Working Paper Series No. 51

ICRISAT Research Program
Markets, Institutions and Policies

Report on

Ex-Ante Evaluation of the Impact of Research Investment in Stay-Green Post-Rainy-Season Sorghum

Achot Lalith P Parthasarathy Rao and S Bhagavatula

ICRISAT
Science with a human face
International Crops Research Institute for the Semi-Arid Tropics

Citation: Lalith Achot, Parthasarathy Rao P and Bhagvatula S. 2013. Ex-ante Evaluation of the Impact of Research Investment in Stay-Green Post-Rainy-Season Sorghum. Working Paper Series No 51. ICRISAT Research Program, Markets, Institutions and Policies. Patancheru 502 324, Telangana, India: International Crops Research Institute for the Semi-Arid Tropics. 32 pp.

Acknowledgement:

The authors would like to thank Dr MCS Bantilan, Director, Research Program on Markets, Institutions and Policies (MIP) for allowing us to undertake this study, for her constant encouragement and guidance in conducting the study. We also thank their external reviewers of the paper for their valuable comments on earlier drafts. Our thanks to all the scientists involved in the project in providing data and information that helped in preparing the report. Finally we thank Dr Vincent Vadez for his support in carrying out this study and funding support from ACIAR project.

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2014

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Ex-ante Evaluation of the Impact of Research Investment in Stay-Green Post-Rainy-Season Sorghum

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1. Introduction

This study presents the findings of an ex-ante impact assessment of an Australian Centre for International Agricultural Research (ACIAR)-funded project entitled 'Improving post-rainy-season sorghum varieties to enhance their competitiveness in the farming system to meet the grain and fodder demand in India'. The ex-ante impact assessment was carried out to provide estimates of the potential economic gains that would accrue to the different economic agents along the sorghum value-chain under varying yield scenarios. Such information would be critical in planning the second phase of the project when the improved materials are disseminated to farmers.

The primary aim of the ACIAR project was to maximize grain/stover yield and quality of post-rainy-season sorghum by maximizing post-anthesis (after flowering) water use and water use efficiency (WUE) to enhance grain filling. This would be achieved by developing single- and multiple-quantitative trait loci (QTL) stay-green introgression isolines, and assessing the contributions of each of these QTL to grain/fodder productivity and grain/fodder quality under normal and drought-stressed conditions. The planned outputs of this project would thus be the isolines with key stay-green QTL that have a higher drought adaptation and fodder quality, and the knowledge of traits that are related to more efficient water use.

The primary target sites of the project are western Maharashtra and northern Karnataka, which represent the largest post-rainy-season-sorghum area in India. The secondary site comprises the sorghum-growing regions of Australia which are similarly water-limited. An added benefit is that the capacity of the scientists in both countries engaged in the project would be enhanced.

Section 2 of this report presents a brief outline and justification of the project, and highlights its planned research outputs and potential outcomes. Section 3 outlines the methodology used in estimating the potential benefits and costs of the project, along with an explanation of the parameters used. Section 4 presents the findings of the analysis. Conclusions are presented in Section 5.

2. Project Background

Water is an important limiting factor in agricultural production, particularly in the rain-fed systems that dominate most developing countries. It assumes an even greater importance in sorghum cultivation, as sorghum is grown primarily in water-limited areas in India and Australia. Consequently, there is a high reliance on limited stored-water resources and variable rainfall.

The aim of the project is to lay the basis for marker-assisted introgression of stay-green[1] QTL that will enhance both the quality and the quantity of grain/stover of post-rainy-season sorghum, and to

[1] Introgression is the transfer of genetic information from one species to another as a result of hybridization between them and repeated backcrossing.

identify, through modeling, the key physiological traits involved in a higher, more stable yield across water-limited environments of India and Australia, and key stay-green QTL contributing to these traits.

2.1 Post-Rainy-Season Productivity Improvement: Background and Rationale

Sorghum is one of the main cereal crops consumed in India after rice and wheat. The crop is primarily produced in the dry tracts of peninsular India in the states of Maharashtra, Gujarat, Rajasthan, Madhya Pradesh, Karnataka and Andhra Pradesh. India is the third-largest producer of sorghum in the world, accounting for 7.15 million tons in 2007, and almost the entire production of sorghum in the country (95%) comes from the above regions/states (GOI, various years). Sorghum is grown in both the rainy (July to September) and the post-rainy (October to February) seasons. In 2007 the area under post-rainy-season sorghum was 4.6 million ha, producing 3.38 million metric tons, while it was 3.6 million ha and 3.7 million tons for rainy-season sorghum in the same year. Yield trends have been relatively stagnant and yield levels in the country are low compared to global averages. These low productivity trends are because post-rainy-season sorghum is grown entirely on stored soil moisture and therefore regularly faces terminal drought stress conditions.

The bulk of the post-rainy-season-sorghum grain is used for food since the grain is of superior quality and hence is preferred for consumption (bold grain, white colour, sweeter taste). In contrast, rainy-season sorghum, with smaller grain, is used for food and industrial uses (poultry feed, alcohol manufacture, etc). Consequently, post-rainy-season-sorghum prices are higher by 20–40% compared to rainy-season sorghum grain.

Besides grain, sorghum stover is an important feed in the livestock sector in India for draft and dairy animals, particularly in the dry seasons when other feed resources are in short supply.[2] Though India has a livestock population of over 343 million, milk and meat productivity is low compared to the world average [Parthasarathy Rao and Birthal (2008)]. Per-capita consumption of milk and milk products is also low at 100 g/head/day, compared to the minimum nutritional requirement of 201 g/head/day of milk. Hence dual-purpose types of sorghum that produce both grain and stover are the preferred types to meet the derived demand for livestock feed, driven by the rising demand for livestock products [Kelley et al. (1993); Kelley and Parthasarathy Rao (1994); Hall (2000)].

3. Data and Methodology

The main aim of the ACIAR-funded project is to identify and lay the basis for marker-assisted introgression of stay-green QTL for post-rainy-season sorghum. By the end of the first phase of the project the planned outputs are the specific stay-green QTL that can then be introgressed to the popular varieties of post-rainy-season sorghum that are grown in India and in the summer season

2. Besides crop residues, the feed and forage resources are available from cultivated fodders, permanent pastures, wastelands and common property resources. It is estimated that the average cultivated area devoted to fodder production is only 4.4% of the gross cropped area, and the area under permanent pastures and cultivable wastelands is approximately 13 and 15 million ha, respectively. These resources are able to meet the forage requirements of the livestock only during the monsoon season. But, for the remaining periods of the year, the animals have to be maintained on the crop residues or straws of sorghum, pearl millet, paddy, wheat and other sources, either in the form of whole straw or as cut fodder, supplemented with some green fodder. Thus, post-rainy season-sorghum fodder is an important animal feed in the major growing states/regions of India

in Australia. Since the project was conceived as a proof-of-concept research, it is an entirely lab-based exercise. There will be no direct social and economic impact at the end of the first phase of the project. A follow-up phase of the project is needed which will involve the interbreeding of the selected stay-green QTL with popular varieties of post-rainy-season sorghum, the dissemination of which will impact farmer livelihoods in India, Australia and countries with similar agro-ecological regions. Therefore, in order to examine the benefits of this project, we assume another project that involves the same partners with an identical budget and project cycle.

To facilitate the ex-ante impact assessment, a structured questionnaire was developed and circulated among the scientists involved in the project, ranging from plant pathologists to breeders, to assess their views on the features of the new post-rainy-season-sorghum stay-green technology. The information that was elicited from the scientists had to do with rates of adoption, the anticipated adoption lag, and the yield and quality improvements in grain and fodder based on research station experiments. Their responses have been tabulated and used in the analysis.

At the time of the survey, two years of the project had already elapsed. There have been several trials testing ‘stay-green introgression lines’. These are genotypes that ‘contain’ a small portion of the genome of a donor parent, which confers the ability to stay-green. The genetic background of these genotypes are the cultivars R16 and S35. The trial was planted at ICRISAT, Patancheru, and in different locations of the Directorate of Sorghum Research (DSR Solapur and Jalna) and the Agricultural Research Stations (ARS Tandur and Bijapur). These trials have been conducted since 2008–09. The third-year trials are underway for the post-rainy season of 2010.

The impact pathway of the technology is confined to the direct impacts, ie, to grain and stover production. The supply and demand for each of the paths is disaggregated and analyzed to quantify the costs and benefits to calculate the impact.

