CHAPTER 4

TECHNOLOGY, NATURAL RESOURCES AND RURAL POVERTY REDUCTION

Unless the poor have the power to participate in deciding which technology to use, they are unlikely to benefit from it. Better farm technology will most benefit farmers who are active partners in setting priorities for both research and extension.

TECHNOLOGICAL CHOICES AND OPTIONS

Over 70% of the world's extreme poor live in rural areas. They use over half their income to obtain staple food; receive over two thirds of their calories from this low-cost source; and, usually, produce it themselves. Yet often they cannot afford enough food to provide safe amounts of energy or micronutrients.

Improved bio-agricultural technology and water control took hundreds of millions of people out of poverty in 1965-90, mainly by raising food-staples production, employment and affordability. Yet large regions and large numbers of the rural poor gained little from this achievement; and progress has slowed down across the world. In many areas technological changes did not take place. In other areas the potential of existing technology seems to be nearly exhausted. New challenges arise, from land lost to erosion, salinity and urban expansion, and from water depletion and diversion to towns. Important, too, is the need to provide adequate, attractive rural employment incomes, as the numbers of working-age people in most poor regions double in the next 35-45 years. New science can meet the challenges if the poor are allowed to participate in the process. Radical changes in research incentives, organization and management, above all in the relationship between private and public, are needed. This report on rural poverty gives a special emphasis to technology.

New agricultural technology has its opponents; many people prefer to explore other ways to cut rural poverty. However, these alternatives are generally complementary to technical progress and are unlikely, without it, to generate an adequate rate of poverty reduction.

- The empowerment of the rural poor – 'the soul of IFAD' – must include better technology in support of their labour, land and other assets. If technology is weak or unsustainable, the power to control it is worth little. Unless the poor have the power to participate in decisions which determine their use of technology, they will be unlikely to benefit from its implementation. Better farm technology will do more for farmers who are active partners in setting priorities for research, as well as extension.
- Improved land and water management is not an alternative form of technical change to rapid bio-agricultural progress. Without bio-agricultural

progress, better land and water management will neither attract many farmers nor reduce poverty much.

- More available food, through technical development, is not an alternative to more food entitlements for the poor; it is often the most affordable way to provide entitlements, through extra income from small farms and hired work.
- Reducing urban poverty, and rural production of cash-crops, livestock or non-farm products, are not alternatives to the increased growth of staples through technology, but are helped by it.
- Better access to assets, institutions and markets for the poor are not alternatives to improved technology for production by the poor. Without such access, the returns to the poor from technical progress will be disappointing, as will their adoption of low-technology assets.

Why does this report emphasize the importance of staples in farm technology? The rural poor neither live by, nor produce, staples alone. Nonetheless, in South and East Asia, sub-Saharan Africa, marginal uplands and semi-arid lands, most of the poor still live mainly from farm or employment income from growing staples. Technical progress to raise income usually requires increases in the productivity of food staples, achieved by labour-intensive methods. In effect, most of the working poor continue to grow some food staples, and the poorest, having little land, usually buy more food than they sell. They gain in two ways if technical progress increases staples productivity – from cheaper consumption and higher income through more productive work. By reducing the risk of hunger, greater quantities, and reliability of food crops reduce the vulnerability of the poor.

Poverty is often concentrated in areas where the technology to improve the production of staples has not yet been introduced. The rapid reduction in poverty in 2000-20 requires technical progress that is substantial at smallholder level; that is quickly adopted by farmers across a wide range of hitherto neglected areas; that creates productive employment; and that improves the growth of food crops, mainly staples.

To reach their targets, techniques to help the poor must be:

- capable of benefiting the mass of rural poor, whatever their status; and
- adapted to tightening constraints of water and land depletion and loss of biodiversity.

Agrotechnical progress has in the past usually occurred in small increments. It has spread slowly; in some cases, as with mechanization of draught, it has reduced employment without raising yields or making them more sustainable. The prospects of the rural poor have fortunately been transformed by the sharp acceleration since the 1950s of two very old forms of technical change that tend to raise staples yields and employment incomes: water control (greatly extended in South and South-East Asia and China in 1950-85), and plant and animal selection and breeding (culminating in the 1965-85 Green Revolution). Poverty incidence in affected rural areas fell, typically from 30-50% to 5-15%.

