4. Social impacts

4.1 Poverty impact pathways

The primary goal of agricultural research during the GR era was to increase food production. Historically, this led to a focus on foodgrains in high-potential areas where the quickest and highest returns to R&D could be expected. This strategy was extremely successful in achieving its primary goal in South Asia. Additionally, it helped cut poverty in the region during the 1970s and 1980s – from 59.1% of the population in 1975 to 43.1% in the early 1990s (Rosegrant and Hazell, 2000). But it did not eliminate poverty or malnutrition, and today, despite the fact that most South Asian countries now have plentiful national food supplies, poverty is still a major problem. About 450 million South Asians currently live below the US$1 per day poverty line (about the same as in 1975), and 80% of these are rural and obtain at least part of their livelihood from agriculture and allied activities (World Bank, 2007; Ahmed et al., 2008). The agricultural research systems have responded to this problem by targeting more of their research towards the problems of small-scale farmers and the rural poor in the hopes of enhancing its poverty-reducing impacts.

Given the complex causes underlying poverty and the diversity of livelihoods found among poor people, the relationship between agricultural research and poverty alleviation is necessarily complex. There are a number of pathways through which improved technologies could potentially benefit the poor (Hazell and Haddad, 2001). Within adopting regions, research could help poor farmers directly through increased own-farm production, providing more food and nutrients for their own consumption and increasing the output of marketed products for greater farm income. Small-scale farmers and landless laborers could gain additional agricultural employment opportunities and higher wages within adopting regions. Research could also empower the poor by increasing their access to decision-making processes, enhancing their capacity for collective action, and reducing their vulnerability to economic shocks via asset accumulation.

Agricultural research could also benefit the poor in less direct ways. Growth in adopting regions could create employment opportunities for migrant workers from other less dynamic regions. It could also stimulate growth in the rural and urban nonfarm economy with benefits for a wide range of rural and urban poor people. Research could lead to lower food prices for all types of poor people. It could also improve their access to foods that are high in nutrients and crucial to their well-being – particularly that of poor women.

However, agricultural research could also work against the poor. Some technologies are more suited to larger farms, and some input-intensive technologies that are in principle scale-neutral may nevertheless favor large farms because of their better access to irrigation water, fertilizers, seeds, and credit. Some technologies (e.g., mechanization and herbicides) could displace labor, leading to lower earnings for agricultural workers. By favoring some regions or farmers over others, technology could harm non-adopting farmers by lowering their product prices even though only the adopting farmers benefit from cost reductions.

Given that many of the rural poor are simultaneously farmers, paid agricultural workers, net buyers of food, and earn nonfarm sources of income, the impacts of technological change on their poverty status could be indeterminate, with households experiencing gains in some dimensions and losses in others. For example, the same household might gain from reduced food prices and from higher nonfarm wage earnings, but lose from lower farm gate prices and agricultural wages. Measuring net benefits to the poor requires a full household income analysis of direct and indirect impacts, as well as consideration of the impacts on poor households that are not engaged in agriculture and/or who live outside adopting regions. Much of the controversy that exists in the literature about how R&D impacts on the poor has arisen because too many studies have taken only a partial view of the problem.

There is a large literature on the impacts of agricultural research on the poor in South Asia but hardly any impact studies exist that quantify the research costs of reducing poverty. Many studies focus on assessing changes in income distribution or poverty in areas where new technologies have been adopted, but only a few attempt to link changes in inequity or poverty to research expenditures. More recently, measures of poverty have also been expanded to include broader and less quantifiable social impacts, such as empowerment and changes in social capital. One consequence is that if we focus only on quantitative studies that evaluate the impact of research investments, this section of the paper would be very short indeed and would not do justice to the large amount of research that has been done on poverty issues or to the large number of studies that shed useful light on how improved technologies can benefit the poor at farm and community levels. Those who invest in agricultural research need to know that relevant work has been undertaken with proven poverty-reduction impacts in the field, even if we do not yet have much quantitative evidence to show which types of research give the best poverty impact per dollar invested.

4.2 Evidence on impacts within adopting regions

The initial experience with the GR in Asia stimulated a huge number of studies on how technological change affects poor farmers and landless workers within adopting regions. A number of village and household studies conducted soon after the release of GR technologies raised concern that large farms were the main beneficiaries of the technology and poor farmers were either unaffected or made worse-off. More recent evidence shows mixed outcomes. Small-scale farmers did lag behind large farmers in adopting GR technologies, yet many of them eventually did so. Many of these small-farm adopters benefited from increased production, greater employment opportunities, and higher wages in the agricultural and nonfarm sectors (Lipton with Longhurst, 1989). In some cases, small-scale farmers and landless laborers actually ended up gaining proportionally more income than larger farmers, resulting in a net improvement in the distribution of village income (e.g., Hazell and Ramasamy, 1991; Maheshwari, 1998; Thapa et al., 1992).

Freebairn (1995) reviewed 307 published studies on the GR and performed a meta-analysis. Nearly all the studies that he reviewed focused on changes in inequality and income distribution rather than on absolute poverty, the latter emerging as a more important issue in the 1990s. Freebairn found that 40% of the studies he reviewed reported that income became more concentrated within adopting regions, 12% reported that it remained unchanged or improved, and 48% offered no conclusion. He also found there were more favorable outcomes in the literature on Asia than elsewhere, and that within the Asian literature, Asian authors gave more favorable conclusions than non-Asian authors. Later studies did not report more favorable outcomes than earlier studies, thereby casting some doubt on the proposition that small-scale farmers adopted, albeit later than large-scale farmers. However, it should be noted that Freebairn's analysis did not include repeat studies undertaken at the same sites over time, such as Hazell and Ramasamy (1991) and Jewitt and Baker (2007), both of whom found favorable longer-term impacts on inequality. Freebairn (1995) also found that micro-based case studies reported the most favorable outcomes, while macro-based essays reported the worst outcomes.

Walker (2000) argued that reducing inequality is not the same thing as reducing poverty, and that it may be much more difficult to achieve through agricultural R&D. More recent studies focusing directly on poverty confirm that improved technologies do impact favorably on many small-scale farmers, but the gains for the smallest farms and landless agricultural workers can be too small to raise them above poverty thresholds (Hossain et al., 2007; Mendola, 2007). However, the poor can benefit in other ways too. Hossain et al. (2007) found that in Bangladesh the spread of high-yielding variety (HYV) rice helped reduce the vulnerability of the poor by stabilizing employment earnings, reducing food prices and their seasonal fluctuations, and enhancing their ability to cope with natural disasters. In India, Bantilan and Padmaja (2008) found that the spread of ICRISAT's groundnut improvement technology based on a RBF concept helped increase social networking and collective action within adopting villages, and this proved especially helpful to poor farmers and women in accessing farm inputs, credit, and farm implements, and in sharing knowledge. Use of participatory research methods in the selection of improved rice varieties in Uttar Pradesh, India has been shown to empower women as decision-makers in their farming and family roles, as well as leading to greater adoption of improved varieties (Paris et al., 2008).

