeds in the farm; measured as a binary variable: 1 if the private sector seed exists in the area, 0 otherwise
District dummies	:	Measured as a binary variable with the base as Kadalur district: 1 for representing district, 0 otherwise

Stochastic frontier production function

The technical efficiency of a given farm is defined as the ratio of the observed production to the corresponding frontier value associated with the farm's factor inputs. A failure on the part of the farm to produce the frontier level of output is attributed to technical inefficiency. A frontier refers to a bounding function, profit function, production function, and cost function. For example, production function represents the maximum output attainable from a given set of inputs. Frontier functions have two main benefits over the average functions: a frontier function will be dominantly influenced by the best-performing farm rather than the average farm, and it also represents a best-practice technology against which the efficiency of farms in a locality can be measured (Coelli 1995). The recent history of efficiency measurement began with Farrell (1957).

Frontier production functions are estimated involving deterministic frontiers, stochastic frontiers, panel data models, and data envelopment analysis (DEA). The DEA, nonparametric mathematical programming approach to frontier estimation, has also been developed independently of the stochastic frontier literature (Coelli 1995).

The stochastic frontier production is defined by

$$\ln Y_i = \ln f(X_i; \beta) + e., \qquad i = 1,2,....N \quad \ldots\ldots\ldots\ldots (2)$$

where,

Y is the output of farm 'i';

X_i is a vector of inputs;

P is a vector of parameters; and

ε_i is an error term that is assumed to be the difference of two independent elements,

$$\varepsilon_i = \quad v_i \quad -u_i \ldots\ldots\ldots\ldots (3)$$

where, v_i is a random error having a zero mean that is associated with random factors such as measurement error in production, weather, etc., which is normally referred to as statistical noise. These factors are beyond the control of the farmer. The model[2] is such that possible production Y. is bounded above by the stochastic quantity ln f(X; p) + v., hence the term stochastic frontier. U_i >0 is the difference

2. This stochastic frontier model was independently proposed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977).

between the maximum possible stochastic output ln f(X; P) + v. and the actual output Y.. Thus u_i represents technical inefficiency. When u_i = 0, the farm's output lies on the frontier and is 100% efficient.

Following most empirical studies, we assume that v. is normal, that is, $v_i \sim N(0, \sigma^2_v)$ and u. is half normal, that is $u_i \sim |N(0, \sigma^2_u)$. Jondrow et al. (1982) have shown that the conditional mean of u. given e. is equal to:

$$E\,(u_i/\varepsilon_i) = (\sigma_u\,\sigma_v/\,\sigma)\,[\{\,\phi\,(\varepsilon_i\,\lambda/\sigma)\,/\,(1-\Phi(\varepsilon_i\,\lambda/\sigma)\}-\varepsilon_i\,\lambda/\sigma\,]$$

where

$\sigma^2 = \sigma^2_u + \sigma^2_v;\ \lambda = \sigma_u/\sigma_v;\ \phi\,(.)$ and $\Phi(.)$ are respectively density and c.d.f. of the standard normal vanate.

A measure of the technical efficiency of farm i is given by

$$TE_i = e^{-E\,(u_i/\varepsilon_i)} \qquad \text{.......... (4)}$$

The population mean level of technical efficiency, as given by Pitt and Lee (1981), is given by

$$E\,[(e^{u}) = 2e^{\frac{\sigma^2_u}{2}}[(1-\Phi\,(\sigma_u)] \qquad \text{..........(5)}$$

When the production function is specified by a Cobb-Douglas

function, (2) takes the form

$$Y_i = X_i\,\beta + v_i - u_i \qquad \text{..........(6)}$$

where Y_i = lnY_i and X. is a column vector of logarithms of inputs. The log likelihood function for a sample of N farms can be written as

$$LnL = [(N/2)\ln(2/\pi) - N\ln\sigma - (\frac{1}{2\sigma^2})\Sigma\,\varepsilon_i^2 + \sum\ln\,(1-\Phi\,(\frac{\varepsilon_i\lambda}{\sigma})] \qquad \text{...... (7)}$$

Estimates of the parameter vector (β, λ,α,[2]) are obtained by maximizing (7). The methods usually followed in the literature are the Davidon-Fletcher-Powell algorithm and Newton's method. These methods need substantial calculations per iteration or many iterations and several function evaluations per iteration. Instead, Greene (1982) has developed an iterative algorithm which is simpler to implement. This algorithm provides a method of solving a set of nonlinear simultaneous equations obtained from the likelihood equations involving the parameters (β, λ,α,[2]). It also provides the variance-covariance matrix for the estimates (β, λ,α,[2])[3].

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3. See Greene (1982) for more details.

Returns to research investment

A significant amount of literature has appeared on evaluating agricultural research. One of the methods adopted is the economic surplus approach, which measures the benefits that have accrued to both producers and consumers due to research output, say, in the form of technology. The economic surplus approach has been used by a number of researchers. The basic data requirements for this analysis relate to costs incurred on research and benefits which result from it. Further, estimates of unit cost reduction, and price elasticities of demand and supply are required to assess the net benefits[4].

Adoption of improved cultivars

This section examines the extent of adoption of improved cultivars of pearl millet in Tamil Nadu and the various factors that influence it. The results of the Tobit model facilitate measurement of the degree of influence of the various determinants of adoption.

Influence of farm size

Table 4 shows the land-use and land-tenure pattern of the sample farms.

Table 4. Land-tenure and land-use (ha) among the sample farms.

	Adopters			Nonadopters		
Land-use/tenure	Irrigated	Dry	Total	Irrigated	Dry	Total
Owned land	0.96	2.97	3.93	0.89	1.66	2.55
Leased-in land	0.03	0.11	0.14	0.01	0.01	0.02
Sharecropped-in	0.01	0.01	0.02	0	0	0
Leased-out land	0.01	0.01	0.02	0.01	0.01	0.02
Sharecropped-out	0	0	0	0	0.07	0.07
Current fallow land	0.02	0.21	0.23	0.01	0.02	0.03
Permanent fallow land	0.02	0.02	0.04	0	0	0
Total	0.95	2.85	3.80	0.88	1.57	2.45

4. See Davis and Godfrey Lubulwa (1994) for more details.

Among the pearl millet-growing farmers, land-leasing was almost absent; in fact, the operated land area was mostly owned land. The average size of land operated by pearl millet IC adopters and nonadopters was 3.80 ha and 2.45 ha respectively. One may suspect that farm size exerts a positive influence on adoption of ICs of pearl millet because large farms generate more income, which provides a better capital base and risk-bearing capacity. Table 4 also shows that dryland area among pearl millet farmers adopting ICs was on an average 1.28 ha larger than among nonadopters. This is a reflection of the large areas of dryland available in the southern districts, e.g., Virudhunagar and Thoothukudi, where pearl millet is mostly grown as a rainfed crop. This is reinforced by the fact that irrigated landholdings are nearly equal among adopters and nonadopters.

Does education influence adoption?

Universally, education is observed to be a fundamental factor for economic and social change (Myrdal 1968). Is formal education always a prerequisite for technology adoption? An insight into the relationship between educational level and adoption of improved cultivars of pearl millet appears in Table 5. The average level of education of adopters and nonadopters differed only negligibly. A greater proportion of adopters had progressed up to high school and Intermediate than nonadopters. Illiteracy was higher by one-third among the nonadopters. Obviously, given the present level of modernization in communication and infrastructure, even less educated farmers do not lag far behind in terms of adoption of ICs. But still, the role of education cannot be ignored as a factor influencing the adoption of improved technologies that are knowledge-intensive.

Table 5. Educational level of heads of households (%).

Educational status	Adopters (N = 235)	Nonadopters (N = 101)
Illiterate	15.32	22.78
Up to primary school	26.38	27.72
Up to middle school	25.53	29.7
Up to high school	20.43	12.87
Intermediate/diploma course	8.51	3.96
Graduation	2.98	2.97
Postgraduation and above	0.85	0

Sources of income

Crop production earned the largest slice of household income for both adopter and nonadopter farms (Table 6). While crop production accounts for about three-fourths of the total income among the adopters, nonadopters drew two-thirds of their income from that source. Nonadopters earned about 16% of their income through trade, which accounted for only 8% among adopters. The share of labor earnings was similar for the two groups. The influence of nonfarm income on adoption was examined using the Tobit results.

Table 6. Share of income (%) contributed by various activities.

Activity	Adopters	Nonadopters
Crop	74.28	68.57
Livestock	1.96	0.84
Trade	7.91	15.69
Labor	9.83	10.69
Other	6.02	4.21

Cultivar profile

Improved cultivars of pearl millet are developed and released by both public and private research systems. Within the public research system, cultivars come from ICRISAT and public sector agencies of NARS. The NARS-private sector is comprised of private seed companies. In order to examine the effect of the source of ICs on the adoption process, different sources of cultivars were categorized as ICRISAT, NARS-Public, and NARS-Private. The number of sample farmers who have adopted ICs and the area under different cultivars during 1994/95 are shown in Table 7. ICRISAT's share was about 25% of the number of adopters and 23% of the area under ICs. The corresponding figures for NARS-Private were 28% and 43%. In terms of area, the products of NARS-Private research had a dominant share (43%). NARS-Public cultivars were adopted by 20% of the adopters, accounting for 12% of the pearl millet area. Of the three ICRISAT cultivars, WC-C 75 occupied about 50% of the total area under ICRISAT cultivars. ICMS 7703 is seen to be the second most important variety. Among NARS-Private cultivars, Pioneer was highly dominant with two-thirds of the total area, followed by Eknath and MAHYCO. The leading cultivars among NARS-Public ICs were CO 7 and KM 2.

Table 7. Cultivar adoption pattern of sample pearl millet growers in Tamil Nadu during 1994/95.

