11 Assessing Economic and Environmental Impacts of NRM Technologies: An Empirical Application Using the Economic Surplus Approach

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Introduction

This chapter addresses methodological and empirical complexities in assessing the impact of crop and resource management research through a concrete case study. It develops an applied economic surplus analysis of welfare gains, using farm survey data to measure farmer benefits from increased yields, reduced unit costs, and higher income. The environmental aspects of natural resource management (NRM) research impacts present special challenges in measurement across time and space. Farmers' perceptions of long-term environmental changes are highlighted as a means to augment or substitute for narrower quantitative indicators.

The case of groundnut production technology (GNPT) in central India illustrates the methodological and empirical issues in estimating research payoffs to NRM research investments. The GNPT was developed for the semi-arid tropics (SAT), a region usually characterised by water scarcity, low soil fertility and land degradation. Impact analysis of GNPT presents estimated costs and benefits using the principle of economic surplus and complements this with a detailed account of both quantitative and qualitative information provided by scientists and experts, including farmers.

Groundnut production technology (GNPT)

The research and development team that developed the GNPT package aimed to raise groundnut production by generating research information on various groundnut crop production components and integrating them into a ‘package’ of technology options. The technology package that was developed in 1986 integrates crop and resource management options detailed in Table 11.1. These components can be divided into five broad categories: land, nutrient, water, insect and pest management, and improved varieties.

Table 11.1. Technology components of the groundnut production technology (GNPT).

Component		Improved package (GNPT)	Local practice
C1	Land management Seedbed	Raised bed and furrow (RBF)	Flat
C2	Nutrient management		
	Farmyard manure	5–12 t/ha	10 t/ha
	Ammonium sulphate	100 kg/ha	Diammonium phosphate: 100 kg/ha
	Single superphosphate	300–400 kg/ha	Murate of potash: 100 kg/ha
	Zinc sulphate	10–20 kg/ha every 3 years	20 kg/ha every year
	Ferrous sulphate	2–3 kg/ha	–
	Gypsum	400 kg/ha	200 kg/ha
C3	Water management	Furrow or sprinkler to improve efficiency of water use	Flood
C4	Disease and pest management (effective control of insects, diseases and weeds, seed dressing/treatment)	Bavistin, dimethoate, monocrotophos	Need based
	Seed dressing	Thiram, Bavistin or Dithane M 45	Thiram
C5	Seed		
	Improved variety	ICRISAT varieties	Local varieties
	Seeding rate	125–150 kg/ha	120–125 kg/ha

During 1987–1991, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), through its Legumes On-Farm Testing and Nursery (LEGOFTEN) Unit, was an active partner with the Indian Ministry of Agriculture and other agencies in identifying and demonstrating appropriate technology options for increased groundnut production. The team reviewed all available and relevant research information and carefully identified production constraints in the major oilseed-producing regions of India. This package was thoroughly discussed with the national agricultural research service (NARS) and State Departments of Agriculture. This collaboration in a technology exchange programme provided ICRISAT with an opportunity to confirm the suitability and viability of the GNPT concept in farmers’ fields. Although some components of the package (i.e. improved varieties, fertilisers, seed dressing) were already being used by farmers, ICRISAT’s value addition took the form of information on appropriate timing and dosage rates of inputs.

The two new essential innovations introduced were land and water management. The land management component of the GNPT entails preparation of raised-beds and furrows (RBF) for groundnut production (Fig. 11.1). Compared to the practice of traditional farmers, who used 1–2 harrowings to sow groundnut on flat land, the RBF technologies were designed to reduce soil erosion, provide surface drainage, concentrate organic matter and fertiliser application, and reduce soil compaction around plants. Over a period of time, the concept of RBF was modified to suit the requirements of the farmers into a narrow-bed and furrow configuration, i.e. a bed of 75 cm, with ridge and furrow systems. The water management component was introduced to improve water use efficiency through furrow and sprinkler irrigation.

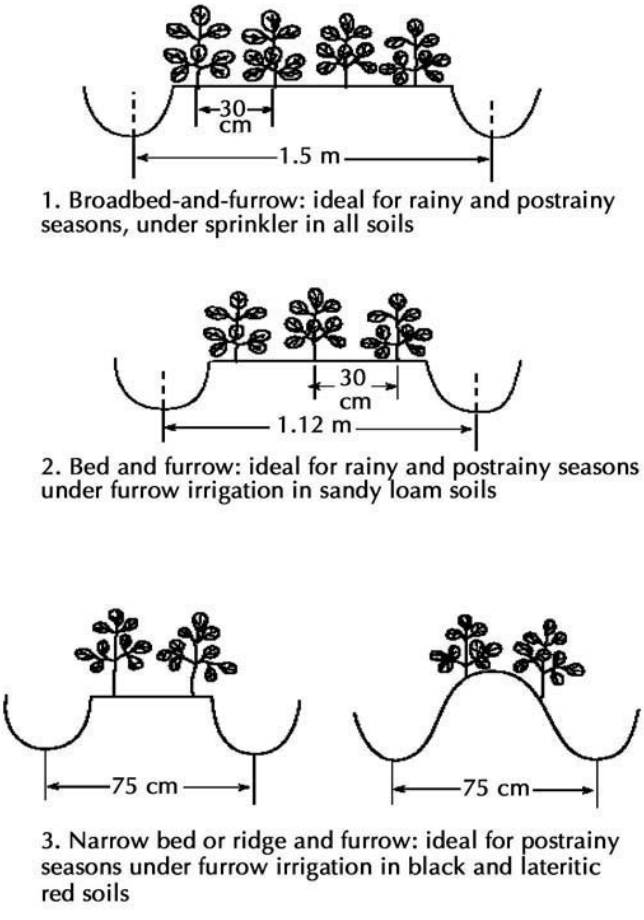

Fig. 11.1. The raised-bed and furrow (RBF) method of groundnut cultivation.

Groundnut Production and Markets in India: Background

India is the world's second largest producer of groundnut after China. Groundnut is one of the most important food and income-generating oilseed cash crops for smallholder farmers in semi-arid India. About 80% of the groundnut crop is rainfed, and is grown in southern, western, and parts of central India during the southwest monsoon. The remaining 20% is irrigated. Groundnut is mostly cultivated in red sandy soils (Alfisols) in many states, but it is also grown in shallow to medium-deep black soils in some parts of the country.