The lessons from many past studies may have less relevance today because of the changing nature of the livelihoods of the rural poor in south Asia. With rapid growth in nonfarm opportunities in much of South Asia as well as shrinking farm sizes, farming and agricultural employment have become less important in the livelihood strategies of the rural poor (Nargis and Hossain, 2006; Kajisa and Palanichamy, 2006; Lanjouw and Shariff, 2004). Within this new context, many poor people with limited access to land gain more from nonfarm opportunities than from productivity gains or wage earnings in farming, though investments in education and access to capital are often crucial for accessing such opportunities (World Bank, 2007; Nargis and Hossain, 2006; Kajisa and Palanichamy, 2006; Krishna, 2005). This is not to say that publicly funded agricultural research cannot still usefully be targeted to the problems of poor part-time farmers. Hazell and Haddad (2001) identified several opportunities, including increasing the productivity of food staples to free up land and labor for other activities, improving the nutrient content of staples, developing new technologies for small-scale home gardening of micronutrient-rich food, and using participatory research methods to enhance the relevance of improved technologies for poor farmers. But questions arise about the efficacy of these kinds of interventions and whether they are cost effective in reducing poverty compared to alternative types of interventions. Answering these questions should be a priority for future impact studies.

4.3 Evidence on economy and sector-wide impacts

There is a large econometric literature that uses cross-country or time-series data to estimate the relationship between agricultural productivity growth and poverty. These studies generally found high poverty reduction elasticities for agricultural productivity growth. Thirtle et al. (2003) estimated that each 1% increase in crop productivity reduces the number of poor people by 0.48% in Asia. For India, Ravallion and Datt (1996) estimated that a 1% increase in agricultural value added per hectare leads to a 0.4% reduction in poverty in the short run and 1.9% in the long run, the latter arising through the indirect effects of lower food prices and higher wages. Fan et al. (2000b) estimated that each 1% increase in agricultural production in India reduces the number of rural poor by 0.24%. For South Asia, these poverty elasticities are still much higher for agriculture than for other sectors of the economy (World Bank, 2007; Hasan and Quibria, 2004).

There is some evidence that the poverty elasticity of agricultural growth may be diminishing because the rural poor are becoming less dependent on agriculture. In Pakistan, for example, agricultural growth was associated with rapid reductions in rural poverty in the 1970s and 1980s, but the incidence of rural poverty hardly changed in the 1990s despite continuing agricultural growth (Dorosh et al., 2003). Dorosh, et al. (2003) show that this is partly because a growing share of the rural poor households (46% by 2001–2002) had become disengaged from agriculture; even small farm households and landless agricultural worker households received about half their income from nonfarm sources.

Some of the studies reviewed in Section 3 that quantified the productivity impacts of public investments in agricultural R&D also assessed the impacts on poverty reduction and provide comparisons with other types of public investment. Fan et al. (1999) found that agricultural R&D investments in India have not only given the highest productivity returns in recent decades, but have also lifted more people out of poverty per unit of expenditure than most other types of public investment (Table 5).

Investments in agricultural R&D and rural roads dominate all others in terms of the size of their impacts, and can be considered the best win–win strategies for achieving growth and poverty alleviation in India.

Fan et al. (2007) have used an econometric model to estimate the impact of rice research in India on poverty reduction, including providing a breakout of an estimate of IRRI's contribution. They found that about 5 million rural poor people have been lifted out of poverty each year as a result of rice improvement research in India. Using plausible attribution rules, they estimated that IRRI's research contribution accounts for significant shares of these annual reductions in the number of rural poor. In 1991, IRRI was attributed with raising 2.73 million rural poor people out of poverty, but because of the lag structures in their model, the contribution declined over time to only 0.56 million rural poor in 1999. They calculated that the number of persons lifted out of poverty for each US$1 million spent by IRRI declined from 59,040 in 1991 to 15,490 persons in 1999. This corresponds to an increase in the cost of raising each person out of poverty from US$0.046 per day in 1991 to US$0.177 per day in 1999.

Fan (2007) also estimated the impact of agricultural research on urban poverty in India. He estimated that in 1970, accumulated agricultural research investments lifted 1.2 million urban poor out of poverty, and this annual reduction increased to 1.7 million by 1995. These numbers correspond to between 2 and 2.5% of the remaining urban poor each year. On a cost basis, 196 urban poor were lifted out of poverty in 1970 for each million rupees spent, and this had declined to 72 urban poor per million rupees by 1995. Since the same investment on research also lifted many rural poor out of poverty (see above), there is a double dividend that makes research investments especially attractive for reducing poverty.

Lower food prices and growth linkages to the nonfarm economy played a large role in most of the results cited above, and these benefit the urban as well as the rural poor. These indirect impacts have sometimes proved more powerful and positive than the direct impacts of R&D on the poor within adopting regions (Hazell and Haddad, 2001). A question arises as to whether the power of these indirect benefits has diminished over time with market liberalization and greater diversification of South Asian economies. Also, if unit production costs are not falling as in the past (as reflected in stagnating TFP growth) this will also constrain future food price reductions. This is an issue that warrants further study.

4.4 Evidence on inter-regional disparities

Agricultural development in South Asia has not benefited all regions equally; some of the poorest regions that depend on rainfed agriculture were slow in benefiting from the GR (Prahladachar, 1983). The widening income gaps that resulted have been buffered to some extent by inter-regional migration. In India, the GR led to the seasonal migration of over a million agricultural workers each year from the eastern states to Punjab and Haryana (Oberai and Singh, 1980; Westley, 1986). These numbers were tempered in later years as the GR technology eventually spilt over into eastern India in conjunction with the spread of tube wells. In a study of the impact of the GR in a sample of Asian villages, David and Otsuka (1994) asked whether regional labor markets were able to spread the benefits between adopting and non-adopting villages and found that seasonal migration did go some way to fulfilling that role. But while migration can buffer widening income differentials between regions, it is rarely sufficient to avoid them. In India, for example, regional inequalities widened during the GR era (Galwani et al., 2007), and the incidence of poverty remains high in many LFAs (Fan and Hazell, 2000).

4.5 Evidence on nutrition impacts

Agricultural research has been very successful in increasing the supply of food and reducing prices of food staples in South Asia. Making food staples more available and less costly has proved an important way through which poor people benefited from technological change in agriculture (Rosegrant and Hazell 2000; Fan et al., 1999; Fan, 2007). Several micro-level studies from the GR era in South Asia found that higher yields typically led to greater calorie and protein intake among rural households within adopting regions. For example, Pinstrup-Andersen and Jaramillo (1991) found that the spread of HYV rice in North Arcot district, South India, led to substantial increases over a 10-year period in the energy and protein consumption of farmers and landless workers. Their analysis showed that, after controlling for changes in nonfarm sources of income and food prices, about one-third of the calorie increase could be attributed to increased rice production. Ryan and Asokan (1977) also found complementary net increases in protein and calorie availability as a result of GR wheat in the six major producing states of India, despite some reduction in the area of pulses grown.