Institution	Cultivar	Number of farmers	Area cultivated (ha)	Proportion of the total area (%)
ICRISAT	ICMS 7703	33	24.70	6.23
	ICMV 221	13	18.22	4.59
	WC-C 75	41	46.82	11.79
	Total	87	89.74	22.61
NARS - Private	Eknath	6	26.11	6.59
	HLL	1	1.62	0.41
	MAHYCO	12	12.96	3.26
	MBH 110	4	5.83	1.47
	PBH 3	1	0.61	0.15
	PG 5822	3	2.23	0.56
	PG 5877	4	5.67	1.42
	Pioneer	68	116.04	29.23
	Total	99	171.07	43.09
NARS - Public	CO 3	1	0.61	0.15
	CO 7	32	19.90	5.02
	KM 2	33	19.76	4.98
	KM 3	3	0.81	0.20
	X 5	2	4.86	1.22
	Total	71	45.94	11.57
Local		97	90.23	22.73
	Grand total	354	396.98	100.00

Temporal performance

Efforts were made to understand the pattern of adoption during the period from 1989/90 to 1994/95. The results are furnished in Table 8 and shown in Figure 5.

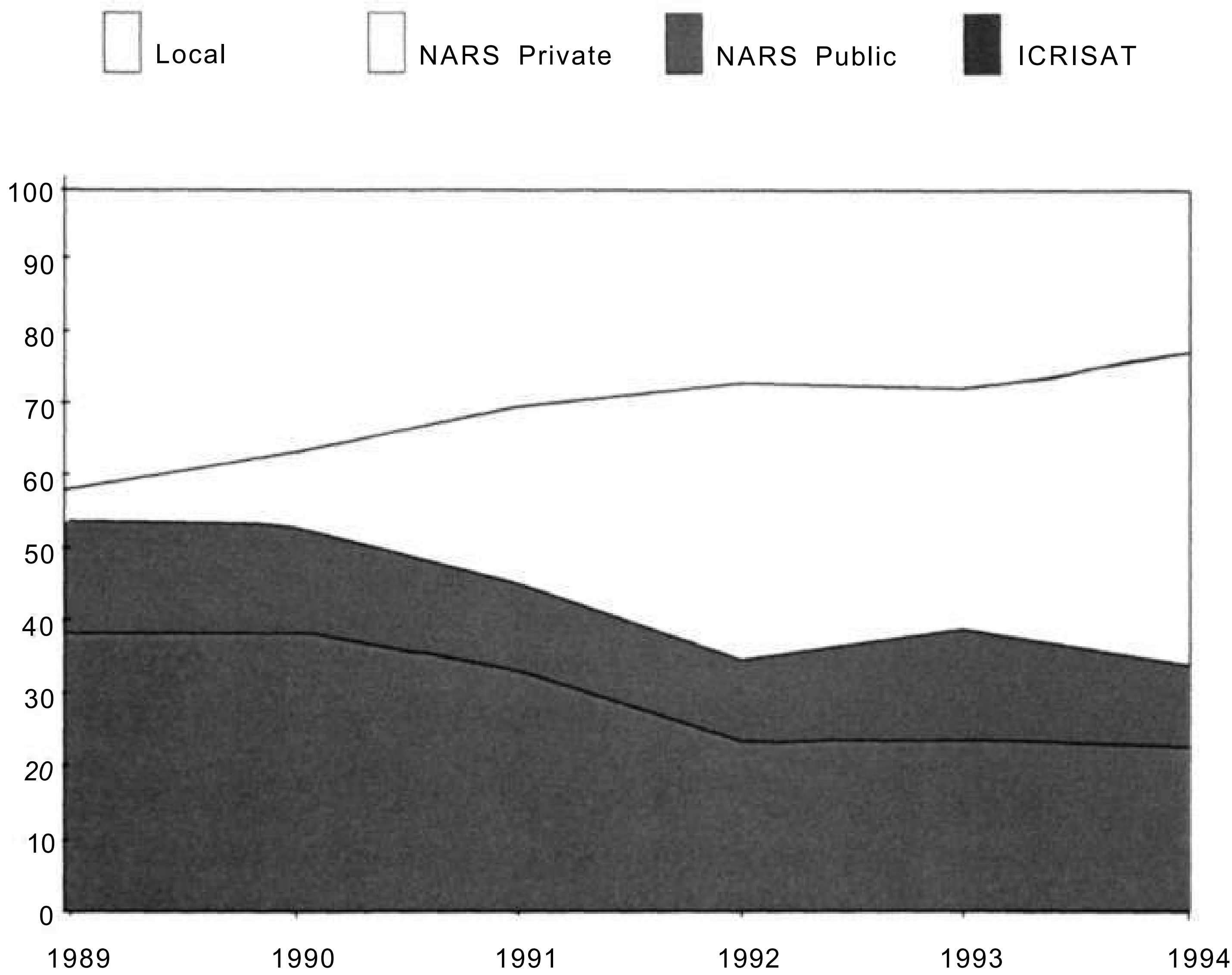

Figure 5. Temporal adoption pattern of improved pearl millet cultivars by growers in Tamil Nadu.

Table 8. Temporal adoption pattern of improved cultivars.

	1989/90		1990/91		1991/92		1992/93		1993/94		1994/95	
	Area		Area		Area		Area		Area		Area	
Cultivar	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%
ICRISAT												
ICMS 7703	5.47	2.41	45.50	7.49	26.36	9.40	22.82	7.21	22.47	7.04	24.7	6.23
ICMV 221									5.87	1.84	18.22	4.59
WC-C 75	81.71	35.9	78.27	31.85	66.89	23.85	51.6	16.31	49.93	15.64	46.82	11.79
Total	87.18	38.31	123.77	39.34	93.25	33.25	74.42	23.52	78.27	24.52	89.74	22.61
NARS-Public												
CO 3					0.61	0.22	0.61	0.19	0.61	0.19	0.61	0.15
CO 7	8.13	3.57	7.91	3.22	13.99	5	13.78	4.36	20.06	6.29	19.9	5.02
KM 2	24.61	10.81	22.68	9.23	17.53	6.25	18.79	5.94	19.47	6.10	19.76	4.98
KM 3	1.01	0.44	1.01	0.41	0.81	0.29	0.41	0.13	0.81	0.25	0.81	0.20
KM 8	1.22	0.54	1.21	0.49								
X 5							2.02	0.64	5.26	1.65	4.86	1.22
Total	34.97	15.36	32.81	13.35	32.94	11.76	35.61	11.26	46.21	14.48	45.58	11.48
NARS-Private												
Eknath					4.05	1.44	18.02	5.70	25.91	8.12	26.11	6.59
HLL									1.62	0.51	1.62	0.41
MAHYCO			5.26	2.14	13.77	4.91	10.53	3.33	11.94	3.74	12.96	3.26
MBH 110											5.83	1.47
PBH 3											0.61	0.15
PG 5822	2.83	1.24	3.24	1.32	2.83	1	2.83	0.89	3.04	0.95	2.23	0.56
PG 5877									4.86	1.52	5.67	1.42
Pioneer	8.11	3.56	17.81	7.25	47.49	16.93	88.99	28.12	58.18	18.23	116.0	29.23
Total	10.94	4.8	26.31	10.71	68.14	24.28	120.37	38.04	105.55	33.07	171.0	43.09
Local	94.53	41.53	89.96	36.60	84.51	30.13	83.58	26.40	83.28	26.09	90.23	22.73
Grand total	227.62	100	245.77	100	280.46	100	316.41	100	319.18	100	396.9	100

Though the share of ICRISAT cultivars in the total pearl millet area in Tamil Nadu declined from 38% in 1989 to 23% in 1994, the area sown to ICRISAT cultivars has remained almost constant. Over this period, NARS-Private cultivars increased their share in the pearl millet area to 43% and the proportion of NARS-Public cultivars declined from 15% to 11%. The area under NARS-Private cultivars increased from 11 ha in 1989 to 165 ha in 1994. Among ICRISAT cultivars, though WC-C 75 dominated the whole period under review, ICMV 221 has been picking up in recent years, mainly in the southern districts where drought occurrence is more frequent. Of the NARS-Public cultivars, CO 7 and KM 2 emerged significant all along. Among NARS-Private cultivars, Pioneer hybrids have earned a higher market share over the years.

Spatial performance

The spread of ICs across the study districts in Tamil Nadu is shown in Table 9. ICRISAT cultivars are seen to be significant in Thiruvannamalai, Virudhunagar, and Thoothukudi districts even though their shares have declined in the latter two districts over time. NARS-Public cultivars dominate in Salem and account for one-fourth to one-third of the area in Villupuram, Thiruvannamalai, and Trichy districts. However, they have totally disappeared in Kadalur. NARS-Private cultivars appear to be increasingly important in Villupuram, Kadalur, Virudhunagar, and Thoothukudi districts, but are yet to make their presence felt in Trichy, Salem, and Thiruvannamalai districts. This mixed presence of different cultivars over space may be attributed to the interplay of various factors.

Table 9. Share (%) of pearl millet area sown to different groups of cultivars in seven districts of Tamil Nadu, 1988/89 - 1994/95.

District	Group of cultivars	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95
Villupuram	ICRISAT	41.87	46.98	45.30	49.12	22.88	26.01	10.17
	NARS-Public	3.50	6.08	8.10	9.87	15.30	15.28	21.97
	NARS-Private	0	0	0	5.42	16.61	25.62	32.80
	Local	54.63	46.94	46.60	35.58	45.21	33.09	35.06
Kadalur	ICRISAT	15.37	13.44	14.50	20.07	4.27	2.38	2.55
	NARS-Public	35.90	43.78	33.90	11.04	2.89	0	0
	NARS-Private		10.36	24.10	41.68	68.65	77.16	80.08
	Local	48.73	32.42	27.60	27.21	24.19	20.45	17.36
Thiruv- -annamalai	ICRISAT	29.58	31.37	42.75	59.54	59.25	66.06	62.21
	NARS-Public	43.71	35.41	36.85	22.11	26.20	23.75	25.58
	NARS-Private	0	0	3.10	2.42	0	2.13	2.45
	Local	26.71	33.22	17.30	15.93	12.40	8.06	9.75
Salem	ICRISAT	0	3.43	18.47	23.52	14.44	6.51	6.32
	NARS-Public	44.60	47.29	37.54	49.25	66.36	74.29	73.89
	NARS-Private	0	0	0	0	0	0	0
	Local	55.40	49.25	43.98	27.23	19.19	19.21	19.80
Trichy	ICRISAT	21.61	7.22	13.37	23.51	22.43	13.75	10.15
	NARS-Public	31.87	30.56	24.38	35.94	26.61	31.59	34.38
	NARS-Private	0	0	0	0	0	0	0
	Local	46.52	62.22	62.25	40.55	50.96	54.66	55.47
Virudhunagar	ICRISAT	44.63	64.27	52.12	27.90	27.93	20.20	18.92
	NARS-Public	0	1.61	0	1.25	3.14	3.40	3.63
	NARS-Private	5.86	5.62	18.30	54.86	59.25	71.09	70.59
	Local	49.52	28.51	29.60	15.98	9.68	5.36	6.87
Thoothukudi	ICRISAT	60.38	33.51	62.24	43.94	26.74	29.45	34.33
	NARS-Public	0.91	2.31	1.35	0.95	0.45	0.37	0
	NARS-Private	0	7.24	12.14	27.18	56.70	58.44	58.97
	Local	38.15	35.24	24.27	27.94	16.11	11.73	6.70

Mostly, suitability of cultivars and the role of different agencies in promoting the cultivars appear to determine the pattern across districts.