Trends in post-rainy-season-sorghum area and production was estimated by fitting a liner trend equation to the data from published GOI sources for the ten years preceding 2007, for Maharashtra, Karnataka and Andhra Pradesh, separately, and then aggregating. The trend equation was extrapolated to obtain the projected areas till the year 2030, which was taken as the last year in which to quantify the project impacts for the purpose of this study.

The form of the equation was:

$$Y = a + bT + u$$

Where Y is the variable under study, T is the trend variable, a and b are the constants in the equation and u is the disturbance term.

The compound rate of growth was computed for various periods, using the growth equation:

$$Y = at^{b}e^{u}$$

Where the compound growth, g, of the variable is calculated as follows: g = b - 1. The resulting time series of area and production projections for India are presented in Table 3. Fodder production is assumed to be double the grain production, ie, a stover-to-grain ratio of 2:1.

3.1 Area Trends

The area under sorghum in the country has been declining over the years (see Figure 1 and Table 1). The rate of decline in rainy sorghum area is of the order of 4.34% per annum between 1980 and 2007 (the overall period). The rate of decline had accelerated marginally from -3.28 to -3.90 % between 1980 and 1994, and 1994 and 2007, respectively. The rate of decline of the post-rainy-season-sorghum area has been somewhat marginal at -1.16% for the entire period, and 1.03% and 1.64% during periods 1 and 2, respectively. This trend has resulted in a larger area under post-rainy-season-sorghum, compared to rainy sorghum, since 1998–99. However, because the yield increase in rainy-season sorghum was higher than that in post-rainy-season-sorghum, the share of rainy-season sorghum production in the total sorghum production declined less drastically. The higher yield in rainy-season sorghum can be attributed to the adoption of hybrids and improved cultivars grown under improved production technology. A similar breakthrough in post-rainy-season sorghum was not achieved since the post-rainy-season crop is grown on residual soil moisture and suitable improved cultivars are yet to be fully adopted.

The reason why post-rainy-season sorghum is able to hold its position in the cropping pattern in the dry areas is because there are few alternative crops that can be grown on residual soil moisture. Additionally, the crop not only provides grain as a staple but also serves as fodder for dairy animals, which is gaining in importance as a farm enterprise, on account of the growing demand for milk and the stable and the regular income that milk sales provide throughout the year.

The relative importance of post-rainy-season sorghum in selected states of India can be seen from Figure 2. Almost 62% of the post-rainy-season-sorghum area in the country is in Maharashtra, followed by Karnataka with 28% of the area. Andhra Pradesh a distant third with an area share of 7%.

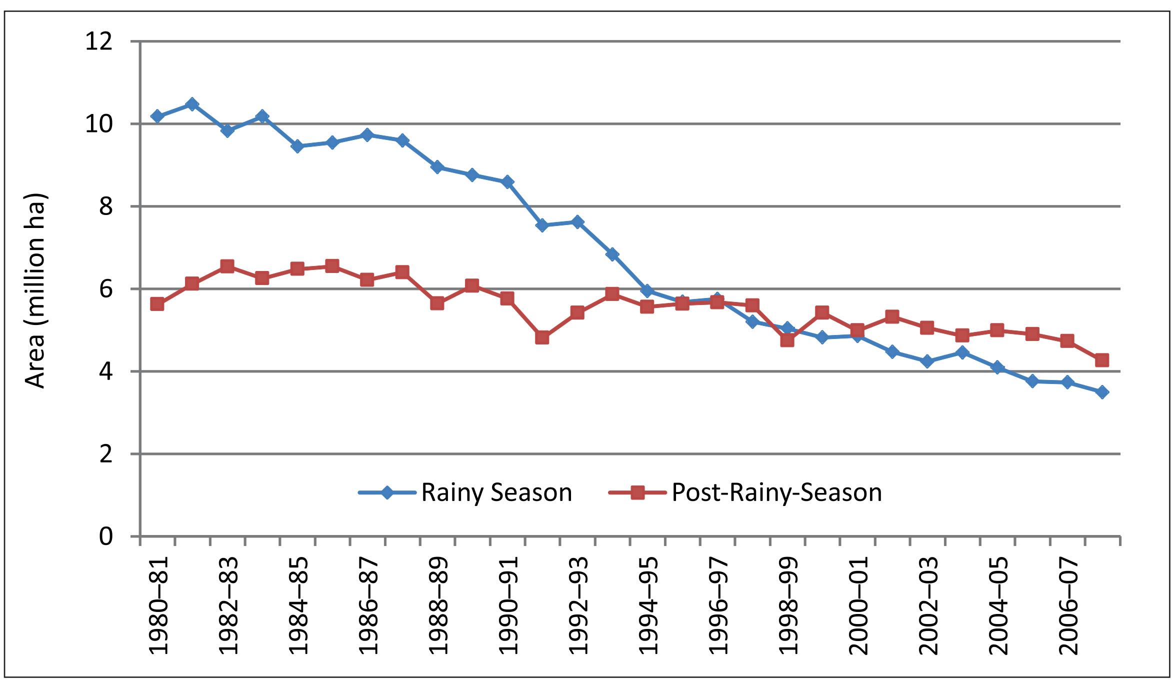
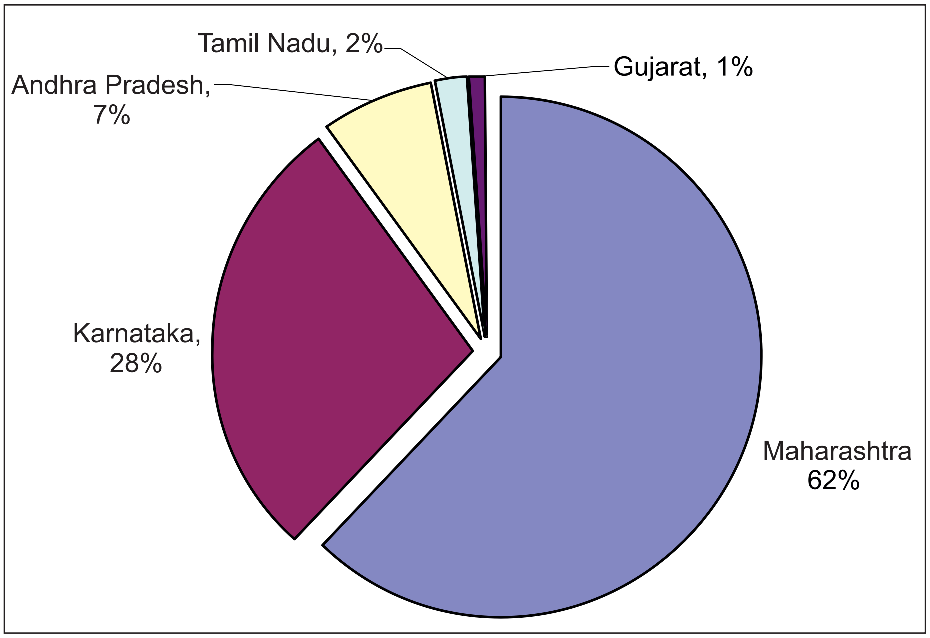


Figure 1. Trends in rainy and post-rainy season-sorghum area in India, 1980–2007.



Source : GOI, various years

Figure 2. Share of area under post-rainy-season sorghum in India, 2005–07.

Table 1. Annual rate of growth in sorghum area in India (% per annum).

Period	Rainy season	Post-rainy-season	Total
1980–81 to 1994–95	-3.28*	-1.03*	-2.35*
1994–95 to 2007–08	-3.90**	-1.64*	-2.72**
1980–81 to 2007–08	-4.34**	-1.16*	-2.88**

Note: * indicates significant at the 5% level; ** indicates significant at the 1% level

The declining trend of post-rainy-season-sorghum area observed for the country as a whole is clearly reflected in the major producing states as well (see Table 2). However, the rate of decline in area between 1994 and 2008 is lower in Maharashtra as compared to Andhra Pradesh and Karnataka, at around -0.71% vis-à-vis -6.63% and -2.94% in the latter two states.

Table 2. Annual rate of growth in post-rainy-season-sorghum area in major growing states of India (% per annum).