More aggregate analysis of the impacts of rising incomes on diets and nutrient intake has proved more complex, particularly as concern has shifted from calorie and protein deficiencies to micronutrients and broader nutritional well-being. Food price declines are, in general, good for households that purchase more food than they sell, as this amounts to an increase in their real income. Real income increases can be used to increase consumption of important staples and to purchase more diverse and nutritionally rich diets. However, a study of Bangladesh showed that a downward trend in the price of rice between 1973–1975 and 1994–1996 was accompanied by upward trends in the real prices of others foods that are richer in micronutrients, making these less accessible to the poor (Bouis, 2000). Similar patterns were observed in India during the 1970s and 1980s when farmers diverted land away from pulses to wheat and rice, leading to sharp increases in the price of pulses and a drop in their per capita consumption (Kennedy and Bouis, 1993; Kataki, 2002).

Since then, there have been substantial changes in food intake patterns in rural India. In particular, the share of cereals in total food expenditure has declined, while that of milk, meat, vegetables, and fruits has increased. Per capita consumption of cereals has also fallen in absolute terms (Nasurudeen et al., 2006). It is significant that these substitutions occurred both among the rich and the poor; not only do the top 25% spend relatively greater amounts on milk, meat, and other nutrient-rich foods, the decline in the share of staples is also apparent among the poorest 25% (J.V. Meenakshi, personal communication). However, since deficiencies in iron and the B vitamins are common among the poor, the increases in micronutrient-rich foods must not always have been high enough to offset the decline from cereals. Other micronutrient deficiencies exist (e.g., vitamins C and D), but these are not related to reductions in cereal consumption.

Agricultural research has been directed at the problem of enhancing the nutritional quality of the diets of the poor. The main research strategies are:

- Improvements in the productivity of fruits, vegetables, livestock, and fish, both in home gardens and ponds for on-farm consumption and more generally to increase the marketed supplies of these nutrient-rich foods
- Promotion of food-crop biodiversity, especially traditional crops and cultivars that are rich in nutrients
- Biofortification of major food staples.

Ali and Hau's (2001) assessment of AVRDC's program in Bangladesh showed significant improvements in nutrition among participating farm families, as well as increased supplies and lower-priced vegetables in the market. However, they also found that while home gardens can increase incomes as well as improve nutritional intake, they are not sufficient to improve nutrition to desired levels and there is still need for nutritional education. After reviewing 30 agricultural interventions (including six from South Asia) to improve nutrition among participating families, Berti et al. (2004) also conclude that interventions need to be complemented by investments in nutrition education and health services and targeted in ways that empower women with additional spending power.

Biofortification research is relatively new and, although the CGIAR and its national partners are working together on some aspects of this under the aegis of the Harvest Plus Challenge Program (Bouis et al., 2000), it is rather early to measure any impacts, although one *ex ante* study has been completed (Meenakshi et al., 2007).

5. Environmental impacts

5.1 Environmental impact pathways

Agricultural growth can impact on the environment in many ways and it is helpful to distinguish between the problems associated with intensive irrigated and high-potential rainfed areas, where agricultural growth is largely of the land-intensification (yield-increasing) type, and the problems of less-favored or less-developed areas, where agricultural growth is often of the expansionary (land-increasing) type. It should be noted, however, that the problems of the two types can sometimes overlap. The drivers of change and the appropriate research and policy responses are quite different in these two environments (Hazell and Wood, 2008).

In LFAs, crop area expansion is often realized by reductions in the length of fallows and by encroachment into forests and fragile lands (e.g., steep hillsides and watershed protection areas), resulting in land erosion, declining soil fertility, and loss of biodiversity. Expansionary pathways in South Asia are typically associated with areas of poor infrastructure and market access, poverty, and population pressure.

Agricultural intensification in high-potential areas helps avoid the kinds of problems that prevail in many LFAs. By increasing yields, it reduces pressure to expand the cropped area, helping to save forest and other fragile lands from agricultural conversion (Nelson and Maredia, 1999). But intensification often brings its own environmental problems. These include water contamination with nitrates and phosphates from fertilizers and manures, pesticide poisoning of people and wildlife, unsustainable extraction of irrigation water from rivers and groundwater, and loss of biodiversity within agriculture and at landscape levels (Santikarn Kaosa-Ard et al., 2000; Pingali and Rosegrant, 2001). Intensification pathways are associated with the GR and arise mostly in irrigated and high-potential rainfed areas.

Just how serious are the environmental problems associated with agriculture, and are they likely to undermine future production and South Asia's ability to feed itself? Measuring environmental impacts of research and technological change is difficult and as a result good empirical evidence is fragmentary, often subjective, and sometimes in direct contradiction with the overall trends in agricultural productivity. The available evidence tells a mixed story.

Some good news is that despite continued agricultural growth, the total forest area in South Asia has changed little since 1990 (Table 11). Declines in Nepal, Pakistan and Sri Lanka have been offset by forest expan-

Table 11. Change in extent of forest and other wooded land ('000 ha)

	Forest			Other wooded land		
Country	1990	2000	2005	1990	2000	2005
Bangladesh	882	884	871	44	53	58
Bhutan	3035	3141	3195	566	609	611
India	63,939	67,554	67,701	5894	4732	4110
Nepal	4817	3900	3636	1180	1753	1897
Pakistan	2527	2116	1902	1191	1323	1389
Sri Lanka	2350	2082	1933	0	0	0
Total	**77,580**	**79,677**	**79,238**	**8875**	**8470**	**8065**

Source: FAO (2005)

sion in India. There has, however, been a 10% decline in the total area of other woodland, including a 30% reduction in India, which may be a better indicator of the competition between tree cover and agricultural expansion, particularly in LFAs.

Less encouraging are several international land-assessment exercises that have reported widespread degradation of most types of agricultural land in South Asia. The Global Land Assessment of Degradation (GLASOD) mapping exercise of Oldeman et al. (1991) found that 43% of South Asia's agricultural land was degraded to some degree. Young (1993) subsequently revisited these estimates using additional national data, claiming the problem was actually more severe and that nearly three-quarters of the agricultural land area was degraded to some extent, and that 40% was moderately or severely degraded (Table 12). Degradation associated with irrigation accounts for 23% of the total degraded area and for 25% of the moderately or severely degraded area. For India, Sehgal and Abrol (1994) estimated that 64% of the land area is degraded to some extent, with 54% moderately to severely degraded.