Entry of ICRISAT cultivars

The frequency of first-year adoption of ICRISAT cultivars by subsets of sample farmers and the area sown to each variety is shown in Table 10.

Table 10. First year of adoption of ICRISAT cultivars by the sample households.

Variety	Year of adoption	Number of farmers	Area (ha)
WC-C 75	1985	6	12.55
	1986	2	0.85
	1987	14	12.17
	1988	5	7.49
	1989	21	51.62
	1990	13	22.34
	1991	14	16.60
	1992	21	22.26
	1993	15	10.45
	1994	6	4.66
ICMS 7703	1990	4	1.42
	1991	9	16.40
	1992	18	13.81
	1993	9	7.44
	1994	5	1.98
ICMV 221	1994	5	5.87
	1995	7	14.88

WC-C 75 made its entry in the sample households in 1985 following its release in 1982, with only six farmers growing it. It picked up over the years but by 1994 additional adoptions sharply declined. ICMS 7703 first appeared in 1990 following its release in 1985 and reached a peak in 1992. ICMV 221 made its entry in 1994 following its 1993 release, and its adoption seems to be picking up. In the course of this survey, it was learnt that farmers in Tamil Nadu consider ICRISAT cultivars to be superior to the local cultivars in terms of yield and responsiveness to nutrient applications in drought situations. Further, ICRISAT cultivars are resistant to downy mildew. A Rapid Rural Appraisal (RRA) conducted as a part of the project confirmed that ICRISAT cultivars are found in about 50% of the pearl millet-growing areas of Tamil Nadu. The competition to ICRISAT cultivars grown in irrigated and good-rainfall regions has come from private-sector cultivars that are superior to the ICRISAT cultivars in terms of yield.

Sources of seed and information

Sources of seed and information are of critical importance in the spread of improved cultivars. Easy availability of information and seeds may help the new cultivar reach more farmers in a given time. The sources of information and seed for cultivators for three ICRISAT cultivars and seven private cultivars of pearl millet are shown in Table 11. The state Department of Agriculture is the major source of information as well as of seed for ICRISAT cultivars. Other farmers and relatives also play a significant role as sources of information. In addition, seed shops and cooperative societies are also involved in dissemination of seed of ICRISAT cultivars. Information about private hybrids also reaches farmers through more than one source. The Department of Agriculture plays a minor role while other farmers, relatives, and seed shops play a larger role in the distribution of private sector seeds. Seeds find their way to farmers primarily via seed shops (except Hindustan Lever seeds). The inference from this analysis is that all the agents (private and public sector agencies, and farmers and their relatives) have to play a complementary role to efficiently disseminate improved cultivars to farmers.

Table 11. Sources of seed and information (%).

	ICRISAT cultivars			Private cultivars					
	WC-C 75	ICMS 7703	ICMV 221	HLL	MAHYCO	MBH 110	PBH 13	PG 5877	Pioneer
Source of seed									
Other fanners	0.85								
Relatives	1.7		8.33						
Seed shops	7.69	17.78	8.33		100	100	100	80	98.68
Department of agriculture	85.47	82.22	75	100				20	1.32
Cooperative societies	4.27								
Others	1.7		8.33						
Source of information									
Other farmers	14.52	6.67	16.67		33.33	75	50		28.95
Relatives	7.69	2.22	16.67		26.67				27.63
Seed shops	3.42	4.44	8.33		33.33		50	60	18.43
Department of agriculture	73.5	80	58.33	100		25		20	10.52
Research institutes	0.85								
Others		6.67			6.67				14.47

Preference for improved cultivars

Our survey and interaction with biological scientists working on pearl millet facilitated identification of 18 different factors that may induce farmers to go in for improved cultivars of pearl millet. These factors and an insight into the extent of their influence are shown in Table 12.

Table 12. Reasons cited by pearl millet farmers (%) for adoption of improved cultivars.

Reason	Villu-puram	Kada-lur	Thiruvann-amalai	Salem	Trichy	Virudhu-nagar	Thoothu-kudi	All
High yield	70.40	63.41	52.08	60.00	59.10	51.51	70.37	59.34
Availability of seed	3.70	12.19	12.5	5.00	4.54	9.09	3.70	8.79
Drought tolerance	3.70		4.17		13.64	15.15	9.26	10.26
Good grain size	3.70	4.88	8.33	5.00		6.06		4.03
No pests and diseases	3.70	7.32	2.08	10.00	4.54		1.85	1.10
Fewer bird problems	3.70		4.17					1.10
Require less water	3.70				4.54			0.73
Influence of private traders/family members	3.70	4.88	2.08	10.00	6.09	4.54	5.55	4.76
Compact ear head	3.70							0.37
Short duration		2.44	2.08			4.54		1.83
Short height		2.44						0.37
Uniform maturity		2.44						0.37
Good market price			6.25		4.54	3.03	5.55	3.29
Less input requirement						3.03	1.85	1.10
Seed production			6.25			1.51		1.46
Good taste				5.00				0.37
More fodder yield				5.00		1.51		0.37
Easy threshing							1.85	0.37

More than half the sample farmers preferred ICs to local cultivars (LCs) because of their higher yields. More than 70% of the farmers in Villupuram and Thoothukudi districts cited this reason. Assured supply of seeds, drought tolerance, larger grain size, and pest and disease resistance characteristics of ICs were the other important factors cited. It appears that seed dealers influenced about 10% of the farmers in Salem district, and the good market price induced 6% of the pearl millet growers in Trichy district. Tolerance of ICs to drought emerged as the second most important influencing factor in Trichy, Virudhunagar, and Thoothukudi districts. It is natural that different factors nurture adoption of ICs but higher economic returns in the form of higher yields emerged as the single most significant factor. Pearl millet breeders must take note of this important aspect.

Seed replacement

Purity of seeds is critical for realizing the full benefits of an IC. How smart are pearl millet growers in optimum utilization of seeds of a given variety? Table 13 shows that in the case of nonhybrids, more than 70% of the farmers use new seeds every year, and 6% replace seeds once in two years. Only in the case of WC-C 75 has the replacement of seeds been done up to once in seven years. On an average, 17% of the farmers never replaced their seed. The story of hybrid seeds is different. Technically, they must be replaced each season. Only a small proportion of farmers either used hybrids beyond one season or did not replace them at all.

Table 13. Proportion (%) of farmers replacing pearl millet seed at different durations.

	Seed replacement frequency (years)							
Cultivar	1	2	3	4	5	6	7	Nonreplaced
ICRISAT								
ICMS 7703	80	9						11
ICMV 221	71							29
WC-C 75	64	10	5	3	3	2	1	12
Average	71.66	6.33	1.67	1	1	0.67	0.3	17.33
NARS-Private								
HLL	100							
MAHYCO	73	7						20
MBH 110	75							25
PBH 13	100							
PG 5877	92	6						2
Pioneer	95	5						
Average	76.43	2.57						6.71

Life of cultivars

The standing of a variety in the field depends on several factors, which may include the desirable and nondesirable traits of the variety, supply of seeds, entry of new cultivars, and strength of the extension services. Of the several cultivars examined, KM 2 and WC-C 75, among the nonhybrids, had a longer life than the other cultivars (Table 14). Since these were the first of the widely adopted nonhybrids to be released, this finding is not unexpected.

Hybrids had relatively shorter lives. The entry of new cultivars is primarily responsible for reducing the life of existing hybrids. Further, competition among private companies results in better and improved products in the market, which curbs the life span of existing cultivars. Finally, the disease resistance of genetically uniform hybrid cultivars is overcome more readily by pathogens like downy mildew than is the disease resistance of genetically variable, improved open-pollinated cultivars. This forces more rapid turnover of hybrid cultivars. In the course of RRAs conducted as part of the project, farmers were found to be unambiguous in their views that they need cultivars with further improvements.

Table 14. Effective life of selected improved pearl millet cultivars in Tamil Nadu.

Cultivar	Range (years)
KM 2	2 - 8
WC-C 75	3 - 7
ICMS 7703	3 - 4
CO 7	3 - 5
HB 3	1 - 3
Pioneer	2
PBH 13	1
MBH 110	3
MAHYCO	3

Tobit results

Marginal effects

Descriptive statistics on the selected variables and the estimates of the Tobit model are presented in Tables 15 and 16 respectively.

Table 15. Descriptive statistics on the variables used in the empirical model.

Variable	Mean	Standard deviation
Proportion	68.14	45.95
Education	0.68	1.67
Nonfarm income	0.29	0.45
Farm size	3.56	5.48
Irrigation	30.59	45.78
Market distance	10.04	7.29

Education seems to have positively and significantly influenced farmers' adoption of ICs. Nonfarm income was negatively related with adoption. The negative sign of the coefficient implies that when farmers earned more nonfarm income they paid little attention to pearl millet. This can be particularly observed in Salem district where nonfarm income was higher.