Groundnut yields in India vary widely depending on the production system (Freeman *et al.,* 1999). Rainfed groundnut yields roughly 0.9 t/ha, while the irrigated crop yields about 1.6 t/ha. Important improved groundnut cultivars include TMV 2, SB 11, CG 2, JL 24 and J 11, although these have never completely replaced the local cultivars. After the introduction of GNPT by LEGOFTEN, the area under groundnut production in India increased from 6.84 million ha in 1987/88 to 8.67 million ha in 1991/92 and groundnut production increased from 5.88 million t in 1987/88 to 7.07 million t in 1991/92. Rainy-season groundnut yields increased from 700–1000 kg/ha to 1.5 t/ha; postrainy season-yields rose from 2 to 4 t/ha, and summer yields rose from 1 to 3 t/ha after the introduction of GNPT.

Groundnut demand increases were driven by population growth, although the increase was moderated by rising prices. About 80% of Indian groundnuts are crushed for oil, and groundnut remains the vegetable oil of preference; but its share in the vegetable oil market is declining as consumers shift to such cheaper alternatives as rapeseed, sunflower, and imported palm oil. Large quantities of the groundnut meal produced in India are traded. Groundnut oil is thinly traded because in India substantial quantities of the oil produced are domestically consumed.

Methods for Research Evaluation

The unique empirical challenges of NRM impact assessment include both problems of measurement, and the attribution of research impacts. An impact analysis begins by measuring research benefits. Information on the actual cost of research and development (R&D) and technology transfer is combined with the stream of benefits based on the rate of technology uptake or levels of adoption. The approach quantifies those impacts that were amenable to quantification, while systematic documentation describes those that were difficult to quantify. For a five-component package like GNPT, the research evaluation includes measurement of the stepwise adoption of various technology options, estimates of on-farm benefits, and the relative significance of specific components among quantifiable variables. For the non-quantifiable impacts, researchers and farmers are important sources of detailed descriptions that may serve as a basis for evaluating as many effects as possible, or qualitatively understanding associated research impacts.

Research impacts documentation

The practical measurement of research impacts necessarily involves tracking and understanding the process based on detailed description by both researchers and research beneficiaries. In the absence of hard facts or documented data, detailed descriptions are an important way to understand the basis for estimates of costs and benefits associated with economic and environmental effects.

Because post-project long-term monitoring of GNPT was not undertaken, a systematic process of documentation was crucial for the evaluation process in order to carefully delineate various types of impacts: market and non-market, on-site and off-site, as well as intra- and inter-temporal effects. The implications of these aspects for impact assessment also require the analysis of counterfactuals for non-market effects. Additionally, the complexity of estimating impacts considering economic vs. environmental effects is recognised when some effects are already reflected in yield gains, but some environmental effects are non-quantifiable and do not relate to markets.

Data

Information was collected through farm interview surveys using a structured questionnaire, focus group meetings and participatory rapid rural appraisals, together with interviews with researchers on technical aspects of GNPT. Data on the following aspects were collected from farmers for the 1994/95 crop season:

1. Size of holding, total sown area, irrigated and non-irrigated areas
2. Land use and cropping pattern
3. Cost of groundnut production
4. Input and output data
5. Crop yields and prices
6. Farmer perceptions of sustainability issues and the constraints to adoption of GNPT.

Information on adoption trajectories for different technology options was collected, including:

1. Total groundnut area
2. First year of adoption of different GNPT components
3. Extent of adoption of different GNPT components in the first year
4. Extent of adoption during the period 1992–1994
5. Modification in technology components, if any.

District-level data for area and production were compiled from the Maharashtra State Department of Agriculture records, and disaggregated data below the district level were obtained from the Office of the Agricultural Development Officer (ADO) in each district. Rates of adoption obtained from the survey were also crosschecked with the ADO. Price data were re-collected from seed dealers and several traders dealing with the GNPT components. Estimates of elasticities used earlier estimates by Murty (1997), Radhakrishna and Ravi (1990) and ACIAR (1992), and were validated using expert opinion.

The sample

Multi-stage stratified random sampling (using size of holding and intensity of groundnut cultivation as the basis for stratification) was used to select a representative group of groundnut farmers in order to assess the adoption and impact of different GNPT components. The technology was originally targeted at eight states in the Indian SAT: Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, and Uttar Pradesh. However, only in Maharashtra did government and non-government agencies follow up with the dissemination of technologies, and the State Ministry of Agriculture recommended the full GNPT package. Since the objective was to assess the adoption and evaluate the impact of the package, the evaluation of its impact therefore focused on Maharashtra.

The first and second stages of sampling involved stratification by the intensity of groundnut cultivation, while the last stage was stratified by size of holding. In the first stage of sampling, all districts growing groundnut were stratified into high and low intensity categories by the total area sown to groundnut. Two districts each from the top 50% and lower 50% intensity groups were selected at random. In the second stage of sampling, each selected district was stratified into three groups of *talukas* (sub-districts) by tercile of area sown to groundnut (high, medium, or low). Similarly, villages in each *taluka* were subdivided into three strata, also by tercile of groundnut sown area (details in Joshi and Bantilan, 1998). In the last stage of sampling, farm households were grouped into large (>4 ha), medium (1–4 ha) and small (<1 ha) categories according to size of farm holding. The final sampling units were identified through random selection of farmers in randomly selected villages in selected *talukas*. The final sample included 355 farm households.

Estimating the adoption pathway

Many crop and resource management technology packages that include several components are adopted component by component in step-wise patterns (Byerlee and Hesse de Polanco, 1986; Traxler and Byerlee, 1992). Establishing an accurate picture of adoption patterns among groundnut farmers can be complex. The five components of the GNPT package can be combined into ten pairs, ten triples, five quadruples, and one set of all five (Table 11.2). The adoption pattern can be established from the survey data by analysing farmers' responses when asked whether they practised different GNPT components. If the answer was yes, the farmer was asked to recall the first year of adoption for different components. Two additional questions were useful: 1. the extent of adoption of different GNPT components in the first year; and 2. the extent of adoption during the last 3 years ending in 1994. Several components of the technology package were already known and had been adopted even before the introduction of the package, and farmers were free to choose and adopt any of its subsets. Hence, adoption sequences were evaluated by tracking discrete subsets of options available to the farmer, for example, all subsets that included at least the land management option (shown as shaded components in Table 11.2). A systematic approach to tracking multiple technology adoption entailed measuring all subsets of technology components that included: 1. at least one option (say, land management); 2. two specific options (say, improved variety and land management); and 3. all options (full adoption).