Although these data provide a useful warning, they do not tell us much about the causes. Agriculture is only one contributing factor; others include geological processes (especially in the Himalayas), mining, road construction, and urban and industrial encroachment. Even where agriculture is responsible, we need to separate out the land degradation due to agricultural extensification versus agricultural intensification. It is also hard to reconcile some of these estimates with the continuing growth in average yields and land productivity across South Asia. While there are reports of hotspot areas where degradation is adversely affecting both the productivity and sustainability of land, there must be large areas where agricultural productivity is not adversely affected and where the problems are overstated. Some of the problem areas are intensively farmed irrigated areas, but many are rainfed farming areas that, especially in the Himalayas and semi-arid areas, are farmed more extensively.

More detailed data are available about the impact of irrigation on the waterlogging and salinization of irrigated land:

- About 4.2 million hectares of irrigated lands (26% total) are affected by salinization in Pakistan (Ghassemi et al., 1995). Chakravorty (1998) claims that one-third of the irrigated area in Pakistan is subject to waterlogging and 14% is saline. Salinity retards plant growth – he also claims agricultural output is lower than it would otherwise be, by about 25%.
- Dogra (1986) estimates that in India nearly 4.5 million hectares of irrigated

Table 12. Extent of degradation of agricultural land in South Asia[a]

Type of degradation	% total that is degraded	% total that is moderately or severely degraded
Water erosion	25	15
Wind erosion	18	13.9
Soil fertility decline	13	1.3
Waterlogging	2	1.5
Salinization	9	6.5
Lowering of water table	6	2.4
Total	**73**	**40.6**

a. Includes Afghanistan, Bangladesh, Bhutan, India, Iran, Nepal, Pakistan, and Sri Lanka.
Source: Young (1993) as summarized by Scherr (1999)

land are affected by salinization and a further 6 million hectares by waterlogging; India had about 57 million hectares of net irrigated land in the late 1990s. Umali (1993), quoted in Maredia and Pingali (2001, p. 13) claims that 7 million hectares of arable land has been abandoned in India because of excessive salt.
- In a random sample of 110 farmers from four villages in Uttar Pradesh, Joshi and Jha (1991) found a 50% decline in crop yields over 8 years due to salinization and waterlogging in irrigation systems.

Even more disconcerting for irrigated agriculture is the threat from the growing scarcity of fresh water in much of South Asia. Many countries are approaching the point where they can no longer afford to allocate two-thirds or more of their fresh water supplies to agriculture (Comprehensive Assessment Secretariat, 2006). Most of the major river systems in South Asia are already fully exploited, and the massive expansion of tubewell irrigation in Bangladesh, India, and Pakistan has led to serious overdrawing of groundwater and falling water tables.

On the Indian subcontinent, groundwater withdrawals have surged from less than 20 cubic kilometres to more than 250 cubic kilometres per year since the 1950s (Shah et al., 2003). More than a fifth of groundwater aquifers are overexploited in the Punjab, Haryana, Rajasthan, and Tamil Nadu, and groundwater levels are falling (World Bank, 2007; Postel, 1993). Even as current water supplies are stretched, the demands for industry, urban household use, and environmental purposes are growing (Comprehensive Assessment Secretariat, 2006; Rosegrant and Hazell, 2000). It would seem that either farmers must learn to use irrigation water more sparingly and more sustainably, or the irrigated area will have to contract.

Finally, as discussed in Section 3, there is growing evidence from long-term crop trials and declining TFP of the adverse impact of environmental stress on crop yields in some GR areas. This may be the result of the formation of hard pans in the sub-soil, soil toxicity buildups – especially iron – and micronutrient deficiencies – especially zinc (Pingali et al., 1997).

5.2 The R&D response

A growing awareness of these environmental problems has led to significant changes in agricultural R&D in South Asia since the early GR years. It has led to the entry of environmentally oriented NGOs, some of whom have contested the GR approach and undertaken research and extension activities of their own to broaden the spectrum of technologies and farming practices available to farmers. The national and international R&D systems have also invested heavily in NRM research and technologies and management practices for improving water, pest, and soil fertility management.

One of the outcomes of greater NGO involvement has been a lively debate about competing farming paradigms, and 'alternative' farming[8] has been offered as a more sustainable and environmentally friendly alternative to the modern-input based approach associated with the GR. The alternative farming approach includes extremes that eschew use of any modern inputs as a matter of principle (e.g., organic farming), but also includes more eclectic whole-farming systems approaches such as low external input farming (Tripp, 2006) and ecoagriculture (McNeely and Scherr, 2003). Pretty (2008) provides a useful review of these approaches.

While the alternative farming literature provides many successful examples of agricultural intensification, most of these have arisen in rainfed farming systems that largely missed out on the GR. We shall review several of these experiences in Section 5.4 on LFAs. But by 'sleight of aggregation', proponents of alternative agriculture frequently mix these kinds of successes with much more modest results obtained in GR areas, giving the impression that productivity levels can be increased significantly across the board by switching to alternative farming approaches. In fact, most alternative farming approaches cannot match the high productivity levels achieved by modern farming methods in GR areas. Pretty et al. (2007) in a revisit of Pretty et al. (2003) examined yield claims for 286 sustainable agriculture projects

8 Sometimes also called 'sustainable' or 'ecological' farming.

disaggregated into eight farming systems categories developed by Dixon et al. (2001) and showed that the more sizeable gains nearly all arose within rainfed farming systems. Moreover, the gains reported for rice and wheat yields, the main GR crops, were modest, sometimes even negative.

Despite significant R&D investments in environmentally oriented research of both paradigms, there are very few impact studies of the value of that work. As with poverty impact assessment, the state of the art in assessing environmental impacts in ways that can be quantified in social cost–benefit calculations is still poorly developed. This is partly because of difficulties in measuring environmental changes over the time spans and levels of scale required, and also because of difficulties in assigning economic values to changes, even when they can be measured (Freeman et al., 2005). The few impact studies that exist either report changes in selected physical indicators or rely on farmers' perceptions of change in resource or environmental condition. However, these are sufficient to demonstrate that relevant work has been undertaken with proven productivity and environmental impacts in the field, even though we do not yet have calculations of the rates of return to those investments to show which types of institutions or research give the best returns.

In reviewing these developments and their impacts, we continue with the useful distinction between intensively farmed GR areas and extensively farmed LFAs.

5.3 Evidence on impact in Green Revolution areas

Only a few GR critics argue for a drastic reversal from GR to traditional technologies of the kinds that dominated South Asia before the GR (e.g., Shiva, 1991; Nellithanam et al., 1998). Such authors claim that yield growth rates were already high before the GR, but ignore the fact that this was largely the result of the spread of irrigation and fertilizers prior to the introduction of HYVs (Evenson et al., 1999). More generally, R&D has contributed to a broad range of technologies for improving soil, water and pest management in GR areas that span the spectrum from zero use of modern inputs to high but precision-managed use.