The nonsignificance of the influence of farm size on adoption reaffirms that ICs as a technology are neutral to the scale of farm operations. Irrigation appears to be a more dominant variable. It shows that improved cultivars are preferred in irrigated conditions. The higher level of adoption of hybrids in Kadalur district supports this view.

Table 16. Results of the empirical Tobit model.

Variable	Coefficient	Asymptotic t-ratio
Constant	-5.9931	-0.4390
Education	3.7092	1.9110*
Nonfarm income	-11.4130	-1.6620*
Farm size	0.1056	0.4310
Irrigation	0.3535	4.004**
Market distance	-0.9358	-1.9080*
Private sector dummy	62.7530	5.8410**
Villupuram dummy	-18.2150	-1.4840
Thiruvannamalai dummy	48.2980	3.1040**
Salem dummy	57.6270	3.7320**
Trichy dummy	0.9925	0.0720
Virudhunagar dummy	19.1960	1.5460
Thoothukudi dummy	24.2230	2.0190**

Log-likelihood = -1343.9.
N = 336.
*** Significant at 5% level.**
**** Significant at 1% level.**

Distance to the factor and product markets is negatively related to adoption. Most of the improved cultivar seeds are available at seed shops or agricultural depots, which are not located within the village. Thus distance to the markets plays a significant role in adoption. The presence of private seed sector outlets in the locality favored adoption significantly, and had a very large effect on adoption of ICs. Dummies represent the strong regional characteristics (agroclimatic, infrastructure, etc.) that favor or disfavor adoption. The results suggest that Thiruvannamalai, Salem, and Thoothukudi districts provided a better environment for adoption of ICs than the benchmark district, Kadalur. The three remaining districts—Villupuram, Trichy, and Virudhunagar—do not have the same level playing field as the above three; so the rates of adoption are lower.

Elasticities

The elasticities computed using the Tobit model results are shown in Table 17. The elasticity of a change in the level of a given explanatory variable comprises two effects: one is the change in the elasticity of adoption intensities of pearl millet growers who are already adopters; and the other is the change in the elasticity of the probability of being an adopter.

The elasticities suggest that the magnitudes of adoption intensity are considerably higher for all the variables. Overall, the computed elasticities show inelastic responses.

Table 17. Total elasticity decomposition for changes in influencing Variables.

	Elasticity		
Variable	Adopt:ion intensity	Adoption probability	Total elasticity
Irrigation	0.1230	0.0010	0.1350
Market distance	-0.0921	-0.0009	-0.0930
Farm size	0.0104	0.0001	0.0105
Nonfarm income	-0.0292	-0.0003	-0.0295
Private sector	0.1736	0.0024	0.1760
Education	0.1882	0.0016	0.1898

The elasticity of adoption intensity is higher for irrigation, education, presence of the private sector, and market distance. The total elasticity for education is 0.1898, which is decomposed into 0.1882 for intensity of adoption and 0.0016 for the probability of adoption. This suggests that a 10% increase in the number of years of schooling is expected to result in a 2% increase in adoption and intensity of adoption. Nonfarm income and scale of farm operation show little, if any, elasticity of adoption.

Impact analysis

Efficiency

Economic efficiency' comprises two components, namely 'technical efficiency' and 'allocative efficiency'. It is hypothesized that pearl millet producers are rational and, like any other entrepreneur, want to maximize their profits given technology and prices of inputs and products. This section attempts to: (1) assess the economics of pearl millet production, looking particularly at the costs and returns in pearl millet production covering local and improved cultivars (economic efficiency); and (2) estimate the stochastic frontier production function to determine the technical efficiency of individual farms.

Costs and returns

The per hectare costs and returns using the conventional framework have been computed for select cultivars and are presented in Table 18. It is clear that improved pearl millet cultivars offer large yield and income benefits compared to the local cultivars. The yield gains relative to local cultivars are about 100% for ICMS 7703 and CO 7 and 150% for Pioneer hybrids. In terms of net income, ICMS 7703 scores high. CO 7 shows only 25% additional income. These differences in yield across cultivars are not reflected in the net income owing to the stochasticity in input and product prices that exists over space and across farms, and variation in the management efficiencies of farmers. The unit cost reduction ranges from Rs.610 to Rs.860 r^{-1} for improved cultivars, and this is achieved via large yield gains. Given grain yield advantages of about 700 kg for ICMS 7703 and CO 7 and about 1000 kg for Pioneer hybrids, the adopters of these cultivars realize cost reduction to the extent of Rs. 700 to Rs.1000 ha"^{1} under pearl millet. Thus, improved cultivars are more efficient in use of resources than the local cultivars.

Table 18. Costs and returns (Rs ha"[1]) of pearl millet production in Tamil Nadu, 1991-93.

Item	Local	ICMS 7703	CO 7	Pioneer
Costs				
Male labor	732.03	1268.86	915.14	610.17
Female labor	785.92	1138.58	1235.62	722.79
Bullock labor	433.04	599.44	335.68	275.63
Tractor	188.61	283.33	667.15	331.54
Thresher	11.02	42.94	66.00	88.44
Seed	48.65	88.68	91.29	300.16
Farmyard manure	613.53	430.21	487.58	1508.85
Fertilizer	156.88	515.29	253.53	931.82
Pesticides	0	3.68	0	9.34
Irrigation	5.1	58.01	13.36	2.82
Total variable costs	2974.89	4429.02	4065.35	4781.52
Returns				
Grain yield (kg)	692.11	1436.73	1412.51	1689.63
Grain value	4289.70	7669.58	5662.87	7476.52
Fodder value	280.56	326.87	397.18	353.03
Gross income	4570.33	7996.45	6060.05	7829.55
Net income	1595.44	3567.43	1994.70	3047.99
Unit cost	345.95	285.52	259.69	262.10

Frontier production function

Variables. The Cobb-Douglas production frontier (stochastic) function was fitted separately for farmers growing local and improved cultivars of pearl millet with grain output as the dependent variable. The explanatory variables were: land sown to pearl millet (hectares), rent (reflecting the irrigation availability and fertility of the soil), cost of fertilizers and manure, labor days, cost of bullock and machinery services, seed cost, and management (educational level). A summary of the values of the variables is presented in Table 19[5].

The mean land area under pearl millet for the sample was 1.07 ha for farms growing local cultivars and 1.60 ha for those growing improved cultivars. Fertilizer and manure application was about 29% more for improved cultivars, and the cost of bullocks and machinery used in tillage about 18% more. The value of seeds ha^{-1} was three times that for the local variety. The labor required ha^{-1} for improved cultivars was 20% more than for local cultivars. The average output ha^{-1} was 742.17 kg for improved cultivars against 1592.44 kg for local cultivars. So the grain yield of improved cultivars was 100% higher than that of local cultivars.

Table 19. Summary statistics of the variables used in the calculation of frontier production function.

Variable	Unit	Mean value: Local cultivars	Mean value: Improved cultivars
Output (grain)	Kg	742.17	1592.44
Area	Hectare	1.07	1.60
Rent	Rupees	488.32	514.46
Fertilizer and manure	Rupees	794.55	1080.12
Bullock and machine	Rupees	651.51	720.05
Seed	Rupees	49.94	135.49
Human labor	Day	55.91	78.03
Education	Year	2.34	2.65
Sample size	Number	63	211

5. To avoid zero values in the selected variables, 274 farms were considered for estimating the frontier function out of the total sample of 336.

Model results. The maximum-likelihood estimates of frontier stochastic production functions are set out in Table 20. The coefficient for land is positive and significant, and accords with a priori expectation for improved cultivars. This means allocating a larger area for improved cultivars will add significantly to the output. The rent, which reflects the fertility of the land, is significant for local cultivars, implying that local cultivars could perform better in fertile lands. Surprisingly, the coefficient of rent is not significant for improved cultivars. This may be because ICs are cultivated on fertile lands with least variation in fertility. Fertilizers and manure significantly influence pearl millet production, irrespective of the cultivar. Additional investment in land preparation by hiring more bullocks and tractor services has a significant impact on yield in the case of improved cultivars, but this was not observed for local cultivars. This is perhaps an indication of the generally low level of inputs used by most sampled farmers growing local cultivars of pearl millet. The labor variable shows significant impact on output of both varietal types. Interestingly, education is positive and significant in influencing the output in the case of improved cultivars, but not so in the case of local cultivars. This implies that education plays an important role in production management of improved and hybrid pearl millet production. Overall, the estimated production function for local and hybrid cultivars turned out well. Estimated equations serve as a vehicle to estimate the final product, namely technical efficiency. The estimated value of λ is 3.0 for local cultivars and 1.96 for improved cultivars (Table 20), implying that the one-sided error term u dominates the symmetric error v.

Table 20. Maximum-likelihood estimates of the stochastic frontier production function for pearl millet in Tamil Nadu, 1991-93.

Variables	Coefficients		t-ratio	
	Local variety	Improved variety	Local variety	Improved variety
Constant	3.1022	4.0555	2.487*	10.473**
Area (land)	0.1656	0.4365	0.660	6.968**
Rent	0.1699	0.0359	2070*	0.854
Fertilizer and manure	0.1667	0.1191	2.577**	3.100**
Bullocks and machinery	0.0076	0.0986	0.051	1.862*
Seed	-0.0891	0.0585	-1.023	1.590
Human labor	0.6113	0.2997	4.040**	4.178**
Education	0.0243	0.1707	0.137	2.523**
Log likelihood	-45.22	128.11		
	3.00	1.96	1.39	5.265**
α	0.7899	0.6421	5.614**	14.576**
α^2_u	0.56158	0.3271		
	0.0621	0.0851		

* = 5% level of significance.
** = 1% level of significance.

Technical efficiency. The discrepancy between the observed output and frontier output is due to both technical and allocative inefficiency. The average inefficiency was found to be about 40% in the case of local cultivars and 33% in the case of improved cultivars (Table 21).

Table 21. Frequency distribution of the technical efficiency (TE) of pearl millet farmers in Tamil Nadu, 1991-93.