	Area		
Period	Andhra Pradesh	Karnataka	Maharashtra
1980–81 to 1994–95	-5.51**	2.98**	-0.76
1994–95 to 2007–08	-6.63**	-2.94**	-0.71
1980–81 to 2007–08	-5.32**	0.29	-0.69**

Note: * indicates significant at the 5% level; ** indicates significant at the 1% level

Area and production of the three states in question have been projected using the liner trend equation and projections of area obtained up to the year 2030 (see Figure 3). Projections of area would be used to estimate the adoption levels for assessing the benefits accrued by the introduction of improved cultivars. For the purposes of this paper, only project impacts on the primary project area, India, will be evaluated. A simple linear trend has been extrapolated for the state-wise areas of the three principal post-rainy-season-sorghum-growing states, viz., Andhra Pradesh, Karnataka and Maharashtra

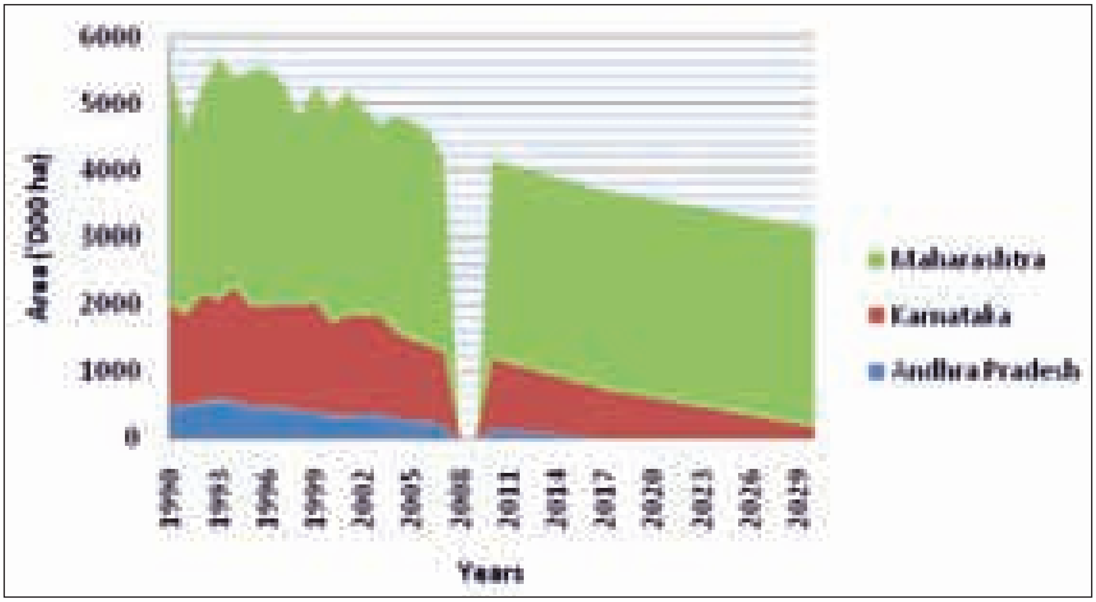


Figure 3. Past trends and projected area under post-rainy-season sorghum in India.

3.2 Scenarios

Based on the survey responses of the panel of scientists, for the purpose of analysis, three scenarios were generated. One is a 'Conservative scenario' where the expected accomplishments of the technology are conservative, with adoption rates and yield improvements at the lower end of the spectrum. The second scenario is an 'Optimistic scenario', where favorable responses have been used, and the third is the 'Likely scenario' or the 'most-likely scenario', in which the yield and success parameters lie between the two extreme scenarios. The assigned values of the parameters of the three scenarios are presented in Table 3.

The range of perceptions with regard to increase in grain yield from the new technology was between 2–28%. The average increase is assumed to be around 12%. The projections on the increase in fodder yield were much higher and ranged between 5 and 30%, with an average of 18%. A very substantial reduction in yield variability was expected, ranging between 10–30%. Fodder digestibility, a key factor determining milk yield, was expected to increase to about 43–50% as against the digestibility in ordinary stover ranging between 40–45%.

While the technology is currently in the research stations, the scientists perceived that there would be no change in the cost of production of the improved post-rainy-season sorghum. Some scientists involved with the project did, however, mention that there might be a marginal increase in the seed cost by about 10%, which has not been factored into the analysis, as the impact is negligible.

Table 3. Responses of the experts regarding the features of the stay-green post-rainy-season-sorghum-breeding program.

Features of the Variety	Unit	Conservative	Optimistic	Likely
Increase in Research Station (Grain)	%	2	28	12
Increase in Farmer's Field (Grain)	%	0.66	9.33	5
Increase in Research Station (Fodder)	%	5	30	18
Increase in Farmer's Field (Fodder)	%	1.67	10	5
Reduction in Yield Variability	%	10	30	20
Grain Size (Grains/100 gm) Premium	%	2	10	7
Fodder Digestibility: Existing Varieties	%	40	45	43
Fodder Digestibility: Post-Rainy Stay-Green Varieties	%	43	50	47
Increase in Irrigation Cost		No	No	No
Increase in Fertilizer Cost		No	No	No
Increase in Pesticide Cost		No	No	No
Increase in Labour Cost		No	No	No
Increase in Other Cost		No	No	No
Increase in Total cost		No	No	No
Seed Cost		No	Yes	Yes
Other		No	No	No
Total Cost		No	Yes	Yes
Exchange Rate INR/AUS$		43.90	43.90	43.90

Technology, while being developed in the research station, would have to overcome several hurdles and uncertainties on the field, which could hinder the realization of its full potential. Until the final product is delivered to the farmers, its development and subsequent success are not guaranteed. Hence, the views of the experts with regard to the probability of success and commercial viability of the variety being developed were ascertained. The ranges of their responses are presented in Table 4. The proof of concept and the probability of the development of the variety is ratified and indicated by probabilities ranging from 0.5 to 0.7. Thus, a probability of adoption of 0.65 that the variety will be developed was assumed, as the panel of scientists was confident that the technology development and its commercialization looked promising. The farmers will accept the technology fully during a period of 5 to 10 years from the end of the project's research phase, where the level of adoption will vary between 30–70%. They have thus set a most likely target of 50% adoption of the improved technology. However, this has been scaled down to 10% for this analysis, keeping with ground-level realities.

Table 4. Perceptions with regard to the progress of the technology in different scenarios.

Perceptions	Unit	Conservative	Optimistic	Likely
Probability of Success	Prob	0.65	0.65	0.65
Anticipated Adoption Lag	Years	10	5	8
Maximum Level of Adoption	%	30	70	50
Number of Years to Maximum Adoption	Years	10	5	5
Research Costs (Total)	Rs (million)	88.12	88.12	88.12

This project targets improvements in yields and quality, primarily of fodder and also of grain of post-rainy-season sorghum. As such, the impacts in two separate markets have to be considered in order to gauge the full impact of the technology. For the grain market, initial quantities that are used in calculating the effect on the supply and demand curves are derived from published secondary sources such as 'Area and Production of Principle Crops in India' from the Directorate of Economics and Statistics (GOI, various years). Data on supply–demand and prices for fodder in India are not readily available owing to the large volume of transactions in the informal sector. However, an attempt has been made to capture the ultimate effect that the stay-green technology will have on the fodder availability. The details are presented in the following section.

The respondents also felt that if this research project had not been taken up by ICRISAT, the chance of an equivalent technology being developed elsewhere is virtually nonexistent.

3.3 Analytical Framework

3.3.1 Economic Surplus Model

Alston and Pardey (1998) suggested several approaches to evaluate agricultural technology. Despite criticism of the economic surplus approach (including measurement errors, general equilibrium effects, ignoring transaction costs, and externalities), its use is still justified when appropriate assumptions about impacts of research are made. The economic surplus model is also more advantageous than cost-benefit analysis and econometric models, since it does not assume either perfectly inelastic or perfectly elastic supply or demand. A number of projects that had similar outputs to the project under review also utilized this approach and came up with fairly robust results.[3]

Earlier studies have shown that increasing sorghum yields in the major growing countries would have large welfare effects. Nambuya et al. (2005) assessed the impact of two improved sorghum cultivars, Sekedo and Epurpur, in Uganda, and concluded that investment in sorghum

3. Napasintuwong and Traxler (2009) estimated that the only way that total economic surplus in the range of $650 million to $1.5 billion would be generated within the first 10 years of adoption of GM papaya would be if Thailand were to authorize the use of GM technology. These benefits would accrue primarily to small-scale papaya farmers and would accrue even with the loss of export markets. Paris et al. (2002) conducted a comprehensive analysis of various ACIAR-funded projects using the generalized unit cost reduction model to estimate the impact of ACIAR-supported projects in the Philippines, based on a preliminary evaluation by Bantilan (1992) that PRSV-resistant varieties could result in a 50% reduction in unit cost, based on a 350% increase in yield.

research yielded positive net present value (NPV) of Rs 87 million, and an internal rate of return (IRR) of 62.3%. Longmore et al. (2007) evaluated a project that aimed at developing a sorghum transformation system to enable the creation of post-rainy-season-sorghum strains resistant to common pests such as the stem borer and shoot fly. They discovered that the legacy from the capacity building will lead to substantial benefits and they also underscore the importance of measuring the capacity-building elements of a project, as failing to do so would lead to a serious underestimation of project benefits.