Table 11.2. All possible combinations of the five components[a] of the groundnut production technology (GNPT) package.

One component adopted	Two components adopted	Three components adopted	Four components adopted	All components adopted
C1	C1C2	C1C2C3	C1C2C3C4	C1C2C3C4C5
C2	C1C3	C1C2C4	C1C2C3C5	
C3	C1C4	C2C3C4	C1C2C4C5	
C4	C3C4	C1C3C4	C2C3C4C5	
C5	C2C3	C1C3C5	C1C3C4C5	
	C2C4	C1C4C5		
	C2C5	C1C2C5		
	C1C5	C2C3C5		
	C3C5	C2C4C5		
	C4C5	C3C4C5		

[a]See Table 11.1 for a description of the components.

Farm survey data also served to estimate and project the adoption patterns of different GNPT components over time. By fitting a logistic function to data on the first year of adoption and data for the period 1989–95, the proportion of farmers affected by GNPT could be projected. The logistic function is defined as:

$$A_{it} = \frac{C_i}{(1 + e^{-(a+bt)})} \tag{1}$$

where A_{it} is the percentage adoption of the i^{th} component of the GNPT in the t^{th} year; C_i is the adoption ceiling of the i^{th} component; b is the rate of adoption; and a is the constant intercept term.

Research benefits and costs

Estimation of market benefits

Underlying the empirical application of the measurement of GNPT impacts is the principle of economic surplus, described in detail in Alston *et al.* (1995) and Swinton (Chapter 7, this volume). This principle is based on the idea that improved technologies enhance productivity or reduce the groundnut producers' unit cost of production, which translates into an outward shift in the producer's supply curve. Considering the conventional, comparative-static, partial equilibrium, closed economy model of supply and demand in the groundnut commodity market, and assuming simple linear demand and supply equations, a parallel supply shift (*k*) may be expected to occur due to a measurable reduction in unit cost of production when farmers adopt the GNPT technology package. As a point of reference, Fig. 11.2 shows the supply shift from S_0 (without GNPT) to S_1 due to measured unit cost reduction (*ae*) with the adoption of GNPT. For each cropping season, the change in the groundnut consumer surplus (ΔCS) and producer surplus (ΔPS) can be calculated using the formulae

$$\Delta CS = P_0\, Q_0\, Z\, (1 + \tfrac{1}{2}\, Z\, \eta) \qquad (2)$$

$$\Delta PS = (J - Z)\, P_0 Q_0 (1 + \tfrac{1}{2}\, Z\, \eta) \qquad (3)$$

where P_0 and Q_0 are the base groundnut price and quantity; $Z = -(P_1 - P_0)/P_0$; k is the unit cost reduction (equal to distance *ae* in Fig. 11.2); $J = k/P_0$; $(P_1 - P_0)$ is the change in market price; and η is the absolute value of the price elasticity of demand.

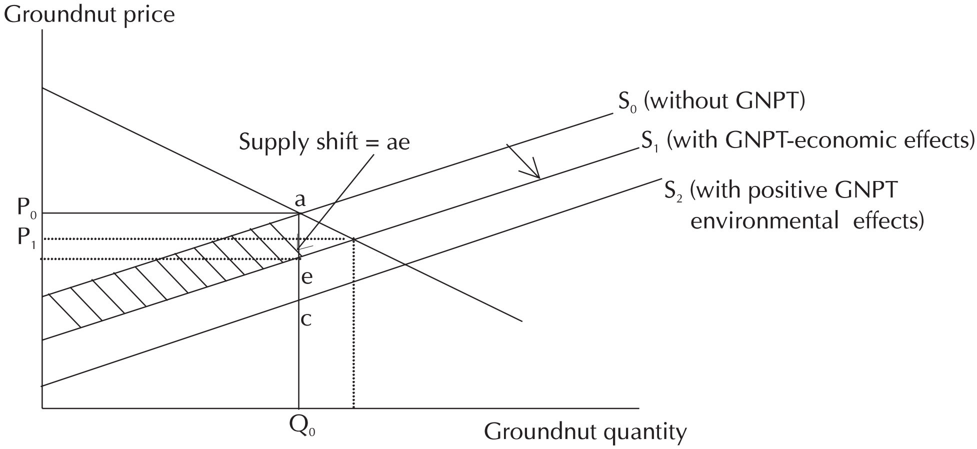

Fig. 11.2. Measurement of economic and environmental benefits due to adoption of groundnut production technology (GNPT) components.

Equations 2 and 3 can be used to calculate the empirical market benefits from adoption of the technology package. Annual gains are computed over the horizon the benefit is expected to accrue at actual adoption levels. The above estimation process only covers benefits accruing due to measurable market effects.

Computing the value of a supply shift

By custom, the magnitude of a supply shift (distance *ae* in Fig. 11.2) is measured by the change in unit cost of production and referred to as '*k*' (following Alston *et al.*, 1995). Establishing the actual supply shift (*k*) for adoption of GNPT involves understanding the unit cost reduction resulting from adoption of each of the possible GNPT options available to the farmer. This complex procedure can be overcome by categorising discrete subsets of options, among the whole range of 31 GNPT component mixes identified in Table 11.2.

Estimates of the *k*-shift in the supply function can be derived by using information available from on-farm trials. For analysis of the GNPT package, Pawar *et al.* (1993) provided results from trials managed by farmers and supervised by researchers. Different sets of technology options under on-farm trials presented alternative scenarios, namely:

- With and without improved package: This allowed comparison of the improved package of the GNPT, including improved varieties, RBF method, and other management practices, with the local package (full adoption)
- With and without RBF: This set compared only the effects of RBF with the flat land method of groundnut production, keeping the remaining components of the improved technology at their recommended level (at least RBF)
- With and without improved management practices: This option considered the use of improved varieties and compared the improved package of management practices with the traditional management package (i.e. partial adoption involving management practices only holding the effect of improved varieties).