In spite of these advances, relevant outlays have plummeted since the early 1980s; and in some countries agricultural research, investment and extension are increasingly being privatized. Public and NGO outlays have not only been reduced but have also been diverted from water control and biological improvement. This has deflected effort from improving the production of poor people's food staples. Imaginative steps to reverse these trends are necessary for reviving the rapid reduction in rural poverty.

One plausible alternative – the substantial expansion of arable land – is not feasible for most rural populations in Asia, and increasingly in much of Africa and Latin America. In areas where it is feasible, it usually results in rising costs and falling returns. The expansion of staples into marginal areas has often exposed the crops to severe environmental stress (for example, maize in

Table 4.1: Rate of yield growth (percentage): cereals, roots and tubers, 1961-98

Cereals	Africa	Developing	E SE Asia	L. America & Caribbean	South Asia	Sub-Sahara
1961-71	1.03	2.76	1.96	1.43	1.88	(0.29)
1971-81	1.98	2.76	2.03	2.38	2.33	2.04
1981-91	(0.75)	1.86	1.67	0.74	3.09	(-0.07)
1991-98	(1.13)	1.55	0.86	2.72	1.7	(0.97)
1966-82	1.94	2.7	2.36	2.23	2.3	1.76
1982-98	0.75	1.67	1.35	2.05	2.69	(0.06)
Roots and tubers	**Africa**	**Developing**	**E SE Asia**	**L. America & Caribbean**	**South Asia**	**Sub-Sahara**
1961-71	0.65	2.95	(0.4)	1.57	4.13	0.65
1971-81	1.52	1.19	2.92	-0.77	1.73	1.44
1981-91	1.95	0.73	1.06	1.07	1.62	1.91
1991-98	(0.34)	0.99	(0.09)	1.02	1.09	(0.25)
1966-82	0.61	1.12	2.38	-0.56	2.04	0.52
1982-98	1.42	0.7	(0.21)	0.87	1.5	1.42

Entries are exponential growth-trend fit betas. Numbers in brackets not significant at 10%.

* significant at 10%. All other entries significant at 5%.

Source: FAOSTAT data tape 1999.

Southern Africa and rice in East Bangladesh). In most cases increasing farm income and employment requires a raising of yields. Yet growth in the yield of staples has declined sharply (Table 4.1).

Staples yield growth in developing countries fell from 3% annually in the 1970s to barely 1% in the 1990s, and staples employment growth from about 2% to below 0.5%, far below the projected growth in the rural workforce through 2015. In the leading-edge areas, farm progress has faltered. Many of the remaining rural poor live in areas largely untouched by modern farm technology. In leading and lagging areas alike, further irrigation and agrochemical use are limited by degradation in natural resources. Appropriate, sustainable land and water management is essential, and advances in livestock and cash-crop technology are desirable.

Meeting the UN target to halve dollar poverty in 1995-2015 demands a revival in technical progress to improve sustainable production of staple foods, with the potential to enhance further employment. Yields can be raised through extension, but it seldom pays farmers to incur the costs and risks of achieving yields beyond, say, 30-50% of research-station yield potential. If the varieties of seed available are not improved, the farmers' yields will not improve either.

Institutions, markets and governments, in their efforts to convert the rural poor to the use of new techniques and technology, should stimulate suppliers and advisers to encourage and support farmers in their adoption of new methods and products.

What techniques are most likely to help the poor? Pro-poor techniques are likely to concentrate on food staples; on better use of water; and on methods of production that raise demand for labour; they are especially well suited for smaller and more deprived farms, particularly those with fewer assets.

New techniques should be:

- more productive of output per unit of input, that is, should cut unit cost;

- more labour-intensive (uses more labour per unit of land or fixed capital); but
- adapted to seasonal labour demand and food needs;
- more robust against climatic, pest and labour-supply risks;
- more stable in labour use and product-flow across seasons and years;
- selecting products mainly made and/or used by the poor;
- cutting or stabilizing the price of staples; and
- more sustainable in terms of land, water and biodiversity.