For the purposes of this study, the economic surplus model based on Mills and Karanja (1997), Mills (1998) and Alston et al. (1995) was adopted to calculate the economic returns (benefits) to research the improved post-rainy-sorghum cultivar. The analysis of costs and benefits of the new technology were carried out at two levels; firstly, at the grain market, where sorghum grain supplied by the farmers constitutes the supply, and the food demand for grain represents the demand, and, second, the stover market where the farm supplies of stover constitutes the primary supply, and demand from milk represents the derived demand for stover. The superior quality of stover of the post-rainy season as envisaged by the panel of experts is converted at a premium price based on the study by Blummel and Parthasarathy (2006), where they estimated a function $Y = -4.9 + 0.17x$, which sets the relationship between invitro digestibility and price of stover, where x is the digestibility in %, and Y is the price per kg of stover.

Stover being a bulky commodity is not traded internationally, and interstate trade within the country is also low. Trade in post-rainy-season-sorghum grain is also thin, and most of the harvest is consumed in the states where it is grown. Hence, a closed economic model that assumes relatively little international trade is deemed to be appropriate. This implies that increased production of either grain or stover would result in a decrease in the prices of the respective commodity.

The mechanics of the impact of the new technology is analyzed as follows. The adoption of cost reduction or yield-enhancing technology increases the supply of post-rainy-season-sorghum grain and stover due to the shift in the supply curve to the right of both the commodities. Since the demand for grain and stover is localized, the increase in supply could reduce the prices of the commodities to the consumer as well as the unit cost to the producers. The simple case of linear supply and demand curves with the parallel shifts was chosen as it was considered appropriate if the spillover effects can be captured by disaggregating the production process into homogenous stages [Davis (1994)][4]. Claessens et al. (2009) observed that spatially explicit integrated assessment models require highly detailed data that is rarely available, particularly for ex-ante assessments. In this study, the data on costs of production is not available since the crop is not yet on farmers' fields. Hence we rely on estimates derived from various sources from the literature.

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4. Davis (1994) in his paper investigated an important point raised by Lindner and Jarrett Rose in the discussion of alternative mathematical representations of the impact of research on supply functions. He averred that a better understanding of their points may provide improved appreciation of the impact of technologies, and if a linear, parallel shift assumption can be shown to be a reasonable approximation in many cases, then empirical applications will be simpler and therefore the risk of user error reduced. If disaggregation is adopted, the question of spillover impacts of research becomes important. It is observed that in most previous studies, since the aggregate, usually national, supply level has been used, the implicit assumption has been that the research is applicable to all production, either uniformly or on a proportionate basis, even when there is a significant diversity in production environments in that geographical region, may not be valid. He goes on to illustrate his concept diagrammatically, with the basic assumption that the supply curve is curved and derives a total-variable-cost curve used in estimating the benefits accruing to the producer. He concludes that if the research evaluation analysis was disaggregated to relatively homogeneous production situations, then a linear parallel supply shift would, in most cases, provide a good approximation of the research gains.

The impact of the research project is assessed based on the expected changes in the grain yield as well as fodder output. As a first step, the investment in research and the additional returns from sorghum grain and fodder are estimated. Post-rainy-season-sorghum area for the three states was projected using historical data for a period of 10 years and the area projections were arrived at. Then the adoption rates were assumed and projected to follow a sigmoid curve and the incremental area under the improved post-rainy-season sorghum was projected. The incremental gain was calculated using the historical growth rate in area and production. Incremental fodder output was derived, assuming a grain to fodder ratio of 2 tons of stover to 1 ton of grain.

The feedback from the scientists indicated that there would not be any changes in farm-level costs of production due to the improved technology, apart from a nominal increase in seed cost. For ease of calculations, this increase has not been factored in the analysis. For the purpose of the computations several parameters have been used which are detailed in Table 5. The model parameters for grain yield, grain and milk prices have been derived from the published statistics (GOI, various years), while demand and supply elasticities and grain to fodder yield ratio have been taken from relevant published literature.

Table 5. Summary of information used for the Consumer Surplus Model to assess gains to producers and consumers due to research.

	Scenario 1		Scenario 2		Scenario 3	
	Conservative		Optimistic		Likely	
Parameters used	Grain	Stover	Grain	Stover	Grain	Stover
Production Quantity Q_0 (million tons)	2.9	6.0	2.9	6.5	2.9	6.2
Annual Area Growth (%)	-1.64	-1.64	-1.64	-1.64	-1.64	-1.64
Current Yield (Tons/ha)	0.75	1.5	2	4	1	2
Price P_0 (Rs/ton)	9,000	3010	9,000	3350	9,000	3180
Increase in Yield (%) 'k'	0.013	0.084	0.187	0.50	0.10	0.25
Cost Reduction (%) 'z'	0.010	0.084	0.144	0.20	0.077	0.10
Supply Elasticity (ε)	0.50	0.20	0.50	0.20	0.50	0.20
Demand Elasticity (η)	-0.5	-0.3	-0.5	-0.3	-0.5	-0.3
Maximum Adoption Level (%)	7	7	15	15	10	10
R&D Lag to First Adoption (year)	10	10	10	10	10	10

3.3.2 The Distributional Impacts of Welfare Changes

For ease of understanding, the impact of a supply shift due to the new technology have been depicted in Figure 5, for the grain markets of post-rainy-season sorghum and Figure 6 for fodder markets of post-rainy-season sorghum. The presentation is for the Likely scenario only.

The shift in supply, denoted as 'k', for grain is estimated between 0.013 to 0.187, and for fodder between 0.084 and 0.50 (see Table 5). And 'z', the decrease in price parameter works out to 0.01 to 0.144 for grain, and 0.033 to 0.20 in case of fodder. This is because post-rainy-season-sorghum

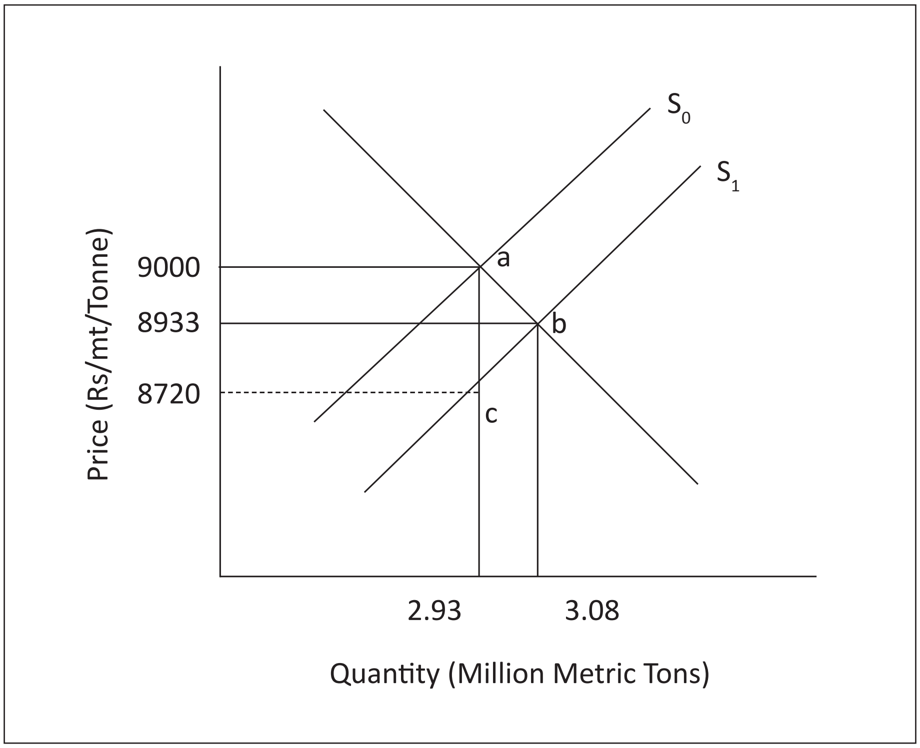

Figure 5. Schematic representations of the impact of sorghum stay-green technology on the producers and consumers of grain.