The calculation of the supply shift *k* involves the use of the on-farm input and output data generated for each of the above scenarios. In particular, unit cost of production (Rs/t) was calculated based on total input cost and corresponding yield levels. Pairwise comparison of the unit cost incurred for the improved options versus the benchmark package generated a supply shift estimate for each scenario.

Inclusion of environmental impacts in the evaluation of NRM research benefits

In the process of examining the inclusion of environmental impacts in the evaluation of NRM research, it is useful to conceptualise specific scenarios detailing the nature of impacts by considering whether or not: 1. the effects of the technology intervention can be valued using conventional markets; 2. the effects are on-site or off-site or both; and 3. they have dynamic effects. Following this idea, Lubulwa and Davis (1997) identified four types of impact:

1. *On-site market impacts*. These impacts are specific to the site targeted by the technology intervention, do not have downstream effects, and can be evaluated using conventional markets. One example is exploitative farming systems that do not adequately replenish nutrients extracted during agricultural production. This activity has negative impacts as it reduces soil depth, degrades soil structure, decreases aeration, and increases salinity. The effects are on-site and may also have dynamic effects on crop productivity. These impacts are reflected in declining crop yields and can be valued using markets for the relevant crops.
2. *Off-site market impacts.* This represents off-site effects at locations different from where the technology impacts are targeted (e.g. downstream effects). Using the same example above, downstream effects that can be valued using markets include silting of rivers, reduced capacity for water storage, lowering water-table levels and the high costs of dredging irrigation canals.
3. *On-site non-market impacts.* This type of impact is specific to the site targeted but is not reflected in the marketplace. A good example is the slash and

burn practice used by farmers to expand cultivation area. A major impact of this practice is the loss of ecological biodiversity at the slash and burn site, but this impact cannot be valued using conventional markets. Contingent valuation or other similar techniques would be needed to value such an impact.

4. *Off-site non-market impacts.* This type reflects impacts that affect non-targeted locations as well as future generations. Water purification, carbon sequestration, and reduced flooding are all examples of down-stream benefits resulting from upland watershed management.

Systematic process documentation of the research and impact pathways is necessary in order to understand the source of the impact and quantify the nature of the impact. More importantly, this process documentation enables identification of those variables that have market impacts and those that have non-market environmental impacts. The measurement of environmental effects in monetary terms within the context of the principle of economic surplus draws from changes in the social marginal cost of production (supply curve) and the demand for the marketed product. Figure 11.2 illustrates the measurement of a positive environmental effect as an additional supply shift resulting from the reduction in environmental damage or positive environmental effects caused by a specific option. In this case, cost-reducing research will shift the supply curve further from S_1 to S_2 thereby reducing the marginal cost by '*ec*'. The total cost reduction effect is represented by the sum of the supply shift due to cost reduction of the technology and a further shift caused by environmental effects. Thus, marginal environmental benefits are accounted for in the total unit cost reduction that is estimated as $ac = ae + ec$. This process adjusts the benefit calculations for implicit price changes. If, however, the effect of the resource management technology is negative, the supply curve S_2 shifts backwards reflecting the environmental damage and corresponding increase in cost. The following section details the analysis of market and non-market impacts of GNPT.

Research cost

Data on research costs can be based on project report documents and historical evidence, as well as on interviews and discussions with the scientists and extension staff who were directly involved in conducting research, on-farm trials, and technology transfer activities. The annual cost of developing and packaging the GNPT, plus the cost of its diffusion and dissemination were estimated by using the formula:

$$GNPTRC = C_{ic} + C_{nars} + C_{ext} \quad (4)$$

where *GNPTRC* is the annual research and technology transfer cost of all components; C_{ic} is the annual research and overhead costs incurred at ICRISAT; C_{nars} is the annual research and other costs at the NARS; and C_{ext} is the annual cost of extension incurred by the technology transfer department of NARS.

Evaluation of Economic and Environmental Benefits

Farm-level benefits of the GNPT: quantitative estimates

Accounts of actual on-farm practices by representative farmers derived from the sample survey gave estimates of the benefits realised by farmers that include yield gains, cost saving and higher incomes (source: survey data of 1994/95 crop season):

1. The average groundnut yield among adopters was 2.2 t/ha, an increase of about 38% over the 1.6 t/ha among non-adopters
2. The unit variable cost of groundnut production under improved management was Rs3.86/kg in compared to Rs4.58/kg under local practices, a saving of about 16%; and
3. Net incomes among adopters averaged Rs21,470/ha in contrast to Rs15,580/ha among non-adopters, a gain of about 38% for the adopters.

Note that these estimates were obtained without accounting for the possibility of selection bias, an aspect that warrants consideration in future research.

On-farm trial data also provide estimates of the yield gain and unit cost reduction effects of GNPT. The value of the unit cost reduction is summarised for the three subsets chosen for this analysis based on on-farm trials detailed in Table 11.3:

a. k_1 = Rs1,198/t is achieved with the improved GNPT package (including improved varieties, RBF method, and other management practices), compared with the local package (full adoption)
b. k_2 = Rs564/t is achieved with the improved package of management practices compared with the traditional management package (with use of improved varieties in both cases), i.e. partial adoption involving management practices only, holding the effect of improved varieties.
c. k_3 = Rs270/t comparing the effects of RBF with the flat land method of groundnut production, keeping the remaining components of the improved technology at their recommended level (one component). This estimate is assumed to measure the unit cost reduction due to RBF.

Table 11.3. Cost of production and yield of groundnut under on-farm trials with different technology options, Maharashtra, India, 1987–91 (adapted from Pawar *et al.,* 1993).

Technology components		Yield	Cost	Unit cost
Management	Variety	(t /ha)	(Rs/ha)	(Rs/t)
Improved	Improved	3.49	6990	2002.86
Improved	Local	1.97	5990	3040.61
Local	Improved	2.56	6570	2566.40
Local	Local	1.74	5570	3201.15

By the nature of the measurable market effects listed above, the total value of the supply shift is only partially accounted for by taking these estimates of unit cost saving from adoption of the GNPT package instead of the existing practice.

Benefits as described by farmers in surveys and focused group interviews

Farmers described the additional benefits in a pilot survey (1999–2000), participatory rural appraisals and focus group interviews (Box 11.1).

Box 11.1. Welfare changes due to the adoption of groundnut production technology (GNPT) components, based on farm survey, participatory rural appraisals and focus group meetings (Bantilan *et al.*, 2003).