Technical efficiency (%)	Farmers growing local cultivars		Farmers growing improved cultivars	
	Frequency	Total (%)	Frequency	Total (%)
Below 30	6	9.52	2	0.95
30.1 -40	7	11.11	11	5.21
40.1 -50	7	11.11	25	11.85
50.1 -60	9	14.29	29	13.75
60.1 -70	11	17.46	45	21.33
70.1 -80	14	22.22	62	29.38
80.1 -90	8	12.7	36	17.06
90.1 -100	1	1.59	1	0.47
Total	63	100.00	211	100.00

Population level of technical efficiency:

Local cultivars $\sigma^2_u = 0.56158$

$\sigma_u = 0.74939$

$TE = 2e^{\frac{\sigma^2_u}{2}} \left[1 - \Phi(\sigma_u)\right]$

$= 2e^{0.28079} (1 - \Phi(0.74939))$

$= 2e^{0.28079} (1 - (0.7734))$

= 60%

Improved cultivars = 67% (calculated as above)

Obviously, the efficiency gap can be reduced by farmers through efficient management of resources. From the viewpoint of resource use, these findings have obvious policy implications. It appears that farmers growing improved cultivars have a relatively better control over use of resources, though this is not significant, indicating that it is not the type of cultivar but the production management of farmers that determines technical efficiency. The percentage of farmers having less than 30% efficiency was about 10% among those growing local cultivars. The percentage of farmers with an efficiency of over 70% constituted about 37% of the growers of local cultivars as against 47% among growers of improved cultivars. Thus there is a clear case for farmers growing local cultivars to be trained and advised to improve their efficiency. There is also a need for training farmers growing improved cultivars as they also exhibit technical inefficiency of a considerable magnitude.

Equity

A new crop variety or technology is expected to benefit those who adopt it. However, it is possible that some sections of farmers (say those with small landholdings) may not adopt it as intensively as farmers with large landholdings; hence, there is lesser income for small farmers. The gross income derived through adoption may not benefit all owners of factors of production equally. For example, land-owners may realize more benefits than labor households. Sometimes, a technology may add to the problems of farm women, say in terms of drudgery or poor cooking quality of grains of the new cultivar. Another consequence may be that the food security of the region or country is jeopardized. The immediate and direct negative impact of such a situation will be on the rural poor. This section attempts to examine the equity impact of adoption of improved pearl millet cultivars in Tamil Nadu.

Food security

New technologies in agricultural production may change the character of a crop. A subsistence crop may emerge as a commercial crop with diversified use, thus reducing its availability to the economically poor. The price of the new grain may shoot up due to its new uses, making it inaccessible to the less privileged sections of the population. The story of pearl millet in Tamil Nadu is interesting. It was one of the important coarse cereals consumed mostly by all sections of rural people during earlier decades. It appears that more than 85-90% of the pearl millet produced was consumed within the areas of production. During the past decade the scenario has changed very dramatically reversing the trend, so that now about 85% of the produce goes out of the production areas for diverse uses. The proportion of pearl millet produce consumed as food in RRA villages is shown in Table 22.

Table 22. Proportion (%) of pearl millet production consumed as food in RRA villages.

		Pearl millet consumption (%)	
Village	District	1975	1996
Thimmaravuthankuppam	Kadalur	80	10
Konganamoor	Villupuram	85	5
Paramananthal	Thiruvannamalai	90	20
Kalparapatti	Salem	90	30
Silal	Trichy	90	25
Kanjanayakkapatti	Virudhunagar	85	20
P. Duraisamypuram	Thoothukudi	85	25

The key conclusion one can derive from this analysis is that production of pearl millet with improved cultivars has not weakened the food security of the people, particularly the poor. But, how is the reduction in pearl millet consumption compensated? The distribution of rice and wheat at subsidized prices through the well-organized Public Distribution System (PDS) led to pearl millet being reduced to the status of a minor commodity in the food basket of rural households. The absence of a price difference between subsidized rice and nonsubsidized pearl millet resulted in people preferring rice to millet. In due course, as the taste for rice developed, the role of millet in direct food consumption became less significant. One point that needs serious consideration by pearl millet researchers and development planners is the poor preference of improved cultivars for consumption in terms of taste, keeping quality of food, and minor side-effects on health that rural consumers invariably reported in all the study sites.

Gender

The importance of studying the impact of agricultural technologies on gender issues has increasingly been realized. Thus 'gender' is considered an important socioeconomic variable. Gender analysis hypothesizes that introduction of technology affects different members of a household in varying ways. The gender impact analysis of improved cultivars in this subsection considers: (1) participation of women in adoption, input use, and marketing; (2) wages of women across districts; (3) labor use changes; and (4) others.

Table 23 presents data on the participation of women in decision-making. Nearly one-third of the households take into account the views of women in adoption of improved cultivars, whereas in 65% of the households, this area is an exclusive domain of men.

Table 23. Decision-making on cultivation of improved cultivars of pearl millet (figures are % of the households).

Decision	Exclusively male	Exclusively female	Joint decisions
Adoption	65	5	30
Cash/credit	50	0	50
Seed	90	0	10
Farmyard manure	50	0	50
Fertilizers	90	0	10
Pesticides	100	0	0
Hiring labor	15	60	25
Hiring machinery/bullocks	80	10	10
Marketing produce	55	0	45

To mobilize money resources (cash/credit), males of 50% of the households consult women. The only area where women have a significant influence on the decision-making process is in the hiring of labor. One striking observation is that with respect to decision-making on the use of modern inputs like improved seeds, fertilizers, pesticides, and machinery, women generally play only a minor role.

However, their input is appreciated in decisions on the use of traditional inputs such as farmyard manure (FYM) and labor. Another interesting feature is that as the improved technologies created a greater demand for output market-related activities, the role of women has increased in these otherwise traditionally men-oriented activities. Overall, the new cultivars have made inroads while only moderately altering the stereotyped gender roles.

Have improved cultivars burdened women in terms of additional work in field operations? Data on labor absorption in cultivation of select improved cultivars and local cultivars appear in Table 24. While some cultivars such as ICMS 7703 and CO 7 required additional female labor, it declined by about 20% for Pioneer, a private sector hybrid. Statistical analysis indicates that only the Pioneer hybrid used significantly less labor than other varieties. In the course of the RRA it was found that most women do not feel any additional burden in terms of field work. Instead, they felt that harvesting and threshing had become easier with improved cultivars as the panicles are harvested in one stroke as against staggered harvesting in local cultivars.

Table 24. Labor use (in labor days) by gender in pearl millet production in Tamil Nadu.

	Local cultivar		ICMS 7703		CO 7		Pioneer	
Operation	Male	Female	Male	Female	Male	Female	Male	Female
Land preparation	4.30	0.02	6.03	0	2.15	0	2.20	0.01
Seedbed preparation	0.40	0	3.23	1.45	2.33	0.25	0.38	0
FYM application	2.38	1.01	1.96	0	1.96	0.18	2.36	0.11
Seed treatment	0	0	0.02	0	0	0	0	0
Sowing	1.65	2.09	1.08	5.84	1.01	9.63	1.01	0.79
Fertilizer application	0.32	0.07	1.26	0.31	1.00	0	0.59	0.05
Interculture	0.22	0	0.17	0.04	0.06	0	0.34	0
Weeding	0.07	26.05	0	28.57	0.31	23.93	0.08	22.19
Plant protection	0	0	0.09	0	0	0	0.07	0
Irrigation	0.61	0	4.82	0	5.55	0	0.30	0
Watching birds	0.39	2.16	0.39	3.97	0	4.23	0.36	0.84
Harvesting	3.08	20.57	1.88	16.31	1.90	20.62	2.07	19.21
Threshing	4.59	1.15	4.36	1.00	3.87	2.09	3.32	0.61
Total	18.01	53.12	25.29	57.49	20.14	60.93	13.08	43.81

And it may be seen from Table 24 that the labor activity pattern and time allocation of labor between men and women remain the same as before. Thus, it may be concluded that improved cultivars have not disturbed the existing equilibrium of the roles of men and women in pearl millet cultivation. If at all there is an effect, it is only marginal on either side.

Sustainability

Sustainability in the context of agriculture refers to sustainable use of land and water resources so that crop production may be pursued using those resources indefinitely into the future. Many of the improved cultivars of different crops are exhaustive in nature as they require more water and nutrients. It is necessary then to know whether improved cultivars have affected the production system and in what direction. Pearl millet is grown in varied agroclimatic zones in Tamil Nadu. Any negative impact by improved cultivars of pearl millet will have a telling effect on the sustainability of soil and water use. This section aims at understanding the kind of impact improved pearl millet cultivars have on the production systems in different districts of Tamil Nadu.

Soil health

The crop sequences followed in different districts and the accommodation of pearl millet in the sequential set of crop activities appear in Table 25.

Table 25. Pearl millet in cropping sequences in Tamil Nadu.

Village	Seasons				
Thimmaravuthan-kuppam (Kadalur)	*Feb-Apr* Sesame *Feb-May* Irrigated pearl millet	*Jun-Aug* Rainfed pearl millet		*Sep-Jan* Paddy Irrigated rice	*Nov-Feb* Irrigated groundnut
Konganamoor (Villupuram)	*Apr-Jun* Sesame	*Jun-Aug* Rainfed pearl millet		*Sep-Nov* Fallow	*Dec-Mar* Irrigated groundnut
Paramananthal (Thiruvannamalai)	*Feb-Apr* Irrigated pearl millet	*Jun-Sep* Rice		*Sep-Jan* Rice	*Oct-Jan* Irrigated groundnut
Kalparpatti (Salem)	*Mar-May* Rainfed pearl millet+ sesame	*Jun-Oct* Sorghum			*Nov-Jan* Green gram
Silal (Trichy)			*Jul-Sep* Rainfed groundnut		
Kanjanayakkanpatti (Virudhunagar)				*Sep-Dec* Rainfed pearl millet	
P.Duraisamypuram (Thoothukudi)					*Nov-Feb* Rainfed pearl millet

In Kadalur district, pearl millet is sown with the onset of monsoon, and grows under rainfed conditions. Afterwards, the straw is plowed in and kept in the soil for two months during the rainy season. This becomes organic manure for the succeeding crop, irrigated groundnut. In another crop sequence at the same study site, straw from irrigated pearl millet becomes manure for the following rice crop, which is sown in Sep. The straw gets decomposed during the rains of the southwest monsoon. Similar practices can be observed in Villupuram and Thiruvannamalai districts. In addition, chaff from threshed panicles (after removal of grains) are used to produce farmyard manure in the farm. In Salem district, pearl millet is aligned in a cereal-legume-cereal (sorghum-green gram-pearl millet) sequence, the thrust of this practice being the maintenance of soil health. One may witness a different story in Virudhunagar and Thoothukudi districts where pearl millet is grown year after year but only in one season. Focused questions in the RRA confirmed that this practice did not affect soil fertility. It is important to underscore the fact that both local and improved cultivars fit in all of the sequences indicated. Obviously, improved cultivars do not affect the soil health but strengthen it when accommodated in time-tested crop sequences.