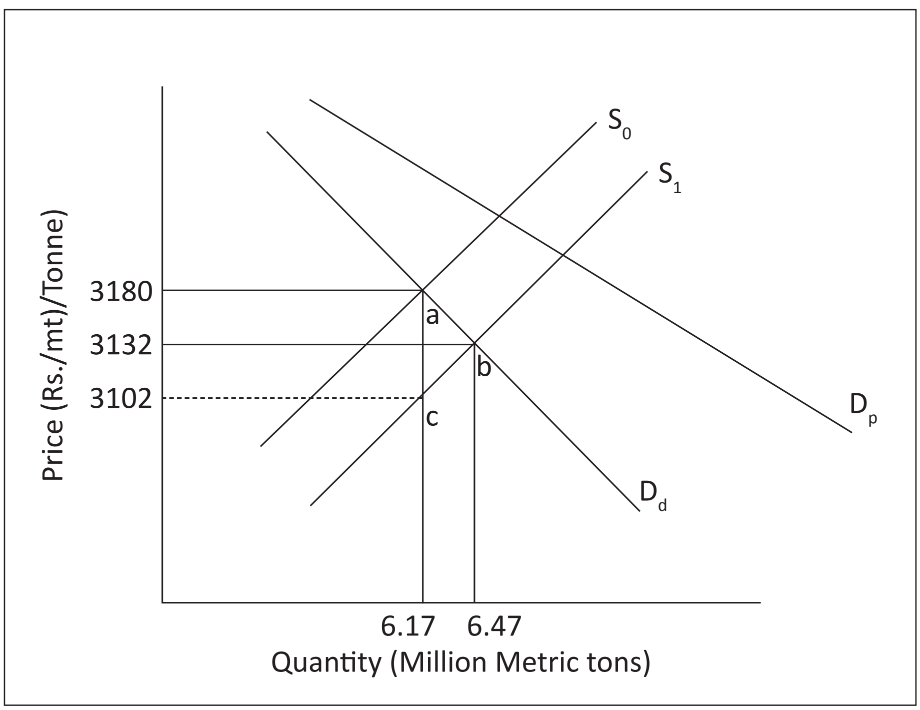

Figure 6. Schematic representation of the impact of sorghum stay-green technology on the producers and consumers of fodder.

grain and fodder follow a closed model, with very little possibility of cross-border trade. Further, Davis (1994) contends that if the research evaluation analysis was disaggregated to relatively homogeneous production situations, then a linear parallel supply shift would, in most cases, provide a good approximation of the research gains. Further, he contends that it is clearly important to understand the implications of different functional forms and shifts at an aggregate level, especially since some of this work will be important in fully understanding the impact of different types of technology. Besides, the analysis is being carried out with limited data, especially with respect to farm-level costs and returns, required to fit models to capture technology and the attendant cost functions. Most of the data used for this analysis is based on the perceptions of the panel of research scientists.

Figure 5 deciphers the likely impact of the change in the market parameters of grain. Currently, the price is around Rs 9,000 per metric ton of grain, which creates a demand of 2.93 million tons of grain. As a result of the new technology, the supply curve shifts from S_0 to S_1, leading to a decrease in the price to Rs 8,993/ton, and a corresponding increase in the quantity demanded to 3.08 million metric tons. The producer benefits from the decline in the cost of production, and the consumer from a decrease in the price of grain. Both the producer and the consumer gain from the technology.

In Figure 6, the supply shifts due to the new technology for fodder have been presented. It can be seen that the supply curve for stover shifts from S_0 to S_1 due to the technology, in the same manner as the supply shift of grain. However, the demand curve D_d for stover is the derived demand for stover at the farm-level, derived from a primary demand function for milk, D_p, at the retail. The elasticity of the derived demand curve of stover is usually less elastic than its primary counterpart. Mittal (2006) has estimated the price elasticity of demand for fluid milk for India to be -0.78. When a product like milk is sold through retailers, the demand for the raw material to produce the milk is the quantity of stover the producers purchase to convert it into the final product. The quantity of stover the milk producers purchase depends on the demand for milk and, consequently, its price. The demand for fodder is the 'derived demand', because it is 'derived' from demand for the final product milk.

It is well known that the elasticities of the derived demand facing manufacturers are generally not the same as the elasticities of the final demand estimated at the retail level [Hosken (2002)]. In general, the relationship depends on the form of the retail demand functions, the cost conditions of retailers and the nature of retailer competition. Since demand elasticity estimates for stover will not be available, it is derived from the demand elasticity for milk in the following manner.

Suppose that the final product in question is milk, which a farmer sells to retailers. Denote the retail price for milk as $P_{m,}$ and the price that milk producers pay for the stover is P_s. The elasticity, E_s, of the derived demand function for the fodder used in milk production can be calculated as:

$$E_s = E_m \times (Ps/Pm) \times E_{fm}$$

where E_s is the elasticity of the derived demand for stover facing the milk producer, E_m is the elasticity of final demand function facing the retailer, and E_{fm} is the elasticity of the farm price with respect to the retail sale price. In other words, it is the price transmission elasticity. In this study the elasticity of the derived demand for stover has been estimated as follows:

$$E_f = -0.78 \times 14/18 \times 0.5 = -0.30$$

The farm-gate price of milk is Rs 14 per liter, the retail price is Rs 18, and the price transmission elasticity from the retail to the farm-level demand for fodder is assumed to be 0.50. Thus, the elasticity of the derived demand for stover is -0.30.

The shift in supply curve, with a constant demand curve for stover, would result in the fodder output increasing from 6.17 million tons to 6.47 million tons, leading to a drop in prices for stover from Rs 3,180/ton to Rs 3,132/ton. This will result in an increase in the consumer surplus. Due to the drop in the cost of production and the larger quantity of supply, the producer is also benefited. These figures have been considered for the most likely scenario, and relate to the seventh year after adoption.

The changes in the producers' and consumers' gains and losses have been quantified for the entire study area, envisaged and presented in Table 6 and Figure 7 for the most likely scenarios under study. The gains from research from the new technology are based on the set of assumptions detailed earlier.

3.3.3 Sigmoid Adoption Rate

In studying adoption, analysts need to model the adoption of a new product for assessing the impact. There are several approaches, but a common one is the S-curve. A logistic function or logistic curve is a common sigmoid curve, formulated by Pierre François Verhulst who studied it in relation to population growth. It models the S-shaped curve (abbreviated to S-curve) of growth of some population P. The initial stage of growth is approximately exponential; then, as saturation begins, the growth slows, and, at maturity, growth stops.[5]

A simple logistic function may be defined by the formula:

$$P(t) = \frac{1}{1 + e^{-t}}$$

Where the variable P might be considered to denote a population and the variable t might be thought of as time [1]. For values of t in the range of real numbers from $-\infty$ to $+\infty$, the S-curve shown is obtained. In practice, due to the nature of the exponential function e^{-t}, it is sufficient to compute t over a small range of real numbers such as [−6, +6].

The computed adoption rates for the various scenarios, based on the abovementioned formula, are depicted diagrammatically in Figure 4. The rates of maximum adoption are based on the responses from the project scientists. The adoption is projected to grow to 7% in the conservative case, and 10% and 15% of the total area in the likely and optimistic cases, respectively, in the eighth year after the technology is released for commercial production