1. Raised-bed and furrow land configuration (RBF) improved soil moisture conservation (75% of survey respondents).
2. RBF was perceived to improve field drainage (75% of survey respondents).
3. RBF saved nutrients and water (28% of survey respondents).
4. Reinvestment in agricultural implements and inputs brought long-term stability to the farming system in the villages.
5. Stability of the farming system increased farmers' options in making decisions about cropping pattern (cash vs. subsistence crops) or investing in production vs. investing in schooling, housing, household assets.
6. The GNPT options were observed to have spillover effects beyond groundnut production. The RBF method was found applicable to such other crops as chillies, soybean, pigeonpea, chickpea, sunflower, mustard and some vegetables. Application of micronutrients to selected crops was also becoming popular where farmers had learned about the GNPT package.
7. Assets acquired for GNPT are being used for other crops, and have enabled cultivation in other seasons.
8. The community has become more socially inclusive, with greater interaction between members of different social categories. Respondents attributed this to a direct consequence of GNPT adoption, as it made landowner farmers more dependent on tribal and landless labour for longer periods throughout the year.
9. Credit rating of the village has risen.
10. Due to the newly found visibility conferred by GNPT adoption successes, the Maharashtra Government targeted the village for special development programmes (e.g. rural sanitation, wasteland development, integrated mother and child development).
11. Empowerment – a general improvement in self-esteem, confidence, ability to innovate were expressed in an increased diversity of crops cultivated, greater choice of investments, and greater access to credit, information, and government agents.
12. Higher pod yields with GNPT generated on-farm employment in shelling, especially for women. The overall labour requirement was about 12% higher with the GNPT than with the existing local practices.
13. For the marginalised groups (tribals and landless labourers), year-round employment ensured adequate food and nutrition for all members of the household.
14. Increased labour demand replaced out-migration of labour by in-migration.

Delineating market and non-market impacts

Table 11.4 summarises the overall impacts of GNPT adoption and delineates the market and non-market impacts in columns 2, 3 and 4. Yield-increasing or cost-reducing benefits cited in column 2 can be measured and directly included in the economic surplus calculations. Quantifiable measurements of these indicators give an initial basis for estimating the parallel *k*-shift in the supply function.

Table 11.4. Analysis of market and non-market impacts of groundnut production technology (GNPT).

Component	Market impacts	Non-market impacts	Environmental effects
C1 Land management			
RBF seedbed	Yield gains Saves 20% of input cost compared to conventional flat system	• Agricultural sustainability • Reduces soil erosion • Reduces water logging • Helps move salts to furrows, and from furrows to drains • Conserves soil moisture during deficit rain • Concentrates organic matter and fertiliser application • Reduces soil compaction, providing loose and well-aerated soil for growing crop • More soil depth for better development of root mass	+ (Greater yield stability, increased water availability off-site and in future, enable cultivation in other seasons) – (Off-site increase in soil salinity)
	Change in labour demand	• More labour required • Reduces drudgery for women in weeding operations (labourers sit in furrows and weed) • Efficient use of tractor and field machinery; interculturing with tractor/bullock implements • Less power requirement for land preparation in successive years	
C2 Nutrient management			
Farmyard manure	Increase in groundnut yields	Improves soil physical properties and soil health	+ (Increase carbon content)

Continued

Table 11.4 Continued.

Component	Market impacts	Non-market impacts	Environmental effects
Ammonium sulphate	Increase in groundnut yields	Environmental effects	+ (Checks soil alkalinity) – (Causes water pollution)
Single super-phosphate	Increase in groundnut yields	Environmental effects	+, –
Zinc sulphate	Increase in groundnut yields	Environmental effects	+, –
Ferrous sulphate	Increase in groundnut yields	Environmental effects	+, –
Gypsum	Increase in groundnut yields	Environmental effects	+, –
C3 Water management			
Sprinkler irrigation	Reduced unit cost due to enhanced water use efficiency	Positive environmental effects due to reduced pest incidence Efficient water utilisation through GNPT offers potential long-term benefits, particularly in increasing water availability off-site and in the future	+
C4 Disease and pest management			
Fungicidal seed treatment	Good quality seeds reduce yield loss and increase employment potential		+, –
Herbicides and pesticides	Reduced yield losses	Negative health effects Adverse effects on water quality	– (Skin allergies)
C5 Seed			
Improved variety	Increase in yields	Conserves biodiversity, checks insect pest incidence	+
Seed rate	Increase in yields	Check insect pest infestation	+
Sowing–dibbling	Yield increase due to good and uniform plant population Increase in employment	Increase drudgery on women	–
Seed dressing	Increased yield	Check insect pest infestation	+

Some non-market impacts may also be indirectly reflected in the calculation of economic benefits to the extent that they affect improvement in yields or unit cost reduction. For example, improvement in the soil physical properties listed in column 3 may be reflected in enhancing groundnut yields. But, there are some indirect or long-term benefits that are difficult to measure as shown in columns 3 and 4 of Table 11.4. These include agricultural sustainability resulting from enhanced biodiversity and health effects. Ideally the value of these impacts can be obtained by seeking appropriate relationships between a chosen GNPT technological intervention and environmental effects. Finding a unique equation or a functional relationship that can be used to quantify, in physical terms, the effect on human health or air quality or other environmental impacts of each component could be difficult. For example, while soil health is believed to improve with the GNPT's land and nutrient management interventions, there are no data or models to measure the specific effects on soil health (J.V.D.K. Kumar Rao, personal communication, 2004). Nevertheless, descriptions of the likely environmental effects of GNPT interventions by Pawar *et al.* could help in impact assessment (1993; and C.S. Pawar, personal communication, 2004):

- The natural acidity of ammonium sulphate checks the alkalinity of the soil. This is a positive effect in alkaline soils, but excess applications of ammonium sulphate can also result in negative environmental effects
- Pollution levels are high with local practices of fertiliser application
- Water quality can be reduced when excess nitrogen is applied to crops
- Micronutrients like zinc sulphate and ferrous sulphate help maintain the yield potential of the soil. Zinc sulphate is used to rectify the zinc deficiencies of the crop. Ferrous sulphate is used to rectify iron deficiencies incurred by waterlogging
- Herbicides and pesticides, if used in large quantities, can cause severe damage to the environment; exposure can also trigger skin allergies in farmers. Prior to the introduction of GNPT, farmers applied excess quantities of pesticides due to lack of awareness. ICRISAT educated the farmers about appropriate dosages and safe handling procedures, thereby mitigating negative environmental effects and farmer health risks.