There is often a trade-off between these features which wise policy can reduce. For example, land sustainability may be enhanced with higher labour/capital ratios by incentives for measures to improve land, by installing vegetative barriers rather than contour bunds. All the above features (except biodiversity) were advanced by the spread of high-yielding cereals in 1965-85, leading to unprecedented poverty reduction.[1]

Technical change to benefit the poor: lessons from history

In a time of popular politics and developed markets, it is now more likely than before that the poor will derive major gains from technology dedicated to improving farming output and employment. Agricultural progress has been driven by research on the farm for millennia; by formal public-sector research since the tenth century in China; and by the Darwin-Mendel scientific revolution which increased the power and pace of such research. Box 4.1 illustrates the process – and shows that some types of technical change have proved likely to spread fast and far and to the poor.

Information in Box 4.1 and recent experience confirm that technical progress in land and water management is usually slow to spread and to bring gains. First, innovations are slow to begin with, and resulting increases in national farm incomes or sustainability are gradual and small. Second, for hundreds of years the range of available techniques has not been enlarged by researched inventions (in land and water management) that substantially raise farm incomes and/or sustainability over a large area. Third, recent decades have seen little acceleration in research outputs. All this is not to deny major local advances.

Much faster gains are normal with technical progress in land cover (animals, crops, varieties), water availability and plant nutrient enhancement. Farmers' choice among available techniques – including shifts among crops, animals, or varieties, together with appropriate nutrient enhancement, and especially with irrigation – often double farm output and income over wide areas in 20 years. Each phase of biochemical advance (Box 4.1) has produced faster farm growth than the previous one; but there is a striking contrast between fast, widespread farm transformation by variety-irrigation-nutrient technology and slow, localized progress from land/water-management technology. Making farmers rely on this, rather than better germplasm or water control, sentences them to a slow reduction in poverty. Most farmers must choose from a slowly changing set of land-water and agronomic methods. Moreover, it pays the farmer to upgrade these only when better germplasm or water control makes it reliable and profitable.

The advances in irrigation over the last two millennia have made much new land usable and boosted crop production on existing land. However, these changes have often produced perverse incentives, with free or subsidized water. This is becoming increasingly hard to maintain as water becomes dearer and scarcer. Water on high-grade land, irrigable for much of the year, will be shifted away from cereals, especially rice, to higher-value crops, such as vegetables. Pressure will be applied to find sustainable methods for growing food staples with high yields, on less productive lands. The

Box 4.1: The global sequence of agrotechnical progress

Each of these advances reduced the amount of work needed to buy food, yet raised demand for – and hence the food-affording capacity of – labour, except 4b, which normally arrives when non-farm labour demand is predominant and expanding.

Time/place	Agrotechnical progress	Information source
1. China c. 5000-2000BC, West Asia 3500-900BC, Europe 2500-700BC-200AD.	Neolithic settlement: from hunter-gathering to crop/animal farming, using sparse labour on underused land. Early crop selection and transformation (maize in Central America).	Bray 1986: 9, 86; Piggott 1981: 30; Ammerman and Cavalli-Sforza 1971
2. Asia 200-800AD, Europe's 'mediaeval revolution' of 600-1200AD. Somewhat later in Africa	First agricultural transformation responding to very slowly rising person/land ratios: from shifting cultivation to stable groups of fields; land levelling, terracing; initial rotation – often cattle as well as crops, interdependent via manuring, draught, and feed.	White 1962; Boserup 1965; Ishikawa 1968
2a. China, much of East/South-East Asia, Near East and North Africa, South India and Sri Lanka; 200BC-1400AD.	Where indicated by water situations, land settlement was followed by the first irrigation revolution: big, centrally managed tanks, but also many small wells and some artesian systems.	
3. China c. 900-1000AD. Europe 1650-1850, 'European colonies' after 1800	Biochemical revolution 1: intense rotation, organic manuring, crop-animal integration, systematic plant breeding	Bray 1986; Mingay 1968: 11; Jones 1974: 78-9
4. Asia, Europe, America 1880-1940	Biochemical revolution 2: applied plant nutrient science (Liebig), formal plant selection; guano, inorganic fertilizers.	
4a. North India, Pakistan, Bangladesh, river valley schemes in China, some of North and East Africa. 1850-90 and 1950-80	Where indicated by scarcities, 'second irrigation revolution' (dams, tubewells).	Pingali *et al.* 1987
4b. After 1920	As farm density rose (Asia) or rural labour scarcity bit (North America, later Europe), draught revolution hoe-animal-tractor	
5. North America from 1930, c. 1955-88 South and East Asia and Europe, parts of Latin America, bits of Africa.	Green Revolution: huge acceleration of staples plant-breeding progress.	

issue of how to make this more sustainable and reliable will become more important.