Water

It is a known fact that pearl millet survives even in harsh environments. It requires less water than the other competing crops such as maize, sunflower, hybrid sorghum, and groundnut. About 85% of pearl millet, irrespective of whether it is local or improved, is grown as a rainfed crop in Tamil Nadu, which indicates that it grows under less and uncertain moisture supply. In six of the seven study sites, pearl millet is raised under rainfed conditions. Only in two districts is it an irrigated crop grown only during the dry months, Feb-May. Pearl millet is in most cases a successor crop to irrigated rice or other cereals, using the residual moisture left in the soil. Besides this, it receives a few supplementary irrigations during its growth. Improved cultivars are as good in terms of drought tolerance as local cultivars. The excellent performance of ICMV 221 in drought years in Thoothukudi district testifies to this. It may be conclusively said that economical consumption of water by pearl millet helps sustainable use of ground water in Tamil Nadu where other crops such as irrigated rice, sugarcane, banana, and vegetables significantly contribute to the decline of the ground water table.

Land

Invariably in all the study villages, farmers pointed out the remarkable ability of pearl millet to survive and grow on marginal lands. In Vallalar and Villupuram districts, local and improved cultivars are grown under the southwest monsoon rains, which are extremely variable in nature. Alternatively, where the southwest monsoon is not important, pearl millet grows either under the northeast monsoon (400-600 mm) in Virudhunagar and Thoothukudi districts or under still lower levels of summer rains in Salem district. It is grown in significantly less fertile lands of varied soil types. It is appropriate to recall at this point that the pearl millet area in Tamil Nadu has declined from 475 000 ha in 1987 to 236 000 ha in 1990, thus releasing a huge area to be sown to other crops in a situation of a shrinking cultivation frontier due to demand of land for various uses. The loss of production due to the shrinkage in area has been well compensated by the higher yields achieved by improved cultivars. Evidently, improved cultivars not only perform well in less fertile and marginal lands but are also land-saving in character. Land-use technologies in Salem and Trichy include improved cultivars as intercrops with sesame and groundnut, the purpose of which is apparently to ensure balanced use of nutrients in the soil and minimize income risks to the growers.

Chemicals

As shown in Table 25, both improved and local cultivars are grown after sesame in Vallalar and Villupuram districts, and as an intercrop with it in Trichy. Indigenous technology suggests that these sequences effectively control pest occurrence, and hence little or no use of pesticides is required. Above all, the downy mildew resistant nature of improved cultivars eliminates the use of fungicides. The three-year crop sequence of cotton-pearl millet-cotton in Virudhunagar district, it is reported, minimizes pest occurrence in cotton. The conspicuous existence of pearl millet hybrids in the crop sequence testifies that improved cultivars are not weaker than local cultivars in ensuring sustainability in agriculture. Viewed from different angles, pearl millet as a crop, particularly, improved cultivars, appears to strengthen rather than weaken the sustainability of agriculture.

Impact of ICRISAT cultivars

After the debacle of HB 1, HB 2, and HB 3 hybrids in the early 1970s, farmers in Tamil Nadu were skeptical about improved pearl millet cultivars. Their reluctance was overcome with the entry of WC-C 75 in 1985; subsequently ICMS 7703 and ICMV 221 were adopted without hesitation. The ICRISAT cultivars made a clear impact on the yield levels of pearl millet in Tamil Nadu, which encouraged farmers to bring more area under improved cultivars. The downy mildew resistance and larger grains of these cultivars also accelerated adoption. The larger grain size of ICRISAT cultivars brightened the prospect of use of pearl millet as a raw material in the poultry and cattle feed industries, thus strengthening the linkage between agriculture and industry. The drought tolerance and shorter duration of ICMV 221 suited the environments of the southern districts of Tamil Nadu. Another direct impact is the mutual exchange of knowledge of breeding techniques between TNAU and ICRISAT. Exchange of germplasm is another significant activity that deserves mention.

The indirect impact of ICRISAT germplasm is mirrored by the rapid spread of private sector hybrids, the adoption of which has resulted in the more than doubling of pearl millet yields in Tamil Nadu. It must be emphasized that most of the private sector research programs may have used ICRISAT germplasm in developing their own proprietary hybrids. Again the attractive color and bold size of pearl millet hybrids from the private sector strengthened the qualification of pearl millet as a raw material in the feed industry. With 75% of the pearl millet area now sown to private sector hybrids in Tamil Nadu and 90% of the grain production from hybrids flowing into the industrial sector, one can easily imagine the notable contribution of ICRISAT germplasm to pearl millet-based economic activities in Tamil Nadu.

Utilization

The structure of the demand for pearl millet grain has drastically changed in the past decade with most of the grain now produced being absorbed by the poultry and cattle feed industry. The consumer preference for rice and the lower real price of subsidized rice have combined to almost perfectly substitute pearl millet with rice as a foodgrain in Tamil Nadu. Data on farm utilization-level of millet are shown in Table 26.

It can be seen that 21% of the grain is either consumed or retained for seed and other purposes. The remaining 79% moves into the market, its final destination being the livestock feed industry. Survey results provide evidence that the bulk of the grain that comes into the market moves to the Namakkal poultry region of Tamil Nadu where 75% of the poultry and cattle feed manufacturing units are concentrated.

Table 26. Utilization of pearl millet (kg) in a subset of sample farms (N = 30).

Cultivar	Gross output	Consumption	Wage payments	Seed	Marketed produce
Private	29 165 (100)[1]	5668 (20)	426 (1)	48(0)	23 023 (79)
Public	7 174 (100)	1103(16)	259 (5)	245 (3)	5 467 (76)
ICRISAT	5 276(100)	541 (10)	115(2)	95(2)	4 525 (86)
Local	712 (100)	267 (38)	43(6)	4(1)	398 (55)
Total	42 327 (100)	7579(18)	943 (12)	392 (1)	33 413(79)

1. Figures in parentheses are percentages of total.

A quick survey of a few feed manufacturing units and a brief interaction with poultry nutrition scientists revealed the growing share of pearl millet in poultry feed. Millet emerged as an economically attractive alternative to maize which is not priced competitively. It appears that there will be a growing demand for millet in the poultry industry in future. The growing demand for millet as an industrial input and its disappearance as a food crop have serious policy implications in terms of the requirement of grain characteristics of millet, income distribution, technology, and sectoral linkages. This new scenario requires further research to better understand the future demand and marketing activities relating to millet and food security, sustainability, and equity issues. There is a definite justification to undertake more research into utilization aspects of pearl millet.

Returns to research investment in pearl millet

One of the objectives of the present study is to assess the rate of returns to investment on pearl millet research by Indian NARS and IARCs with particular reference to ICRISAT. Given the growing scarcity of research resources, it becomes important that investment is made on research projects and in areas where returns are high and research is more productive. In recent years, more and more institutions have started evaluating their research investments. The methodology is also well-developed and redefined to evaluate the research carried out.

Costs

Research on pearl millet is conducted by both NARS and IARCs. The centers that have conducted pearl millet research benefiting Tamil Nadu include TNAU, IARI, AICPMIP (ICAR), ICRISAT, other SAUs, and R&D units of private sector seed agencies. The major contributions to Tamil Nadu have come from TNAU, ICRISAT, and the private sector.

TNAU. Research on pearl millet in TNAU (formerly the Agricultural College and Research Institute, Coimbatore) commenced as early as the 1930s, and the first variety was released in 1939. But for the present study, the costs of research were computed for the period 1970-1996 (Table 27). The components of research cost at TNAU included scientists' costs, working capital, and costs on field trials, production of breeder seed, and transfer of technology.

State Department of Agriculture. The state farm located at Kudumiyanmalai undertook adaptive research on pearl millet and released two hybrids initially identified by breeders at IARI (KM 1 and KM 2). The period of research was from 1972 to 1983. The costs incurred in Tamil Nadu for this research were taken into account in calculating the research costs.

ICRISAT. Pearl millet is one of ICRISAT's mandate crops. The total cost incurred has been apportioned based on the proportion of pearl millet area in Tamil Nadu to the total pearl millet area covered under ICRISAT's mandate. The dollar exchange rate was used to convert the cost in rupees. The costs incurred by ICRISAT relate to the period 1973-1996.

Transfer of technology costs. The costs associated with the spread of pearl millet varieties incurred by the state Department of Agriculture and TNAU transfer of technology units were determined and added to the research costs in order to arrive at the total cost. The time-frame relating to transfer of technology covered the period 1976-1996 (Table 27).

Benefits

A technology may be yield-increasing or cost-reducing in nature. Pearl millet breeding research has mainly focused on overall performance that could improve productivity. Thus productivity of pearl millet has doubled during the period from 1970 to 1996. In other words, there is a vertical shift in the production function that suggests that more could be produced with the same input level or the same cost in real terms.

The unit cost reduction per ton of pearl millet was computed to range from Rs. 610 to Rs. 840. The calculations pertaining to unit cost reduction estimates are shown in Table 28. The farm-level survey data relating to 1994/95 were used to make the cost and return estimates. The benefits realized were due to the investment made on pearl millet research. Assuming the benefits realized per ton apply to the whole period from 1977 to 1996, the total gains for each year were arrived at after adjusting for adoption rates of improved cultivars. The gains were assumed to flow into the future and, for the present analysis, were extrapolated up to 2000 AD.