[5] http://en.wikipedia.org/wiki/Logistic_function

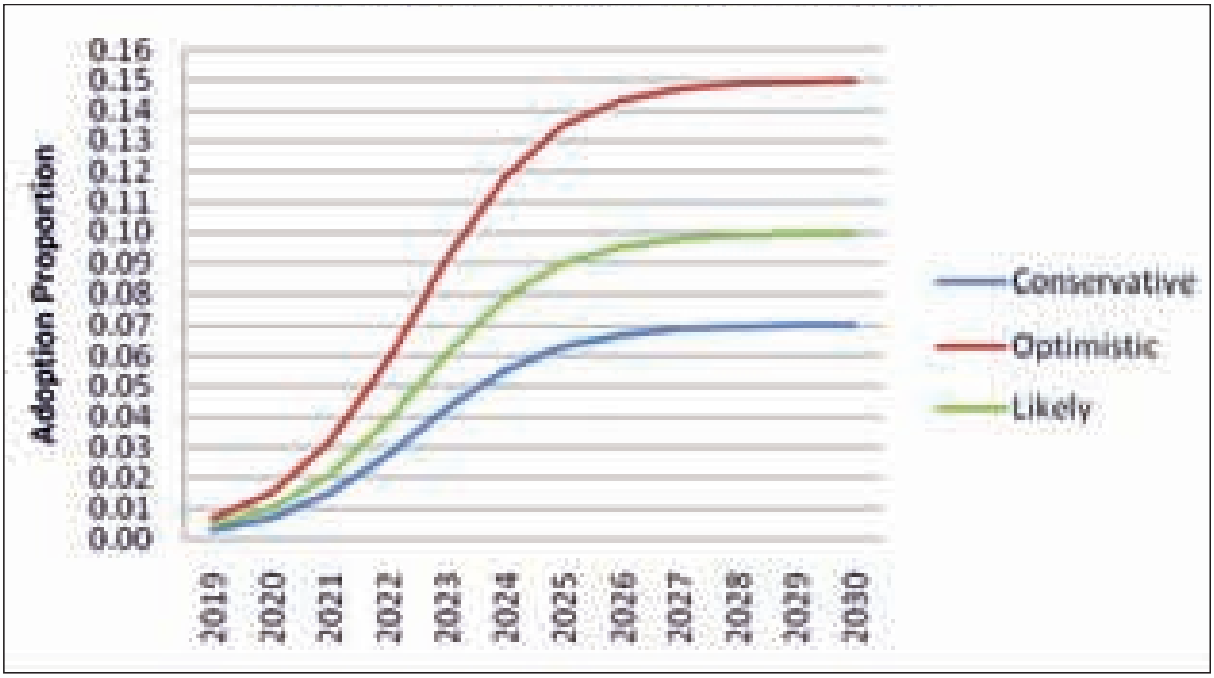

Figure 4. Sigmoid adoption of technology.

3.3.4 Capital Budgeting

In the capital-budgeting technique, research investment is considered for a period of 10 years. The annual research investments, together with the benefits that are likely to accrue to the producers annually, are computed. The benefits are primarily through adoption of the improved stay-green variety, which is assumed to follow a sigmoidal adoption curve. The benefits from the sale of grain are computed at market rates. The benefits from the use of fodder has been computed by first calculating the incremental fodder availability, considering the higher fodder yield obtainable from the new variety, from the projected area. An extension cost of Rs 2 million per annum has been included in the cost for the first three years after release, which is then reduced to Rs 1 million per year for the next three years. The extension work is assumed to start at the end of the second phase of the project and continue for six years. A discount rate of 10% has been assumed.

Based on the procedure detailed above, the cash flow for each year was obtained. The measures of capital budgeting, viz., IRR, Benefit Cost ratio (BC Ratio) and the NPV were computed. The IRR is a measure of the rate of return to investment in a project. The NPV is the present value of the inflows minus the outflows, accomplished by discounting them at the cost of capital.

4. Results and Discussion

4.1. The Distributional Impact of Welfare Changes

In the most likely scenario, most of the gains of the new technology, with regard to the grain, will accrue to the consumer. Measured in terms of NPV, the consumer surplus is of the order of Rs 657 million. The benefit to the producer is of the order of Rs 200 million. On the other hand, with regard to stover production, the producers' surplus is of the order of Rs 950 million, and the consumer appropriates about Rs 630 million. Overall, the value of benefit from the stay-green post-rainy-season-sorghum technology is valued at around Rs 2,440 million, shared in the proportion of 1.85:1 between the producer and consumer, spread over a useful life of 12 years after release. Also, the welfare gains of stover are far greater than the benefits accruing to grain.

These results go to show that the stay-green technology of post-rainy-season sorghum is oriented to the farmer and, to a lesser extent, the consumer, and the benefits from research far outweigh the cost. The overall benefits would be much higher if we consider the indirect benefits that accrue to downstream users like dairy farmers and the superior quality of the grain which is likely to fetch a premium price.

Table 6. Gains to producer and consumers due to the sorghum stay-green variety – Likely scenario (Rs Million).

	Grain			Stover			Total		
Year	ΔPS	ΔCS	ΔTS	ΔPS	ΔCS	ΔTS	Grain	Stover	Total
2019	4.97	16.55	21.52	23.95	15.96	39.91	21.517	39.913	61.430
2020	11.20	37.33	48.54	54.06	36.00	90.06	48.538	90.059	138.597
2021	20.83	69.40	90.23	100.57	66.90	167.47	90.228	167.470	257.698
2022	30.44	101.47	131.91	147.14	97.78	244.92	131.909	244.915	376.824
2023	36.67	122.24	158.91	177.33	117.77	295.11	158.907	295.106	454.013
2024	39.65	132.18	171.83	191.80	127.34	319.14	171.832	319.143	490.975
2025	40.87	136.25	177.12	197.72	131.25	328.97	177.116	328.972	506.088
2026	41.33	137.80	179.13	199.97	132.74	332.71	179.126	332.710	511.836
2027	41.50	138.36	179.86	200.79	133.28	334.08	179.860	334.075	513.935
2028	41.56	138.56	180.11	201.08	133.47	334.55	180.114	334.548	514.662
2029	41.57	138.62	180.19	201.16	133.53	334.69	180.190	334.690	514.880
2030	41.58	138.62	180.20	201.17	133.54	334.71	180.201	334.710	514.910
NPV	197.06	656.91	853.98	952.92	632.92	1,585.85	853.97	1,585.85	2,439.82

4.2. Return to Investment in Research

The project generates benefits that comfortably exceed the research costs that are associated with the project in all three scenarios. The measure of project worth is summarized in Table 7.

The return to investment in research was computed using the measures of project worth, viz., NPV, BC Ratio, and IRR. The IRR ranged from 20% per annum to 56% per annum in the Conservative and most optimistic scenarios, respectively, which are considered high for any project. The BC Ratio and the NPV were all well above the threshold values, thus indicating the economic viability of the research

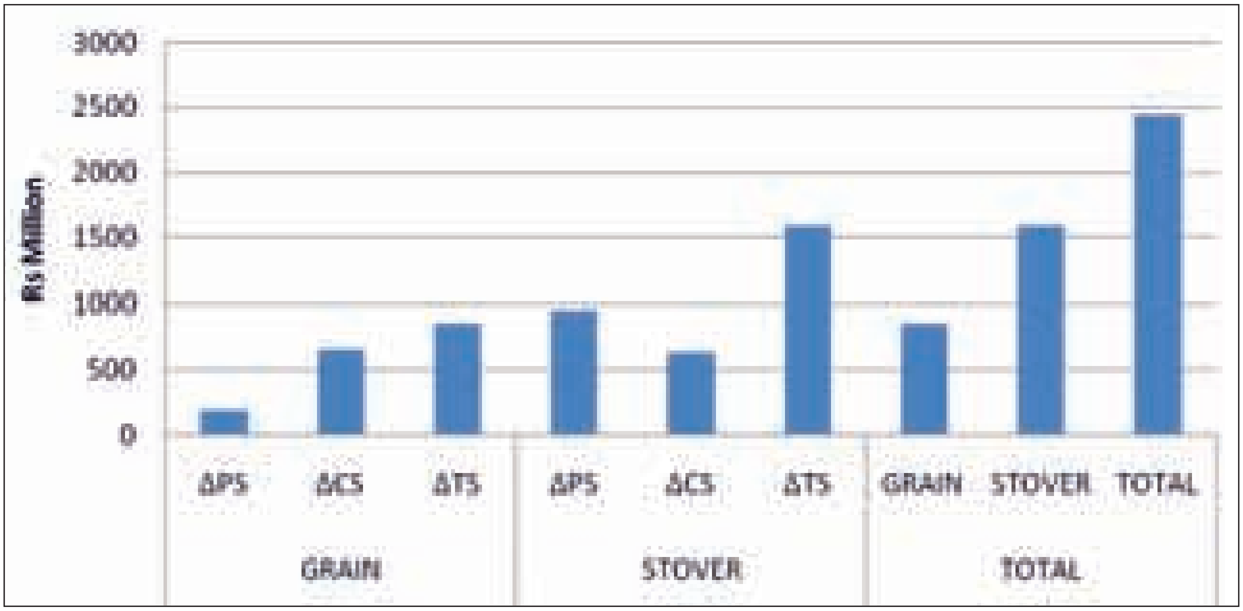

Figure 7. Cumulative present value of benefits accruing to producers and consumers of stay-green post-rainy season-sorghum in India – Likely scenario.

investment. The details of the cash inflow and outflow used in the calculations in each scenario are presented in Appendix I. The total investment in research and the extension of Rs 99.12 million, spread over 10 years, will yield a benefit ranging from Rs 98.43 million to Rs 3,032 million. On an average, the net benefit will be Rs 883.20 million, which translates into a return to investment of 40% per annum, and yielded a return per rupee of investment of the order of 16.37 (BC Ratio). The high rates of return to research investment are due to the widespread adoption of the technology over 0.28 to 0.69 million ha, and the dual benefit of the incremental grain and fodder yield. The payback period for the research investment to be recovered is one to four years, and for the most likely scenario it is about two years.