Organic farming

Despite widespread publicity to the contrary, organic farming seems to have little to offer farmers in GR areas who wish to continue to grow cereals. A recent study (Halberg et al., 2006, p. 40) concludes: "In high-yielding regions with near to economic optimal inputs of fertilizers and pesticides, the yields of organic farming are between 15 and 35% lower than present yields when comparing single crops, and possibly at the low end (35%) when including crop failures and the need for green manure in crop rotations."[9] This statement draws heavily on results from temperate countries, and crop losses could be even higher in tropical countries because of greater problems with pest and disease control. The same study concludes that organic farming has more to offer farmers in less-intensively farmed areas, such as many LFAs, or farmers who can benefit from price premiums for organically produced foods. Zundel and Kilcher (2007) report somewhat lower yield losses for organic farming in temperate and irrigated areas, but do not allow for crop failures and diversion of land to produce green manure and other organic matter.

Badgley et al. (2007) reviewed a large number of published studies comparing organic and conventional crops. Although they claim organically grown grains in developing countries have an average yield advantage of 57%, the more detailed results in their Table A1 tell a more nuanced story. Organically grown rice under irrigated conditions in South Asian countries showed little if any yield gain. The best organic farming yield gains for South Asia were obtained on upland rice and for maize and sorghum grown under

9 Since organic agriculture involves greater generation of plant nutrients and organic matter within the landscape through crop rotations, fallows, green manures, and integration of livestock into cropping systems, each hectare of cropland harvested must be supported by additional land dedicated to these other needs. While it might well be possible to obtain comparable yields for some crops at the plot level, farm level productivity can be considerably lower for organic farming. Yet few studies of yield gains with organic farming seem to make this basic correction, leading to results that are inevitably biased in their favour.

rainfed conditions. These are areas where the conventionally grown crops usually receive limited nutrient inputs of any kind and hence produce low yields.

System of rice intensification (SRI)

SRI was developed in the early1980s by Henri de Laulanie, a French missionary priest in Madagascar, as another alternative farming approach to the available GR rice technologies for small-scale farmers. It has since been widely promoted by a number of NGOs and the International Institute for Food, Agriculture and Development (IIFAD) at Cornell University (http://ciifad.cornell.edu/sri). Not only was SRI initially developed outside the international and public-sector research systems, but if its claimed benefits proved true, it would render irrelevant much of the research on intensive rice farming that has been conducted in recent decades by the public and international R&D systems. Not surprisingly, SRI has attracted the attention of the scientific and donor communities and sparked a lively debate and research agenda.

The main components of SRI are: transplanting of young seedlings (8–15 day-old instead of 3–4 week-old plants) on small hills at much lower plant densities than usual; water management that keeps the soil moist rather than flooded; frequent weeding; and use of large amounts of organic compost for fertilizer.

The claimed benefits include: high yields even with traditional rice varieties; a significant savings in seed; little or no artificial fertilizer required; natural pest and disease control, eliminating the need for pesticides; reduced water use; and a flexible management that allows farmers to experiment and adapt the approach to their particular growing conditions. The approach is claimed to be environmentally sustainable and of particularly relevance for poorer farmers who cannot afford modern inputs (Uphoff, 2003).

Controversy has arisen because of claims of very high yields, sometimes exceeding the best experiment station yields for modern rice technologies, sometimes even without the use of fertilizer or modern varieties. These high yields defy current understanding of the physiology of rice plant growth (Sheehy et al., 2005). Proponents argue that there are strong synergies between the different management components of SRI that lead to strong root growth and higher yields, although these synergies are not well understood (Mishra et al., 2006).

Few of the yield claims have been verified under controlled experimental conditions. Trials undertaken at IRRI found no significant yield differences between SRI and conventional GR practices (quoted in Namara et al., 2003). McDonald et al. (2006) analyzed 40 sets of field trial results reported in the literature (five from Madagascar and 35 from 11 Asian countries) which compared SRI with 'best management practices' appropriate to each site. Apart from the five Madagascar studies, which consistently showed higher yields with SRI, SRI led to an average yield loss of 11% in the other 35 studies, with a range of -61% to 22%.

Yield gains appear to be better in farm adoption studies. Farmers in Ratnapura and Kurunegala Districts in Sri Lanka obtained 44% higher yields on average with SRI than with modern rice farming methods (Namara et al., 2003), and the average yield gain was 32% for farmers in Purila District of West Bengal (Sinha and Talati, 2007). However, in both studies SRI farmers showed considerable variation in the management methods they used, making it rather unclear as to what was being compared in the name of SRI. For example, many SRI farmers used inorganic fertilizer as well as compost, many grew modern as well as traditional rice varieties, and their weeding and water management practices varied considerably.

SRI has yet to be widely adopted in any one country, although it can be found on small scales in many countries, including many parts of South Asia.[10] Some of the reasons for poor uptake include: the difficulties of controlling water with sufficient precision in many surface irrigation systems, the need for large amounts of compost, and the high labor demands for transplanting, hand weeding[11] and generating and distributing

10 See http://ciifad.cornell.edu/sri

11 The combination of wide spacing and reduced flooding creates ideal conditions for weed growth and hence the need for frequent weeding.

compost. This is confirmed by available adoption studies. In Sri Lanka, adoption is positively related to family size (availability of labor) and ownership of animals (availability of manure) and is more common among rainfed than irrigated rice farmers (Namara et al., 2003). Moser and Barrett (2003) obtained similar results in an adoption study in Madagascar. Moser and Barrett (2003), Namara et al. (2003), and Sinha and Talati (2007) all found that adopters only practice SRI on small parts of their rice area despite higher returns to both land and labor, and they also found high rates of disadoption. This again suggests important constraints, possibly labor or suitability of available irrigation systems, as well as disappointing returns.

Improved nutrient management

More pragmatic approaches to intensive farming seek to increase the efficiency of fertilizer use rather than displace it, thereby reducing production costs and environmental problems. Fertilizer efficiency can be improved through more precise matching of nutrients to plant needs during the growing season, and by switching to improved fertilizers such as controlled-release fertilizers and deep-placement technologies.

Site-specific nutrient management (SSNM) was developed by IRRI and its partners as a way of reducing fertilizer use, raising yields, and avoiding nitrate runoff and greenhouse gas emissions (especially nitrous oxide) from intensive rice paddies (Pampolino et al., 2007). Developed in the mid-1990s, SSNM is a form of precision farming that aims to apply nutrients at optimal rates and times – taking account of other sources of nutrients in the field and the stage of plant growth – to achieve high rice yields and high efficiency of nutrient use by the crop. Farmers apply nitrogen several times over the growing period and use leaf color charts to determine how much nitrogen to apply at different stages. SSNM has been tested through on-farm trials in several Asian countries and IRRI has developed practical manuals and a web site (www.irri.org/irrc/ssnm) to guide application.