Listing the positive and negative effects, in Table 11.4, aids in the analysis of market and non-market impacts of the GNPT management options. It records the market impacts representing yield gains or reduced yield losses and changes in unit cost from adoption of GNPT components. The inventory of non-market effects is substantial. The RBF land management appears to have had significant positive environmental effects resulting to greater long-term yield stability, increased water availability off-site and in the future. Agricultural sustainability was enhanced through reduced soil erosion and reduced waterlogging during periods of heavy rain. The other components including nutrient management, disease and pest management and water management improved the soil physical properties and soil health. The environmental benefits included increased carbon content and checked soil alkalinity. Negative effects (environmental costs) from water pollution arose from the use of ammonium sulphate and other micronutrients and pesticide runoff. When pesticide use exceeded recommended levels, it also caused adverse health effects. Finally, although increased groundnut yields increased incomes, denser planting and groundnut shelling created added drudgery for women.

Table 11.4 illustrates how a qualitative understanding of the nature and direction of the impacts can provide a basis for determining the range of possible conditions that would simulate potential benefit levels. In this case it is important to understand the source of the impact, the nature of an impact, and the relationship between an impact and those variables that can affect current, potential, or future producers and consumers. Even though the effects on the environment are complex, the identification and understanding of GNPT effects narrows the field remaining for evaluation. Table 11.4 highlights how the conventional calculations that exclude environmental effects can skew measures of the full technology impact.

Approximations of Economic and Environmental Effects

This section applies the approach discussed above to estimate the total gains due to GNPT technology. Estimates of basic parameters are explained and procedures are illustrated.

Production, price and elasticities

a. The annual base level of groundnut production was 151,280 t in the four selected districts of Maharashtra (average during 1988–1990; source: ICRISAT District-Level Database)
b. The base groundnut price was Rs6533/t (average groundnut price in Maharashtra during 1988–1990, source: ICRISAT District-Level Database)
c. The price elasticity of demand was 0.5 and price elasticity of supply was 0.1 (Radhakrishna and Ravi, 1990).

Research lags

On the estimation of the research lag (i.e. the period of investment required before benefits were realised), the survey indicated that GNPT adoption first took place in 1989. A research lag of 12 years was measured from the time of initial research started in 1974 to the introduction of the technology in farmers' field in 1986 and a further lag of 3 years before first year of actual adoption.

Adoption estimates

Using the methodology introduced in the earlier section on adoption, the survey data covering the period 1989–1994 were used to develop the adoption pathway for GNPT (Fig. 11.3). The results above confirm the situations of partial adoption and step-wise adoption. They indicate that different technology components of GNPT are adopted in a step-wise process of adopting improved varieties, nutrient management, soil management, and other components of the package depending upon: 1. information about the technology, 2. the availability of necessary resources or inputs, 3. marginal returns to the technology, 4. risks, and 5. the suitability of technology traits.

The logistic function was used to estimate the adoption curve and predict the future path, e.g.:

$$A_t = \frac{40}{(1 + e - ^{(-2.6 + 0.69t)})} \quad \text{for adoption of at least RBF} \quad (5)$$

$$A_t = \frac{98}{(1 + e - ^{(-3.2 + 0.34t)})} \quad \text{for adoption of at least improved varieties} \quad (6)$$

Similar estimates can also be obtained for any selected component or subset of GNPT.

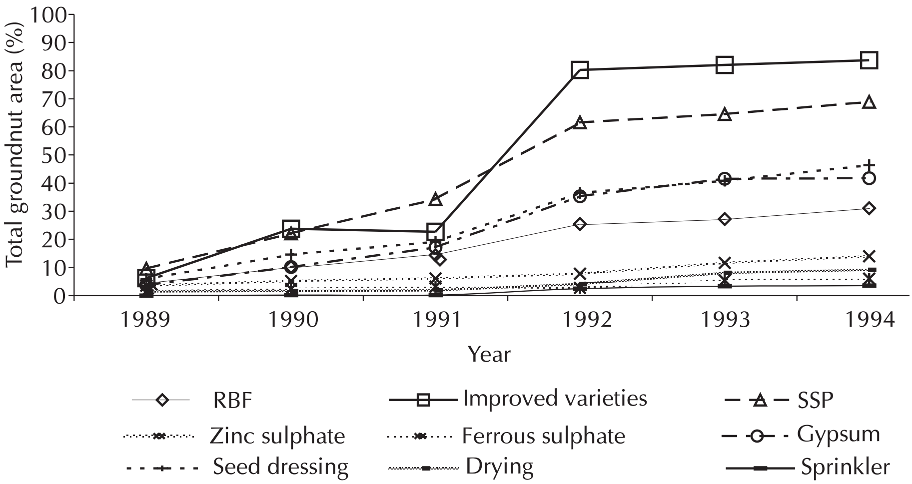

Fig. 11.3. Adoption patterns of groundnut production technology (GNPT) components in Maharashtra.

Figure 11.4 depicts the adoption path for the RBF component, estimated using the logistic function, showing a consistent increase in adoption of the RBF. Because this adoption path reflects those households adopting RBF (some of whom did not adopt other GNPT components), it overestimates adoption of the full package.

Farmers who adopted the concept of RBF but lacked appropriate implements did not strictly adhere to making beds 1.5-m wide. This illustrated an important dimension of crop and resource management technologies: farmers adapt technologies to meet special needs, changing the technologies in the process.