Table 7. Return to research investment in stay-green sorghum.

	Scenario 1 Conservative	Scenario 2 Optimistic	Scenario 3 Likely
IRR (%)	20	56	40
BC Ratio	7.04	53.77	16.37
NPV of net benefits (Rs million)	98.43	3,032.14	883.20
Payback period after release	4 years	1 Year 6 months	2 Years

The measures of project worth are positive and vindicate the economic viability of the project evidenced by the positive NPV, the high BC Ratio and the IRRs under all the scenarios. Even the Conservative scenario produces a BC Ratio of 7.04, and an NPV of Rs 98.43 million.

The three scenarios projected are the Conservative scenario, the Optimistic scenario and the Likely scenario. The discounted cash flows are depicted in Figure 8.

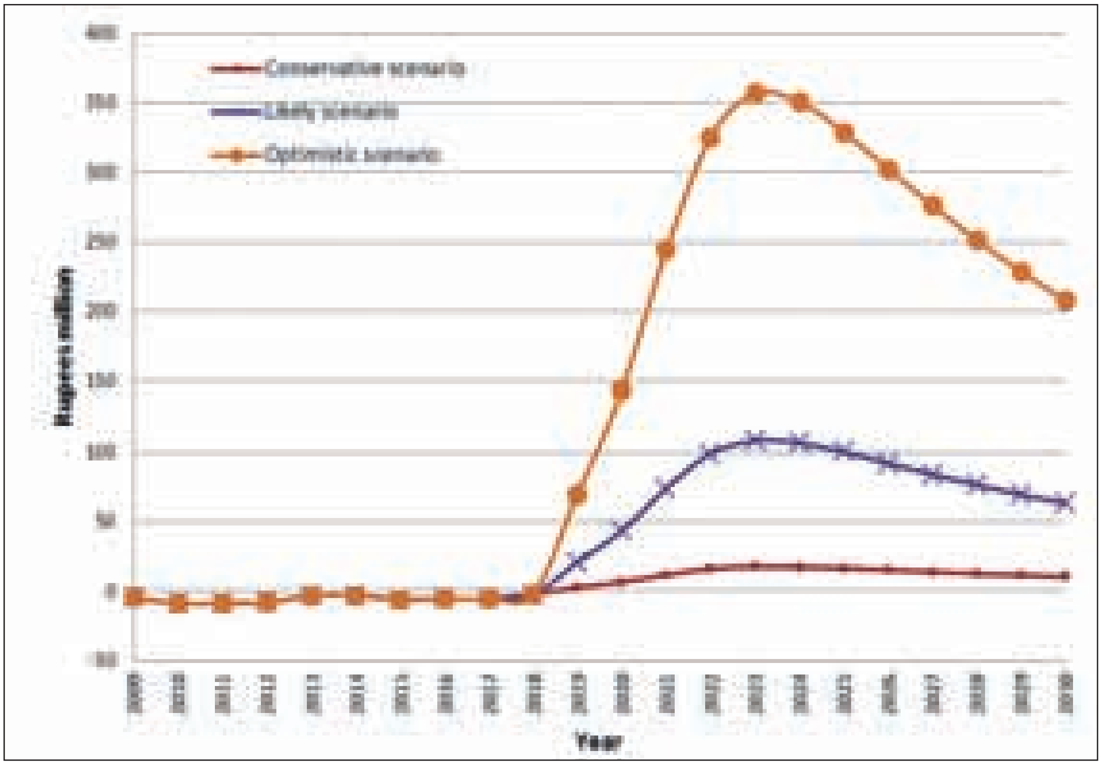

Figure 8. Discounted cash flows under all scenarios.

5. Conclusion

An important output in the ACIAR-funded project entitled ‘Improving post-rainy-season-sorghum varieties to enhance their competitiveness in the farming system to meet the grain and fodder demand in India’, was conducting an ex-ante assessment of the stay-green technology. This report shows that the technology has immense economic potential in both the grain and the stover markets, for sorghum, and, indirectly, in the milk market as well. Even in the most pessimistic scenario with relatively low adoption rates in the target regions and low increases in yields, the economic benefits of the project are Rs 98.43 million, with an IRR of 20% and a BC Ratio of 7.04. The benefits in the most likely scenario with middle-of-the-road yield and adoption parameters are considerably higher at Rs 883.20 million (with an IRR of 40% and a BC Ratio of 16.37. The project has a very short payback period of about two years after it is released for commercial cultivation.

The results of the consumer surplus model reveal that this technology benefits the farmer more than the consumer. The potential benefits amounts to Rs 2,440 million for the entire duration of the project. Of this benefit, Rs 1,586 million is likely to be appropriated by the producer, and the balance of Rs 854 million will go to the consumer.

Non-adoption can be for many reasons. But, two important ones are, firstly, the technology may not be applicable to their production conditions; and, secondly, even if it is applicable, they may still not adopt it for a variety of reasons. The benefit foregone by the group of non-adopters, which could be as high as 93% in some cases, would amount to an opportunity cost which is 7 to 15 times the benefits considered so far. This is a huge amount, and since the post-rainy-season sorghum is grown by poor farmers, the distributive impact of non-adoption would be enormous. With a parallel supply shift, adopters who receive the maximum unit cost reduction from the research will never lose – in most cases, they will receive large welfare gains. On the other hand, non-adopters will always lose – except in the very unlikely, special case when the price does not change, ie, if demand is perfectly elastic. In fact, the larger the gains to consumers – in the aggregated analysis – the larger will be the losses to non-adopters.

As it exists, this particular project provides a proof of concept for marker-assisted introgression of stay-green QTL that increase the water-use efficiency of the plant; additionally, its economic viability is a distinct possibility, with the probability of its development put decisively at 0.65.

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Appendixes

APPENDIX I: Cash Flow of Net Benefits Under Different Scenarios

SCENARIO 1: Benefits from investments made in Research – Conservative

(in million Rs.)

Year	Research Investment & Extension Cost	Grain Value	Stover value	Total Benefit	Cash Flow
2009	5.49				-5
2010	10.67				-11
2011	11.30				-11
2012	12.06				-12
2013	4.94				-5
2014	5.49				-5
2015	11.07				-11
2016	11.70				-12
2017	12.46				-12
2018	5.34				-5
2019	2.00	2	8.28	10	8
2020	2.00	4	18.68	23	21
2021	2.00	8	34.73	43	41
2022	1.00	12	50.77	62	61
2023	1.00	14	61.16	75	74
2024	1.00	15	66.14	81	80
2025		16	68.17	84	84
2026		16	68.95	85	85
2027		16	69.23	85	85
2028		16	69.33	85	85
2029		16	69.36	85	85
2030		16	69.36	85	85

Note: Direct Benefit returns from gain yield; Indirect Benefits returns from dairy

IRR	20%
BC Ratio	7.04
NPV of Net Benefits (Rs million)	98.43

SCENARIO 2: Benefits from investments made in Research – Optimistic

(in million Rs)

Year	Research Investment & Extension Cost	Grain Value	Stover Value	Total Benefit	Cash Flow
2009	5.49				-5.09
2010	11.07				-10.67
2011	11.70				-11.30
2012	12.46				-12.06
2013	5.34				-4.94
2014	5.49				-5.49
2015	11.07				-11.07
2016	11.70				-11.70
2017	12.46				-12.46
2018	5.34				-5.34
2019	2.00	62.730	138.494	201.225	199.22
2020	2.00	141.605	312.646	454.251	452.25
2021	2.00	263.500	581.818	845.318	843.32
2022	1.00	385.612	851.512	1237.125	1236.12
2023	1.00	464.839	1026.512	1491.351	1490.35
2024	1.00	502.806	1110.381	1613.187	1612.19
2025		518.336	1144.686	1663.021	1663.02
2026		524.243	1157.736	1681.980	1681.98
2027		526.400	1162.501	1688.901	1688.90
2028		527.147	1164.152	1691.299	1691.30
2029		527.372	1164.648	1692.019	1692.02
2030		527.403	1164.718	1692.121	1692.12

Note: Direct Benefit returns from gain yield; Indirect Benefits returns from dairy

IRR	56%
Ratio BC	53.77
NPV of Net Benefits (Rs Million)	3032.14

SCENARIO 3: Benefits from investments made in Research – Likely

(in million Rs.)