Pampolino et al. (2007) provide an economic assessment of SSNM compared to farmers' usual fertilizer practices. They undertook focus group discussions with adopting and nonadopting farmers at sites in India and two sites in Southeast Asia. For India, yields of adopting farmers were found to be 17% higher. Modest savings in fertilizer use were largely offset by higher labor costs, but profit per hectare was 48% higher. There was also a useful reduction in emissions of nitrous oxide, a powerful greenhouse gas. In an impact study in West Bengal, India, Islam et al. (2007) found small (but not significant) increases in yields, but 20% savings in nitrogen use and 50% savings in pesticide use, and economic benefits of US$19–27 per hectare depending on the season.

The International Center for Soil Fertility and Agricultural Development (IFDC) has been pioneering urea deep placement (UDP) technology in rice. This involves the deep placement of urea in the form of supergranules or small briquettes into puddled soil shortly after transplanting the rice (Bowen et al., 2005). The method improves nitrogen-use efficiency by keeping most of the urea nitrogen in the soil close to the plant roots and out of the floodwater where it is susceptible to loss. On-farm trials in Bangladesh that compared UDP with standard urea broadcasting practices showed 50–60% savings in urea use and yield increases of about one ton per hectare (Bowen et al., 2005). The briquettes are also simple to make with small pressing machines, and can create additional local employment. Adoption data are not available, but the approach appears to be spreading in Bangladesh with the active support of the government.

Low or zero tillage (ZT)

In response to the declining growth in productivity of the rice–wheat farming system in the IGP, ZT has been adapted and introduced by the RWC, a partnership of CGIAR centers and the NARS from Bangladesh, India, Nepal, and Pakistan. The technology involves the direct planting of wheat after rice without any land preparation. Rice crop residues from the previous season are left on the ground as mulch. The wheat seed is typically inserted together with small amounts of fertilizer into slits made with a special tractor-drawn seed drill. The technology has many claimed advantages over conventional tillage in the rice–wheat system: it saves labor, fertilizer and energy; minimizes planting delays between crops; conserves soil; reduces irrigation water needs; increases tolerance to drought; and reduces greenhouse gas emissions (Erenstein et al., 2007; World Bank, 2007). But it often requires some use of herbicides for general weed control. A key ingredient for its success has been the development of an appropriate seed drill for local conditions in the IGP.

In an assessment of the technology based on a sample of farmers in Haryana, India and the Punjab, Pakistan, Erenstein et al. (2007) found that ZT adoption has been rapid. In Haryana, 34.5% of the sampled farmers had adopted in 2003/04 and 19.4% in the Punjab, even though diffusion of the technology only began around 2000. Adopting farmers used the technology on large shares of their total wheat areas. Adoption has been highest on larger farms with tractors. The study found mixed results for yield gains and water savings (more significant in Haryana than the Punjab) but all farms made drastic savings in tractor and fuel costs. There were no observed impacts on the following rice crop. Although the technology is attractive to farmers, the high percentage of non-adopting farmers together with disadoption rates of 10–15% suggests continuing constraints on its use. No one factor was clearly identified in the study, but access to tractors and ZT seed drills is important, especially for smaller farms. Rental markets for these machines exist but may not offer farmers sufficient flexibility in the timing of their operations, which is crucial if higher yields are to be obtained. Other ZT assessments from adoption studies, on-farm trials and focus group discussions confirm the large savings in tractor and fuel costs, and most show significant water savings and yield gains (Laxmi et al., 2007; Laxmi and Mishra, 2007).

It is estimated that about 200,000 hectares of wheat was planted under ZT in the Pakistan IGP in 2001/02 and 820,000 hectares in the Indian IGP in 2003/04 (about 8% of the total wheat area). The latter had doubled by 2004/05 (Laxmi et al., 2007). Based on an estimated ceiling adoption rate of 33%, Laxmi et al. (2007) undertook an economic assessment of the likely returns to the research costs incurred by the RWC partners in developing the technology for India's IGP. Even with conservative assumptions about yield gains (6%) and cost savings (5%), the estimated benefit–cost ratio is 39 and the internal rate of return is 57%. With more optimistic assumptions (yield gains and cost savings of 10%), the benefit–cost ratio increases to 68 and the internal rate of return to 66%. This analysis does not include any environmental benefits.

Improved water management

Improved water management in South Asian agriculture is essential for redressing growing water scarcities, improving water quality, and halting the degradation of additional irrigated land. This will require significant and complementary changes in policies, institutions, and water management technologies. Agricultural research has been conducted on all three aspects, although little of this research has been subjected to impact analyses.

Technical research has shown the potential to increase yields in irrigated farming with substantial savings in water use (e.g., Mondal et al., 1993; Guerra et al., 1998). Realizing these gains is easiest when farmers have direct control over their water supplies, as with tubewell irrigation or small-scale farmer-managed irrigation schemes. For larger schemes, the best hope lies in the devolution of water management to local water user groups or associations, an approach known as irrigation management transfer (IMT).

IMT began to be adopted in some South Asian countries during the late 1980s as a response to the disappointing performance of many large-scale irrigation schemes. It was hoped that IMT would increase the accountability of water irrigation services to farmers, encourage greater farmer input into the maintenance of irrigation systems, improve cost recovery, and enable improved control of water at local levels. All this was expected to lead to higher water use efficiency, increased agricultural productivity, better environmental outcomes, and irrigation schemes that were more financially sustainable.

Despite the promise, there was little hard evidence to show that IMT did in fact lead to these realized benefits. IWMI therefore embarked on a set of studies in 1992 to monitor and evaluate the experience with IMT and provide guidelines for its successful implementation in the future. The results from the Asian case studies proved disappointing. Sri Lanka, which began to implement IMT in 1988, is typical of the results obtained. Samad and Vermillion (1999) surveyed irrigation schemes that had been transferred and some that had not, and within each there were schemes that were rehabilitated and some that were not. The findings suggest only modest gains to farmers or the sustainability of irrigation schemes. Farmers in IMT areas did not incur additional water supply costs, but neither did they perceive any improvements in the quality of water services they received from their irrigation agency. There were significant gains in yields, land, and water productivity in some IMT areas, but the best results were obtained in schemes that were both rehabilitated and transferred to producer organizations. Simply devolving management without also rehabilitating the irrigation schemes achieved little.

Following these mixed findings, IWMI embarked on a follow-up program of research to identify best practice approaches from around the developing world. Within South Asia, IWMI subsequently provided policy advice to the governments of Sri Lanka and Nepal in developing national IMT strategies, and engaged in action research in Pakistan and Sri Lanka to help improve implementation policies. This led to the development with the Food and Agriculture Organization of the United Nations (FAO) of a handbook on best practice (Vermillion and Sagardoy, 1999) and to a number of guidelines papers on specific implementation issues.

A subsequent assessment of IWMI's work on IMT is provided by Giordano et al. (2007). They claim significant impact on water policies in Nepal and Sri Lanka and some success in affecting the employment of improved techniques in Pakistan and Nepal. They also report high demand for IWMI's guideline publications on IMT.