Among the other GNPT components, the adoption rate of improved groundnut varieties rose dramatically from 6% in 1989 to 84% in 1994. The adjusted rate of adoption of improved varieties was higher for those farmers practising the RBF method. The accelerated adoption of improved varieties may be attributed to the dissemination of information on GNPT. At the time of the survey in 1994 the sprinkler method of irrigation was yet to be

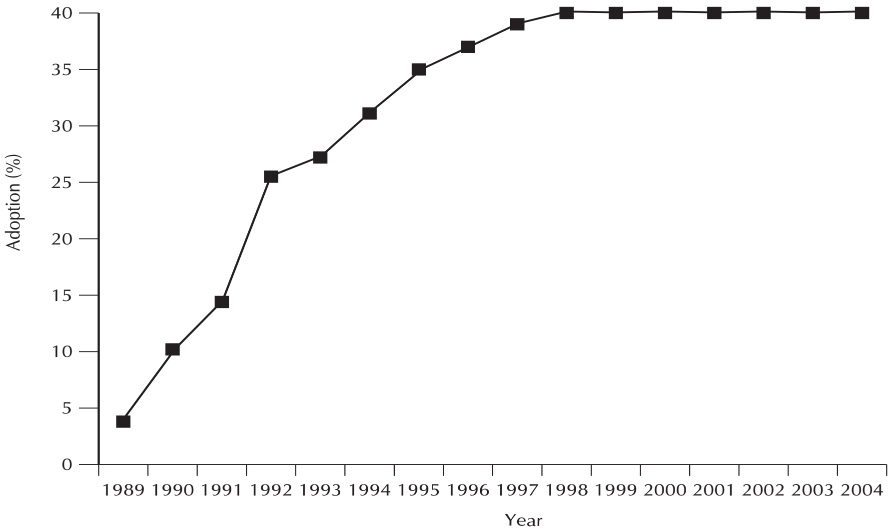

Fig. 11.4. Adoption of raised-bed and furrow (RBF) of groundnut production technology (GNPT) in selected districts of Maharashtra, India, 1989–1995 (projected to 2004).

adopted by the majority of groundnut cultivators. By the late 1990s, the use of sprinkler irrigation in Maharashtra had been substantially enhanced by government subsidies.

Research cost estimates

The estimated cost of research and technology transfer is detailed in Table 11.5. The annual cost of ICRISAT, C_{ic}, was estimated as:

$$C_{ic} = SAL_{ic} + OPR_{ic} + OVR_{ic} + OFD_{ic} \qquad (7)$$

where SAL_{ic} is the annual salary of the research team; OPR_{ic} is the annual operational expenses required to undertake GNPT development, packaging, and diffusion; OVR_{ic} is the annual overhead cost at the Institute; and OFD_{ic} is the annual cost incurred to conduct on-farm trials and demonstrations in farmers' fields.

The salary of the research team at ICRISAT, SAL_{ic}, is considered to include the salaries of all those associated with the research project (SAL_i), each weighted by the proportion (w_i) of their time devoted to developing and packaging the GNPT, that is,

$$SAL_{ic} = \sum_{i=1}^{n} w_i * SAL_I \qquad (8)$$

This annual salary cost was estimated at US\$34,900. The operational cost (OPR_{ic} = US\$12,215) of developing and packaging the GNPT was assumed to be 35% of the salary. This assumption is based on historical norms at ICRISAT. The overhead costs (OVR_{ic}) are usually considered to be half of the research expenses (Byerlee, 1996); this figure (US\$47,115) was based on research resource allocations to different research projects at ICRISAT. Since the technology components were packaged and recommended for groundnut, pigeonpea, and chickpea, the research and packaging costs for GNPT was proportionately distributed. The share of groundnut in the total area of the three crops was used as a basis for allocating research costs to GNPT (US$45,600).

Table 11.5. Annual research and technology transfer cost (US$) of groundnut production technology (GNPT), 1974–2000.

Component	Year	Cost (US$)
Research		
Salary	1974–86	34,900
Operations	1974–86	12,215
Overheads	1974–86	47,115
NARS	1974–91	9,500
Technology transfer		
Packaging/on-farm trials	1987	24,000
On-farm trials	1988–90	20,000
On-farm trials	1991	10,000
State expenses	1992–2000	7,500

The NARS was involved in packaging the technology and conducting on-farm trials. To assess this cost, several researchers who worked for the NARS were consulted. It was determined that, on the basis of NARS participation in the development and packaging of the technology, the NARS incurred a cost of about US$4560 (approximately 10% of ICRISAT's total cost). Similarly the cost of on-farm research and technology transfer activities (OFD_{ic}) undertaken through the LEGOFTEN Technology Transfer Network, which started in 1987, was proportionately allocated. The expenses incurred in technology transfer (C_{ext}) through the Maharashtra Department of Agriculture during the post-LEGOFTEN period were calculated using the share of groundnut in total area in the State as no separate documentation exists on resource allocation for each commodity or technology.

The technology packaging and its transfer started from 1987 through the LEGOFTEN programme. The initial budget for this programme (1987 and 1988) was met through ICRISAT's core funds, and later (1989–1991) through financial assistance from the International Fund for Agricultural Development (IFAD). In the first year, when different components of technology were integrated, the cost of GNPT (US$24,000) was computed on the basis of the proportionate area under groundnut. In subsequent years, the total budget allocated to LEGOFTEN was distributed (US$20,000) to represent the GNPT package that was apportioned according to the number of on-farm trials conducted on groundnut. The budget of the State Department of Agriculture for GNPT extension activities during 1987–1991 was also met through the LEGOFTEN programme. The expenses incurred in technology transfer through the state departments of agriculture during the post-LEGOFTEN period were calculated using the share of groundnut in the total cropped area in the state, as no separate information on resource allocation to each commodity/technology is documented. On the basis of the salary, operations, and overheads, the annual technology transfer cost during the post-LEGOFTEN period was calculated to be US$7,500. This cost was considered from 1992 until 2000. Since the research and technology transfer costs incurred by ICRISAT, NARS, and the state departments of agriculture were rough estimates based on available ICRISAT Annual Reports and interviews with scientists involved in the project, a sensitivity analysis was also performed by increasing the cost of research and technology transfer by 10–20%. The results revealed that the internal rate of return (IRR) is rather insensitive to changes in costs of research and technology transfer.

Supply shift

The unit cost of production (Rs/ton) was calculated based on total input cost and corresponding yield levels. Pairwise comparison of the unit cost incurred by GNPT enhanced options vs. the traditional practice generated supply shift estimates for each scenario. For the three scenarios described in the previous section, three levels of on-farm unit cost reduction were taken: k_1 = Rs1,198/t, k_2 = Rs564/t, and k_3 = Rs270/t.