Year	Research Investment and Extension Cost	Grain Value	Stover Value	Total Benefit	Cash Flow
2009	5.49				-5.09
2010	11.07				-10.67
2011	11.70				-11.30
2012	12.46				-12.06
2013	5.34				-4.94
2014	5.49				-5.49
2015	11.07				-11.07
2016	11.70				-11.70
2017	12.46				-12.46
2018	5.34				-5.34
2019	2.00	21.517	39.913	61.430	59.43
2020	2.00	48.538	90.059	138.597	136.60
2021	2.00	90.228	167.470	257.698	255.70
2022	1.00	131.909	244.915	376.824	375.82
2023	1.00	158.907	295.106	454.013	453.01
2024	1.00	171.832	319.143	490.975	489.98
2025		177.116	328.972	506.088	506.09
2026		179.126	332.710	511.836	511.84
2027		179.860	334.075	513.935	513.93
2028		180.114	334.548	514.662	514.66
2029		180.190	334.690	514.880	514.88
2030		180.201	334.710	514.910	514.91

Note: Direct Benefit returns from gain yield; Indirect Benefits returns from dairy

IRR	40%
BC Ratio	16.37
NPV of Net Benefits (Rs Million)	883.20

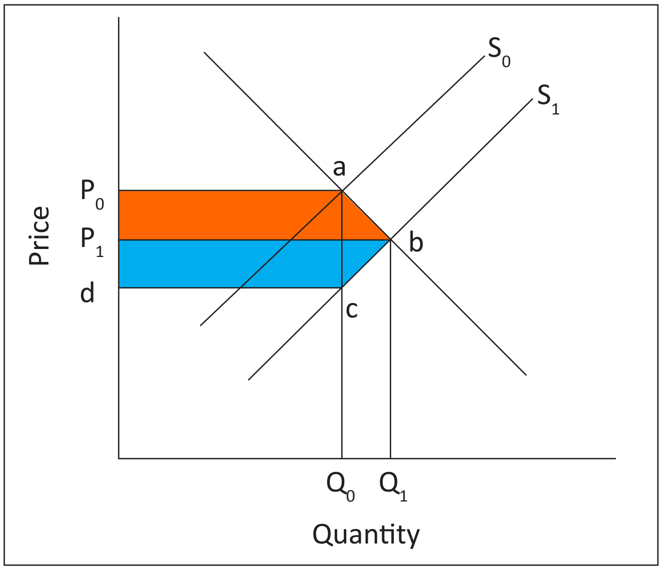
APPENDIX II: Economic Surplus Model and Review of Literature

Appendix Figure 1 illustrates the closed-economy model, assuming that the new stay-green post-rainy-season sorghum will only affect the domestic market since sorghum is not an export commodity from India. The adoption of stay-green post-rainy-season sorghum will shift the supply curve downward from S_0 to S_1; whereas, the demand curve of sorghum remains unchanged. The price of sorghum will drop from P_0 to P_1. As a result, consumer surplus increases, equal to the area P_0abP_1; the change in producer surplus is equal to the area P_1bcd; and total surplus increases to the area P_0abcd.

The consumers of the primary product or the derived product are benefited due to the fall in the prices. Similarly, producers are benefited by the increase in the supply of the product. The algebraic derivation of the total change is shown below.

Initial Price/ton	P_0
Initial Quantity	Q_0
Changed Price/ton	P_1
Changed Quantity	Q_1
Price elasticity of supply	ε
Price elasticity of demand	η
Change in total surplus	$\Delta TS_t = \Delta CS + \Delta PS = P_0Q_0 K_t (1 + 0.5Z_t\eta)$
Change in producer's surplus	$\Delta PS_t = P_0Q_0 (K_t - Z_t)(1 + 0.5Z_t\eta)$
Change in consumer's surplus	$\Delta CS_t = P_0Q_0 Z_t (1 + 0.5Z_t\eta)$

where ΔCS_t is the change in consumer surplus in year t; Z_t is the reduction in price, relative to the price prior to new post-rainy-season-sorghum adoption in year t; and η is the absolute value of the demand elasticity. In this framework, the impacts are assumed to accrue for 12 years after first adoption, which takes place in Year 11 of the project.



Appendix Figure 1. Consumer Surplus Model.

The total value of output was aggregated as mentioned above from the forecasted production from the 11th year of the project to the 22nd year of the project. The total span of the project is 22 years, comprising 10 years of development, and 12 years of useful life. Based on these assumptions the returns and cost streams were computed for the three scenarios outlined in the methodology.

The NPV is calculated from the annual surplus as follows:

a) NPV = NPV = $\Delta TS_t / (1 + r)^t$, where r is the discount factor.

b) Benefit Cost Ratio = BC Ratio = $\{\Delta TS_t / (1 + r)^t\} / \{\text{Research \& Extension Cost} / (1 + r)^t\}$

c) IRR = IRR = r = $\Delta TS_t / (1 + r)^t = 0$

Relevant Studies

Boughton and Frahan (1994) used the economic-surplus approach, which estimates returns to investment by measuring the change in consumer and producer surplus arising from a parallel shift to the right in the supply curve due to technological change. In practice, this approach, they opined, can be implemented using a benefit-cost analysis, as commonly used by international organizations such as the World Bank or UNIDO. Put simply, benefit-cost analysis of a research and extension program compares the time-valued estimate of the net returns from the innovations generated and transferred by the research and extension program as farmers adopt them, with the time-valued costs of the research and extension program. Similar to the economic-surplus approach, it estimates an average rate of return to agricultural research and extension (in contrast to the production-function approach, which provides a marginal rate of return by using econometric techniques).

They used the economic-surplus approach, and estimate the IRR to investment in the maize research and extension program, which is estimated at 135%. The incremental net earnings of the program are estimated at CFAF 9,153 million (US$ 37 million). The research and extension program benefits and costs are estimated over a 21-year period, from 1969–90. All benefits and costs are expressed in 1989’s constant prices. Because it would be difficult to separate the benefits of research from those of extension, returns are estimated jointly for the research and extension investments.

The principal direct benefits of the maize research and extension program are the increased production it has generated and the increased food security for producers and consumers. The direct costs of the program include three components: (1) all the personnel operating expenditures and equipment devoted to maize research in Mali from 1969–90; (2) all the extension expenditures associated with maize technology transfer in the CMDT and OHV areas since 1975; and (3) all incremental costs incurred at farm level in order to adopt the new maize technology. The spillover effects of research undertaken in Mali to other areas of Mali and neighboring countries, as well as any costs of maize research undertaken in other countries or in international research centers, are not accounted for in the economic evaluation.

Paris, Carambas, McMeniman, and Lubulwa (2002) used the generalized unit cost reduction model to estimate the impact of ACIAR-supported projects in the Philippines, based on a preliminary evaluation by Bantilan (1992) that PRSV-resistant varieties could result in a 50% reduction in unit cost, based on a 350% increase in yield. By assuming a maximum adoption rate of 100% and nine-year research lags, they found that PRSV-resistant hybrids could result in savings of AUD $3.46 million in the base case (50% cost reduction), and increase to economic benefits of AUD $4.35 million, if 75% cost reduction is assumed. If 25% cost reduction is assumed, the savings decrease to AUD $1.71 million.

About **ICRISAT**

International Crops Research Institute for the Semi-Arid Tropics

ICRISAT is a member of the CGIAR Consortium

The **International Crops Research Institute for the Semi-Arid Tropics** (ICRISAT) is a non-profit, non-political organization that conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropics have over 2 billion people, of whom 644 million are the poorest of the poor. ICRISAT innovations help the dryland poor move from poverty to prosperity by harnessing markets while managing risks – a strategy called Inclusive Market-Oriented Development (IMOD).

ICRISAT is headquartered in Patancheru, Telangana, India, with two regional hubs and five country offices in sub-Saharan Africa. It is a member of the CGIAR Consortium. CGIAR is a global research partnership for a food secure future.

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579-2013