Integrated pest management (IPM)

Pest problems emerged as an important problem during the early GR era because many of the first HYVs released had poor resistance to some important pests. The problem was compounded by a shift to higher cropping intensities, monocropping, high fertilizer use (which creates dense, lush canopies in which pests can thrive), and the planting of large adjacent areas to similar varieties with a common susceptibility. Control was initially based on prophylactic chemical applications, driven by the calendar rather than incidence of pest attack. This approach disrupted the natural pest–predator balance and led to a resurgence of pest populations that required even more pesticide applications to control. Problems were compounded by the buildup of pest resistance to the most commonly used pesticides. As pesticide use increased, so did environmental and health problems. Rola and Pingali (1993) found that the health costs of pesticide use in rice reached the point where they more than offset the economic benefits from pest control.

As these problems began to emerge, researchers gave greater attention to the development of crop varieties that have good resistance to important pests and biological and ecological pest control methods. This led to the development of IPM, an approach that integrates pest-resistant varieties, natural control mechanisms, and the judicious use of some pesticides. The CGIAR centers have been important sources of research on IPM, and IRRI has been especially important for IPM in rice in Asia (Waibel, 1999).

Bangladesh has been in the forefront of IPM since 1981, and the government, with assistance from FAO, has aggressively promoted the approach through farmers' training schools. Sabur and Molla (2001) undertook a farm survey in 1997/98 and found that IPM farmers used less than half the amount of pesticides on rice than non-IPM farmers and had significantly higher gross income per hectare. Similar results were obtained by Susmita et al. (2007) and by Rasul and Thapa (2003). Both studies found that IPM farmers saved significantly on costs (labor and pesticides). None of the studies report any significant productivity impact from use or IPM, so the main economic benefits arise from lower costs. Farmers perceived fewer health problems with IPM in all three studies, though neither Susmita et al. (2007) or Rasul and Thapa (2003) could find statistical differences between the perceptions of adopting and non-adopting farmers. None of the studies provides any data on environmental impacts.

There is no hard evidence to show that IPM has been widely adopted among South Asian farmers. There are two difficult constraints to overcome. One is farmer training; IPM is knowledge-intensive, requiring farmers have the capability to identify harmful and beneficial insects and the ability to flexibly manage their response to pest attacks. Farmer field schools have had some success in providing the required training (Waibel, 1999; Tripp et al., 2006; van den Berg and Jiggins, 2007). But this can be a slow and expensive way of training large numbers of farmers – particularly if, as Tripp et al. (2006) found in Sri Lanka, knowledge-intensive methods like IPM do not easily spread from farmer to farmer. The other constraint is the need for collective action among neighboring farmers. IPM cannot be successfully undertaken at single plot or farm levels but must be adopted at landscape levels. This is difficult to organize without effective community or producer organizations.

5.4 Evidence on impact in less-favored areas

Following Pender and Hazell (2000), LFAs are broadly defined in this paper to include lands that have been neglected by humans as well as by nature. They include marginal lands that are of low agricultural potential due to low and uncertain rainfall, poor soils, steep slopes, or other biophysical constraints; as well as areas that may have higher development potential but that are presently under-exploited due to poor infrastructure and market access, low population density, or other socioeconomic constraints. Conceptually they include all the shaded areas in Table 13.

An attempt to operationalize this two-dimensioned concept of LFAs suggests that about one quarter of South Asia's rural population live in LFAs (World Bank, 2007).

Much of the deforestation, woodland loss, and land degradation (including soil erosion and soil fertility loss) that has occurred in South Asia arose in LFAs that did not benefit much from the GR. This degradation is often driven by insufficient agricultural intensification relative to population growth. As more and more people seek to eke a living out of these areas, they expand cropping in unsustainable and erosive ways and fail to replenish the soil nutrients that they remove. While migration and nonfarm development have important roles to play in reducing pressures on the natural resource base, more sustainable forms of agricultural growth are needed if the environmental problems in these areas are to be reversed.

LFAs also account for a significant proportion of the rural poor in South Asia. Precise estimation is difficult because poverty data are reported by administrative units rather than by agroecological areas or farming systems. Fan and Hazell (2000) estimated that 41% of India's rural poor (76 million people) lived in LFAs in 1993, and ICRISAT estimates that 40% of India's rural poor live

Table 13. Classification of favored and less-favored areas

Access to markets and infrastructure	Agricultural potential	
	High	Low (biophysical constraints)
High	Favored areas	Marginal areas (LFAs)
Low	Remote areas (LFAs)	Marginal and remote LFAs

Source: Pender and Hazell (2000)

in the semi-arid tropics and another 16% in arid areas and semi-arid temperate areas (Rao et al., 2005). There is some controversy about whether the incidence of poverty is higher among LFA populations than in irrigated and high-potential rainfed areas, but since estimates range from "no significant difference" (Kelley and Rao, 1995) to "higher concentrations of poor in LFAs" (Fan and Hazell, 2000), this controversy need not detract from the importance of agricultural research for LFAs.

An early and appropriate (at that time) bias during the GR era towards R&D spending on irrigated areas and best rainfed areas has changed. Pal and Byerlee (2006) found no evidence of any underinvestment (relative to irrigated areas) in rainfed and marginal lands by 1996–1998. At a commodity level, Byerlee and Morris (1993) did not find any bias for wheat research, but Pandey and Pal (2007) found a modest bias against LFAs in the allocation of research scientists for rice research. These studies calculate desired research shares on the basis of congruency with agricultural or commodity outputs and not on the basis of poverty. An analysis based on poverty might tell a different story, but that would first require resolving the controversy about where the poor are most concentrated, as well as an analysis of the relative merits of the indirect (e.g., food and labor market) benefits from investing in each type of area (Renkow, 2000). An environmental perspective might also justify greater investment in agricultural research in many LFAs[12].

Most LFAs in South Asia are unsuitable for the kinds of intensive monocrop farming associated with the GR. A lack of irrigation potential, erratic and often deficient rainfall, poor soils, and, often, sloped land make crops less responsive to fertilizers, and the fragility of the resource base requires more integrated and mixed farming approaches to avoid degradation. Economically, the remoteness of many LFAs from markets also makes modern inputs expensive relative to the prices farmers receive for their products. In this context, a lot of research has been targeted at improving NRM practices that conserve and efficiently use scarce water, control erosion, and restore soil fertility while using low amounts of external inputs. These kinds of technology improvements can lead to significant gains in productivity and stability while reversing some types of resource degradation. Within this context, there has been considerable convergence between the objectives and approaches of different farming paradigms for LFAs.