The unit cost reduction due to improved cultivars was substantial. The major cost differences between local cultivars and improved ones are given in Table 28. The expenditure on seed, FYM, and fertilizer are much higher for Pioneer hybrids as compared to local cultivars. In the case of ICMS 7703, the costs of seed and fertilizer are higher.

Net benefits and discounting

The NPV of the stream of benefits from improvement of pearl millet cultivars was obtained by analyzing production levels in the study area, cost structures at farm level, adoption levels, and research costs.

The net benefit for each year was obtained by taking the difference between total costs and total gains. The net gains were then computed by considering a discount factor of 10%. The discounted net gains can be seen in Table 27.

Consumer and producer surplus

The total economic surplus is equal to the total value of consumption (the area under the demand curve) minus the total cost of production (the area under the supply curve).

Consequent to a technology adoption, the supply curve may shift to the right, and changes in consumer surplus and producer surplus occur. The difference in the surplus created before and after research relate to the economic surplus accrued to the producers and consumers.

Price elasticities of demand and supply determine the size of the benefits which reach the consumers and producers. The demand and supply elasticities as estimated by researchers in TNAU have been adopted for the present analysis (Table 29). Besides, the other parameters used for the estimation of economic surplus are shown in Table 29. The total net present value of benefits from improved productivity in pearl millet due to research is about Rs. 9 million. The IRR which was estimated using the NPV (Table 27) was 27% for investment made on pearl millet research.

Table 27. Research costs and benefits.

Year	Net benefits (Rs.)	Present value of benefits (Rs.)	Research costs (Rs.) ICRISAT	Other institutions	Total	Research gains (Rs.)
1970	-60440	-54945	0	60440	60440	0
1971	-64053	-52936	0	64053	64053	0
1972	-69183	-51978	0	69183	69183	0
1973	-84609	-57420	8674	75395	84069	0
1974	-102889	-63883	21573	81311	102884	0
1975	-123884	-69616	38026	85302	123328	0
1976	-157818	-80985	39348	118470	157818	0
1977	-1677386	-782513	58676	1618710	1677386	0
1978	-1739161	-737574	84551	165610	1739161	0
1979	91393	35236	77718	1680019	1757737	1849130
1980	584214	204763	85996	1657321	1743317	2327531
1981	939421	299329	122317	1719925	1842242	2781664
1982	1359818	393891	153666	1738495	1892161	3251979
1983	1839576	484418	214840	1733803	1948643	3788220
1984	2230319	533921	246710	1761549	2008259	4238578
1985	2551323	555242	327723	1786750	2114475	4665796
1986	2990647	591684	357028	1797802	2154830	5145477
1987	3766707	677475	361334	1600265	1961599	5728305
1988	3767428	616005	457027	2000467	2457494	6224922
1989	3838074	570505	549576	2029036	2578612	6416686
1990	4535889	612937	590883	1953709	2544592	7080481
1991	4790715	588520	704413	2249147	2953560	7744276
1992	5257274	587123	716250	2213281	2929531	8186806
1993	5270599	535101	698682	221725	2916207	8186806
1994	5793391	534707	558902	2277043	2835945	8629336
1995	5716833	479673	563998	2348505	2912503	8629336
1996	5592327	426570	563998	2473011	3037009	8629336
1997	8850601	613730			0	8850601
1998	8850601	557937			0	8850601
1999	8850601	507215			0	8850601
2000	8850601	461105			0	8850601
Total	92240031		7601908	39065127	46667035	138907066
Present Value	8915235		1206029	8255629	9461657	18376893

.....*Continued*

Table 27 continued.

Year	Adoption level	Annual gains	Gains to consumers	%	Gains to producers	%
1970	0	0	0	0		o
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	11063251	0	0	0	0
1978	0	11063251	0	0	0	0
1979	0.17	11063251	818468	44.26	1030663	55.74
1980	0.21	11063251	1030219	44.26	1297313	55.74
1981	0.25	11063251	1231228	44.26	1550436	55.74
1982	0.29	11063251	1439401	44.26	1812578	55.74
1983	0.34	11063251	1676753	44.26	2111467	55.74
1984	0.38	11063251	1876092	44.26	2362486	55.74
1985	0.42	11063251	2065189	44.26	2600608	55.74
1986	0.47	11063251	2277506	44.26	2867971	55.74
1987	0.52	11063251	2535479	44.26	3192826	55.74
1988	0.56	11063250	2755294	44.26	3469629	55.74
1989	0.58	11063251	2840172	44.26	3576513	55.74
1990	0.64	11063251	3133983	44.26	3946497	55.74
1991	0.7	11063251	3427794	44.26	4316481	55.74
1992	0.74	11063251	3623668	44.26	4563138	55.74
1993	0.74	11063251	3623668	44.26	4563138	55.74
1994	0.78	11063251	3819542	44.26	4809794	55.74
1995	0.78	11063251	3819542	44.26	4809794	55.74
1996	0.78	11063251	3819542	44.26	4809794	55.74
1997	0.8	11063251	3917479	44.26	4933122	55.74
1998	0.8	11063251	3917479	44.26	4933122	55.74
1999	0.8	11063251	3917479	44.26	4933122	55.74
2000	0.8	11063251	3917479	44.26	4933122	55.74
Total			61483456		77423611	
Present value			15850932		19960433	

Net Present Value = 8915235.
Internal Rate of Return = 0.2679.

The rate of return is reasonably high, permitting one to recommend making a further investment in pearl millet research. The flow of net benefits during the period from 1977 to 2000 in nominal and real terms are depicted in Figures 6 and 7 respectively.

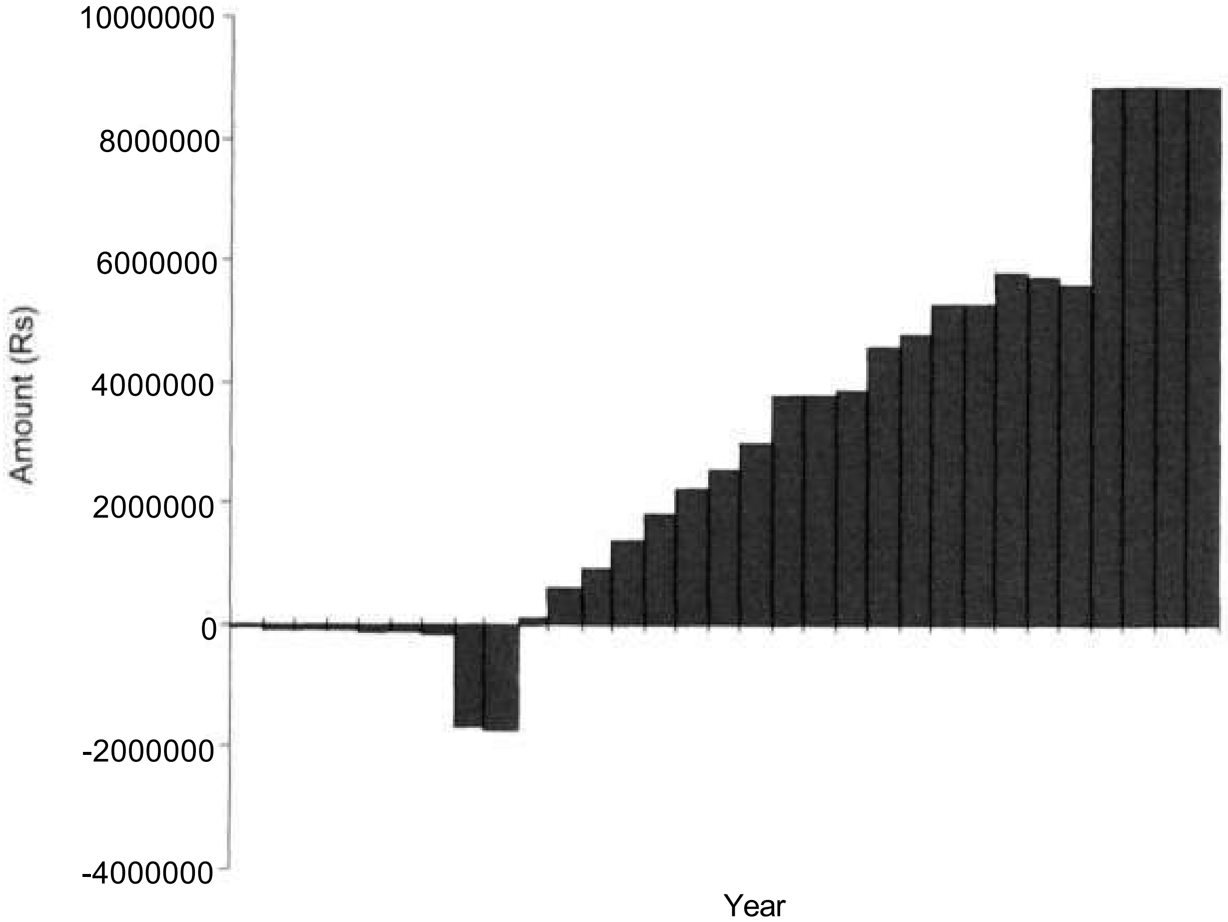

Figure 6. Flow of net benefits at current prices.