Table 11.6 presents the stream of research and technology transfer costs and market-based research benefits using the unit cost reduction estimates (k_1, k_2 and k_3) above, levels of adoption represented by Fig. 11.4, price, quantity and elasticity estimates. It also gives the estimated net present value, IRR, and benefit–cost ratio under three different scenarios. As noted earlier, the estimate using the adoption path for RBF gives an upper bound of the benefit levels. (A lower bound can be estimated using the adoption pathway of the GNPT component that has been adopted least, i.e. at a ceiling level of 15% based on the data.)

The analysis revealed that the IRR of GNPT was 25.3% if the total package of the GNPT is adopted. The total net present value of information from the research and technology transfer programme on GNPT was estimated to be US$3.45 million. The benefit–cost ratio was 9.37, which means that every US$1 invested in developing and disseminating GNPT produced an average benefit of US$9.37 throughout the period.

Given the environmental effects recorded from the analysis above (largely positive but also partially negative), two different scenarios of positive and negative net environmental effects were simulated. Because the major impacts were felt to be captured by the effects on marketable crop yields, the sensitivity analysis scenarios involved modest levels of change: a 10% increase in unit cost reduction from the base level of full GNPT package adoption, and a 5% decrease in unit cost reduction from the base level. The analysis revealed that positive environmental effects that might further increase the unit cost reduction could result in a benefit–cost ratio of 9.73 and an IRR of 26.17. The second scenario of a negative environmental effect by a marginal rate of 5% could reduce the benefit–cost ratio to 8.26 and result in reducing the IRR to 24.95. Negative environmental effects would have to increase the social value of unit production costs by 79% for the benefit–cost ratio to fall to the break-even level of 1.0. Such an increase in units costs is implausibly high, given the dominantly beneficial environmental effects reported by farmers and focus groups. None the less, these simulations show the sensitivity of research impacts when environmental effects are considered.

Table 11.6. Market-based cost and benefit streams for research and technology transfer of the groundnut production technology (GNPT) package.

	Cost (US$'000)		Benefits (US$'000)		
Year	ICRISAT	NARS	Full package	Partial package[a]	Land mgt (RBF)[b]
1974	45.6	4.56	0	0	0
1975	45.6	4.56	0	0	0
1976	45.6	4.56	0	0	0
1977	45.6	4.56	0	0	0
1978	45.6	4.56	0	0	0
1979	45.6	4.56	0	0	0
1980	45.6	4.56	0	0	0
1981	45.6	4.56	0	0	0
1982	45.6	4.56	0	0	0
1983	45.6	4.56	0	0	0
1984	45.6	4.56	0	0	0
1985	45.6	4.56	0	0	0
1986	24.0	4.56	0	0	0
1987	20.0	4.56	0	0	0
1988	20.0	4.56	0	0	0
1989	20.0	4.56	162.57	76.15	36.42
1990	10.0	4.56	460.62	215.75	103.19
1991	0.0	7.50	650.29	304.59	145.68
1992	0.0	7.50	1,151.56	539.39	257.97
1993	0.0	7.50	1,228.33	575.34	275.17
1994	0.0	7.50	1,404.45	657.84	314.63
1995	0.0	7.50	1,580.57	740.33	354.08
1996	0.0	7.50	1,670.89	782.64	374.31
1997	0.0	7.50	1,761.21	824.94	394.54
1998	0.0	7.50	1,806.37	846.09	404.66
1999	0.0	7.50	1,806.37	846.09	404.66
2000	0.0	7.50	1,806.37	846.09	404.66
2001	0.0	0.00	1,806.37	846.09	404.66
2002	0.0	0.00	1,806.37	846.09	404.66
2003	0.0	0.00	1,806.37	846.09	404.66
2004	0.0	0.00	1,806.37	846.09	404.66
2005	0.0	0.00	1,806.37	846.09	404.66
Internal rate of return (IRR) (%)			25.26	19.15	13.50
Net present value (US$ '000)			3,452.94	1,389.06	453.45
Benefit–cost ratio			9.37	4.39	2.10

[a]Partial = management practices only.
[b]Land mgt (RBF) = raised-bed and furrow.

Summary and Conclusions

This chapter principally illustrates an empirical estimate of economic surplus using the case of GNPT developed by ICRISAT and its partners in the Indian NARS. The case study illustrates the critical importance and use of qualitative information in understanding the additional environmental and long-term effects due to the adoption of NRM technologies.

To quantify the returns to investment on research and technology exchange, three aspects were examined:

1. Benefits (both economic and environmental) accruing from the research and technology exchange programme
2. Adoption rates and the spread of different components of GNPT
3. Research and technology exchange cost involving research partnerships among international and national research programmes as the extension sector.

Economic surplus and distribution of welfare gains were estimated by assuming a parallel shift in supply function due to investment in the research and technology development. Internal rates of return, net present values and benefit–cost ratios were computed under three options:

1. Full adoption of the GNPT package
2. Adoption of only management practices
3. Adoption of only land management (RBF) with other practices remaining the same.

Because environmental effects were not measured in monetary terms, two sensitivity analyses were carried out under scenarios related to net positive and negative environmental effects.

The survey results show that farmers initially adopted parts of the crop and resource management package, and adapted the technology options according to their needs, convenience, and resource endowments. Logistic growth functions were estimated to describe the rate of adoption of each GNPT component. The adoption analysis illustrates the nature and dynamics of adoption of NRM technologies.

The estimation of benefits accruing from GNPT involved computation of welfare gains based on yield gains and/or reduction in unit production costs. The inclusion of qualitative environmental effects encompassed impact dimensions not captured via the measurable reduction in unit cost or yield gains due to lack of quantifiable or long-term data. The difficulty of quantifying many environmental costs and benefits challenged the approach to incorporating these effects into cost–benefit analysis. The environmental effects were characterised by systematically tracking both individual and interaction effects of GNPT components. Thorough analysis is based on systematic documentation coupled with reasonable estimates of economic effects.

Environmental effects can have a large overall impact. The results show that if environmental effects reduced fully accounted unit costs by just 10% more than market effects, the net present value of the GNPT would increase by US$0.4 million and the IRR would increase by 1%. Clearly, environmental effects in the assessment of NRM options cannot be ignored. As stated by Winpenny (1991), the environment is not free, even though there may not be a conventional market for its services. In the context of decisions based on cost–benefit analysis, it is important to understand the source of the impact, the nature of an impact, and the relationship between an impact and those variables that can affect current, potential, and future consumers and producers. This means that valuing as many effects as possible and plausible, narrows the field remaining for pure judgement.

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