The analysis by Pretty et al. (2007) of yield claims for 286 sustainable agriculture projects from around the developing world showed that the more sizeable gains nearly all arose within rainfed farming systems. Some of the most successful projects for these areas included improved crop varieties, water harvesting, soil, and water conservation at catchment or watershed levels, and use of organic residues for soil improvement. For South Asia, yield gains of 63% are reported for highland mixed farming systems in India, Nepal, Pakistan, and Sri Lanka, and 79% for rainfed mixed farming systems in India.

Of 293 yield ratios for organic versus modern crop production methods, reviewed by Badgley et al. (2007), only 10 have relevance to LFAs in South Asia. There are five ratios for upland rice (ranging from 1.23 in Pakistan to 3.4 in Nepal) and five for sorghum and millets in India (ranging from 1.65 to 3.5). Organic farming in these locations requires mixed farming, soil and water conservation, and use of organic residues for soil improvement.

While there are grounds to be skeptical about the high yield levels claimed in some of these studies (Cassman, 2007), they are consistent with the fact that the existing farming systems are low-yielding, usually because of low rates of application of fertilizers or organic matter and poor soil and water management. In these circumstances, many improved NRM practices that reverse land degradation, improve soil condition, and provide much-needed water and nutrients for crops can make a large difference, whether motivated by alternative or modern agricultural philosophies. Even so, one recent study undertaken in a less-developed and hilly area of Himachal Pradesh, India, found that while organically grown wheat

12 An attempt to prioritize agricultural R&D on the basis of production, poverty, and environmental goals has been undertaken by Mruthyunjaya et al. (2003).

and maize were more profitable than their modern production counterparts, this was nearly all due to a price premium of about 100% (Thakur and Sharma, 2005).

Important lines of research in LFAs involving CGIAR centers in South Asia include crop improvement, watershed development, and integrated soil nutrient management.

Crop improvement research

Much plant breeding for LFAs has focused on producing varieties that can withstand drought and poor soil conditions and that have greater pest and disease resistance. Such varieties can raise average yield response and reduce yield instability. They can also contribute to reductions in pesticide use and, by raising the productivity of food crops, help reduce the cropped area needed by subsistence-oriented farmers. This can reduce the pressure on more fragile lands and free up some land and labor for other activities. Most of ICRISAT's crop improvement research is directed at LFAs, and there are spill-in benefits to these areas from the crop improvement work that IRRI (upland rice), CIMMYT (maize), and CIP (potatoes) undertake more broadly in Asia.

At an aggregate level, there is evidence from India that crop improvement research is having favorable productivity and poverty impacts in many LFAs (Fan and Hazell, 2000). Based on an econometric analysis of time-series data for three different types of agricultural areas (irrigated, high-potential rainfed, and low-potential rainfed), they found more favorable marginal returns (measured as rupees of agricultural production per additional hectare planted to modern varieties) for crop improvement research in low-potential rainfed areas than in either high-potential rainfed areas or irrigated areas. Moreover, additional crop research investment in low-potential rainfed areas lifts more people out of poverty than in the other two types of areas. Fan et al. (2000a) provide a more nuanced set of results for 13 different types of rainfed zones in India. They found seven zones where the benefit–cost ratio for additional crop-improvement research is greater than five and where there are also favorable poverty impacts. Neither of these studies assesses environmental impacts.

The measured impacts of some of the commodity-improvement work reviewed in Section 3.2 have arisen in LFAs (e.g., maize, sorghum, and millet), although the cited studies do not separate out the impacts in LFAs from GR areas. However, a few examples illustrate the impacts of crop-improvement research that was targeted to the specific problems of poor people in LFAs.

As mentioned earlier, Shiyani et al. (2002) found that ICRISAT-improved chickpea varieties have been widely adopted in a poor tribal area in Gujarat, India, with favorable impacts on yields, unit production costs, and net returns per hectare.

ICRISAT's package of improved groundnut varieties grown in combination with improved agronomy practices built around an RBF concept (see Table 9 and earlier discussion) is another example of a commodity-improvement program that has paid off handsomely in an LFA – in this case the semi-arid tropical areas of central India. The high internal rate of return of about 25% reported by Joshi and Bantilan (1998) is seemingly robust to within a percentage point or two, even when corrected for possible positive and negative environmental outcomes that affect yield and production costs (Bantilan et al., 2005). This is one of the few available impact studies that attempts to value environmental impacts within a benefit–cost analysis framework.

Watershed development

There have been significant investments in research on watershed development in South Asia in recent decades. India began developing model operational research projects in a number of representative watersheds in the mid-1970s, and these were used to test and validate integrated watershed management approaches before they were scaled up in huge publicly funded schemes across the country. By 1999/2000, India had spent Rs. 35,915 million to develop 37 million ha, or 22% of the problem area (Babu and Dhyani, 2005), and by the late 1990s was spending about US$500 million each year on additional watershed development projects (Kerr et al., 2000). The total had exceeded US$2 billion by 1999/2000 (Joshi et al., 2004). ICRISAT and IWMI have both undertaken research on watershed development and related soil and water management issues and have been involved in watershed evaluation work.

There have been many evaluations of watershed development projects in India, though seemingly none on the returns to research on watershed development. Joshi et al. (2005b) undertook a meta-analysis of 311 evaluation studies spanning a large number of types of projects and agroclimatic conditions. They found that the average benefit–cost ratio was 2.14 (with a range of 0.8–7.1), and the average internal rate of return was 22% (with a range of 1.4–94%). On average, the projects created additional employment of 181 days per hectare per year, increased the irrigated area by 34% and the cropping intensity by 64%, and slowed soil losses by 0.82 tons per hectare per year. Among other things, the meta-analysis showed that the benefit–cost ratio was:

- Higher in areas with annual rainfall of between 700 and 1100 mm than in areas with low (less than 700 mm) or high (greater than 1100 mm) rainfall
- 42% greater in macro-watersheds (greater than 1250 hectares) than in micro-watersheds
- Larger when state governments were involved in the planning and execution compared to purely central government projects
- Higher when there was active people's participation.

Kerr et al. (2000) surveyed 86 villages in Maharashtra and Andhra Pradesh, some of which were included in watershed projects and some not. Three types of projects were included: government (Ministry of Agriculture)-run projects, NGO-run projects, and projects that were run collaboratively between NGOs and state government. The government projects largely focused on technical improvements; NGO projects focused more on social organization; and the collaborative projects tried to draw on the strengths of both approaches. Qualitative and quantitative data were both collected, including data on conditions in the study villages before and after the projects were implemented.

Overall, the participatory NGO projects performed better than their technocratic, government-run counterparts. However, participation combined with sound technical input performed best of all. For example, while all projects reduced soil erosion on uncultivated lands in their upper watersheds reasonably well, the NGO and NGO/government collaborative projects had particularly good records in this regard. Greater NGO and community involvement also helped ensure that project investments were maintained over time. Although definitive hydrological data were not available, farmers in villages in NGO and NGO/government projects frequently perceived that the projects' water-harvesting efforts increased the availability of water for irrigation and their net returns to rainfed farming were higher.