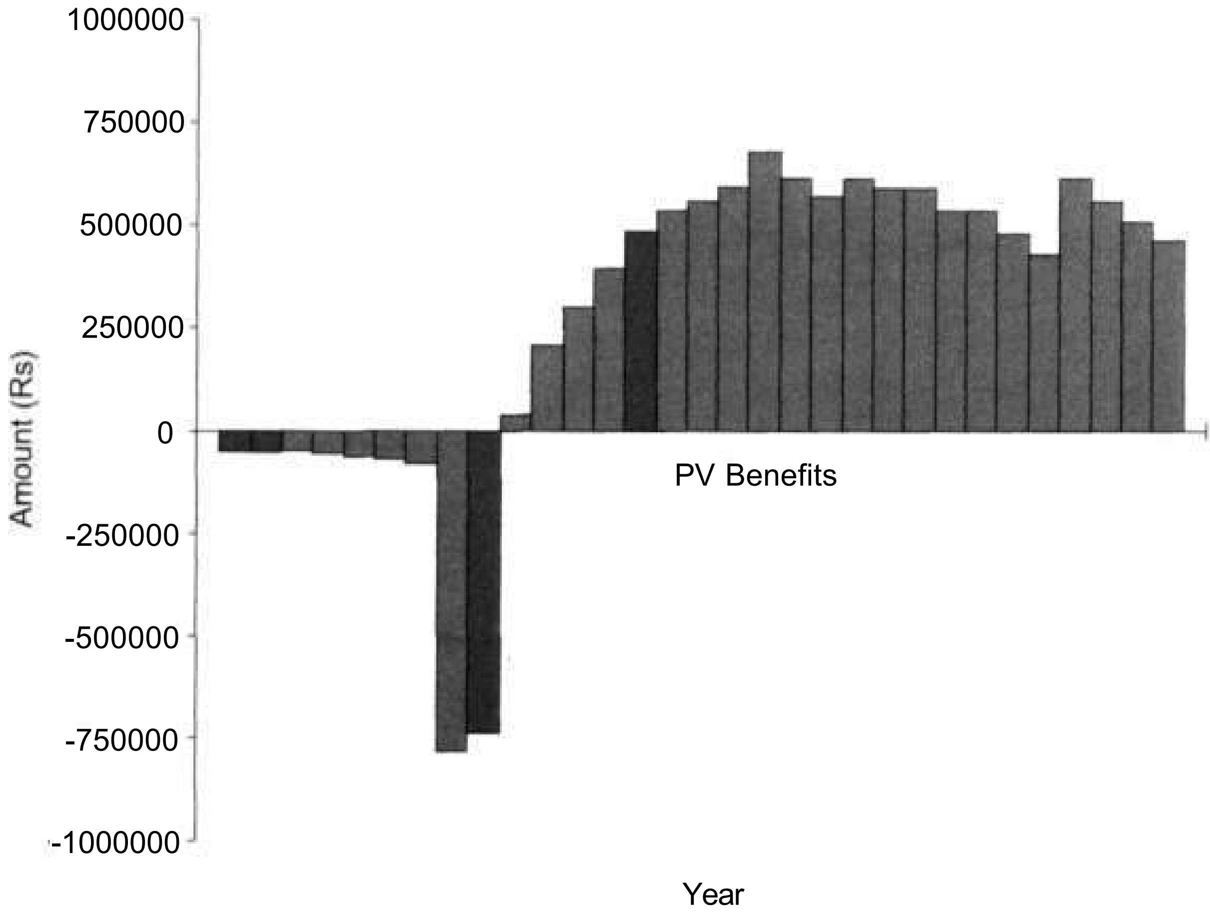

Figure 7. Flow of net benefits at constant prices.

Table 28. Unit cost reduction.

Particulars	Local cultivars	Improved cultivars
Total variable cost (Rs.)	2975.00	4425.00
Fixed cost (Rs.)	2070	2070
(Owned land : rental value, tax Land rent: lease rental landlord share, depreciation and interest on capital, others)		
Total cost (Rs.)	5045	6495
Pearl millet output per hectare per year (t)	0.69	1.51
Percentage change		118.64
Unit cost assessment		
Unit variable cost	4299.13	2924.65
Unit fixed cost	2991.33	1368.14
Unit total cost (Rs. r^{-1})	7290.46	4292.80
Unit cost reduction		
Unit variable cost reduction		1374.48
Unit fixed cost reduction		1623.19
Unit total cost reduction (Rs. r^{-1})		2997.67
Percentage unit cost reduction		41.12

Table 29. Summary data for benefit assessment.

Base level of production	312000 t
Yield change due to improved cultivars	59.6241 %
Base price level (1980)	607 (Rs.r^{-1})
Supply elasticity	0.27
Demand elasticity	0.34
Benefit assessment	
Discount rate	0.1
IRR guess	0.08
Intermediate data	
Total unit cost reduction	2996.26 (Rs. r^{-1})
Slope of supply curve	138.758
Slope of demand curve	174.732
Exchange rate	31.38 (Rs./US$)

Conclusions and policy implications

The adoption of improved cultivars of pearl millet in Tamil Nadu has been impressive with three-fourths of the crop area now sown to the new cultivars. Both public and private sector research have played significant roles in making available these improved cultivars. Earlier contributions and breakthroughs in breeding pearl millet were made by ICRISAT and public sector agencies of NARS. Using the parent material from ICRISAT and the NARS public sector, the private sector came out with a number of hybrids that are increasingly being adopted by more and more farmers mainly due to their grain characteristics and superior yield performance. For the spread of public sector cultivars, the state extension system is the major source of information and seed supply. Private seed dealers play a critical role in the spread of private sector seeds. Of late, farmers are very particular about replacing the seed within two years of the initial purchase, showing their increasing awareness.

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

For farmers the desirable features in a pearl millet variety are high yield, drought tolerance, good grain size, pest and disease resistance, and short duration. Researchers in pearl millet should incorporate these features in their future products. Availability of seed, presence of private dealers, and good seed material are found to be equally important factors for farmers. Agricultural development policy-makers and extension workers must note these points while devising and implementing policies.

The ICs show a distincdy superior performance over local cultivars in terms of yield, net income, and per unit cost reduction, thus proving both the profit-maximizing and cost-minimizing character of these cultivars.

The technical efficiencies derived from the estimated frontier production functions for individual farms showed that there is substantial scope for improving the technical efficiency of pearl millet production in Tamil Nadu. None of the farms in our sample was fully efficient. The most efficient farm growing improved variety was about 7% below the production frontier. Production inefficiency was found to be higher among farmers growing local cultivars. However, the inefficiency is only relatively lower among growers of improved cultivars. This emphasizes the need for strengthening rural education, extension services, and provision of modern inputs and credit.

Growing ICs has not affected the food security of the rural people in any way. Nor have these new cultivars altered the existing equilibrium of gender roles. ICs of pearl millet are highly flexible and can easily find a place in time-tested crop sequences and have not affected sustainability in the use of land and water.

Farmers growing ICs have found a new territory, namely the animal feed sector, to dispose their marketable surplus. This insulates them against the fall in price that would otherwise have been expected owing to the rejection of grains of improved pearl millet cultivars in the consumption bundle of rural households. In addition, the feed industry offers tremendous scope for expanding markets for grains from ICs as a raw material.

The findings of this study, we hope, will provide considerable feedback to both pearl millet researchers and agricultural policy-makers so as to reset or re-prioritize their activities and policies.

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Appendix 1

Area, production, and yield of pearl millet in Tamil Nadu, 1970-1994.

Year	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})
1970	475	312	658
1971	448	273	609
1972	430	260	606
1973	401	340	849
1974	372	214	576
1975	449	329	733
1976	456	460	1010
1977	437	374	857
1978	408	454	1112
1979	370	329	881
1980	328	264	805
1981	336	310	922
1982	295	207	702
1983	344	321	934
1984	322	320	992
1985	305	371	1215
1986	298	281	942
1987	293	314	1075
1988	270	304	1125
1989	261	291	1212
1990	274	296	1081
1991	246	272	1104
1992	219	251	1144
1993	236	338	1121
1994	192	231	1203

Appendix 2

List of villages selected for the study.

District	Taluk	Villages
Villupuram	Thirukkoilur	Konganamoor
		Tulukkapalayam
	Villupuram	Naraiyur
		Kedar
Kadalur	Kurinjippadi	Thimmaravuthankuppam
		Karuppanchavadi
	Nallore	Sirumangalam
		Seppakkam
Thiruvannamalai	Chengam	Paichal
		Paramanandal
	Polur	Chinnapushpagiri
		Kuppam
Salem	Salem	Kalparapatti
		Sevampalayam
	Attur	Kamakkapalayam
		Vetanayakapuram
Trichy	Jeyankondam	Silal
		Pudukkudi
	Karur	Emur
		Seetapatty
Virudhunagar	Aruppukottai	Kanjanayakkanpatti
		Chinnapuliyampatti
	Sattur	Pettareddiyapatti
		Sippiparai
Thoothukudi	Ottapidaram	Melamudiman
		Duraisamypuram
	Vilathikulam	Padarndapuli
		Pillayamatham

Appendix 3

District-wise area, production, and productivity of pearl millet in Tamil Nadu, (average of 1991-1993).

District	Area ('000 ha)	Production ('000 t)	Yield (kg ha-1)	Rainfall (mm)
Kadalur	87.3	113.5	1300	1137
Villupuram[1]				
Trichy	48.0	36.0	750	824
Thoothukudi	17.5	25.4	1452	662
Salem	12.3	20.2	1644	842
Virudhunagar	10.3	16.3	1587	812
Thiruvannamalai	12.2	8.3	681	1075
Madurai	7.6	10.6	1390	827
Periyar	7.0	7.2	1023	660
Dindugal	6.8	11.5	1694	834
Dharmapuri	6.1	10.8	1755	857
North Arcot	4.0	7.0	1752	953
Ramanathapuram	2.1	2.3	1068	828
Chengalpattu	1.6	2.9	1765	1165
Tirunelveli	1.5	1.5	1204	889
Coimbatore	1.1	2.0	1792	647
Pudukkottai	0.3	0.3	1126	911
Sivaganga	0.2	0.2	1086	905
Tanjavur	0.1	0.1	1243	1135
Nilgiris	0	0	0	1857
Kanyakumari	0	0	0	1457
Nagapattinam	0	0	0	1215
Total	226.1	276.1	1221	925

1. The earlier South Arcot district has been bifurcated into Kadalur and Villupuram districts.

List of publications in this series

Bantilan, M.C.S., and Joshi, P.K. 1996. Returns to research and diffusion investments on wilt resistance in pigeonpea. (In En. Summaries in En, Fr.) Impaa Series no. 1. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 36 pp. ISBN 92-9066-356-1. Order code ISE 001.

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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.

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