The biochemical Green Revolution and major irrigation expansion have stalled, after early success. Yet there are three grounds for hoping that poverty will be substantially reduced through further transformation of farming technology.

First, less responsive lands might increase yield, employment and income through sustainable, low-input techniques. But these, however successful, cannot contribute enough to reduce global poverty. There are difficulties:

- If low-input techniques are also low-output, they do not generate much food or income.
- Low-input, high-output techniques that do not increase plant or livestock conversion efficiency of water and nutrients into economic farm output must use up soil nutrients or water and are therefore likely to be unsustainable.
- If such techniques safely and substantially raised conversion efficiency, they would have been adopted by farmers long ago. IFAD's support for extension to accelerate adoption is justified. Areas that received more extension in the past are far quicker to adopt research findings later on,[2] but repeated efforts to introduce rejected innovations seldom achieve much.

The second ground for hope for agrotechnical transformation lies with areas (and perhaps crops) that seem less responsive but in reality are not so, at least not in 2000. In India and China since the early 1990s some agriculturally backward regions show higher marginal returns to irrigation, roads and/or research than the forward irrigated areas.[3] In Southern and Eastern Africa, however, agricultural support outlays appear to have been skewed unduly towards slow-growing farming areas.[4] Also, plants and animals in many such areas are selected for hardiness, despite scarce or unreliable water or nutrients, not for high yield when such inputs are ample. Substantial yield improvements are therefore much less likely from crossing within species such as millets or goats, adapted to marginal semi-arid/arid environments, than within species such as rice or water buffalo, adapted to more resource-rich natural environments.

In these marginal environments, therefore, large rises in crop and livestock productivity may require introduced genes from other species. For many areas and crops, the best hopes lie in a revived Green Revolution, now being made more environmentally sensitive through biotechnology.[5] The scientific prospects are excellent,[6] but at present limited by the focus of research and development on a form of agriculture that caters mainly to rich people in rich countries, not to the food needs of the world's poor.[7] In spite of promising signs of change, substantial gains for the rural poor will require reorganization and revival of public research, and new incentives to private research, both in developing countries and globally.

However, while research is critical, even within the sphere of technology, it is not enough on its own. The rural poor need more information about technological options. Given that sources of "advice" are proliferating (increasingly including private-sector interests and NGOs), it is imperative that the capacity of the poor to evaluate advice is enhanced. This is the necessary social revolution in technology: elevating the poor from technology objects (or recipients) to technology subjects, involved in specification of need, evaluation of responses and choice of productive strategies.

Bio-agricultural research

Farmers and breeders raise yields by genetic selection for plant shape or chemistry that improves response to the normal environment, and to unusually good or bad seasons for, say, rainfall or insect populations. The selection and manipulation of crops and animals into high-yielding varieties (HYVs) is as old as farming. Breeders speed up the process by scientific selection, controlled

Box 4.2: Crop and animal improvement versus biodiversity

There is a conflict in biotechnical progress between biological improvement and biodiversity.

Improvement favours predominance of plant and animal species and varieties that better meet local human needs to raise and stabilize economic returns, cut costs and displace unwanted life-forms (such as weeds). Crop and animal improvement, plus farmers' responses to incentives, mean that plants and animals currently perceived as economically 'good' drive out 'bad'.

Yet this reduces biodiversity. Biodiversity permits complementarities (for example, among nutrient demands and supplies of different plants and animals). It prevents species attrition and losses that often prove disastrous later. Increasing reliance on a few carefully bred crop varieties contributes to a loss of spatial diversity in genetic resources, and to a common vulnerability to the same pest and weather-related risks. For example, IR-36 rice was planted on more than 10 million hectares in Asia. Such varietal specialization has occasionally led to widespread crop losses due to outbreaks of diseases and pests (tungro and brown planthopper in rice) and has necessarily diverted agricultural research expenditures from yield enhancement towards defensive research: maintenance research and germplasm conservation programmes (Anderson *et al.* 1987).

Farmers resolve the conflict by, for example, rotation and mixing of crops and herds; formal researchers, by such means as seed banks. The pressures towards fast improvement are strongest for the poorest, but so is the damage if lost biodiversity induces sudden heavy losses due to pest attack.

crossing, and access to an increasingly wide range of crossing materials and methods. This greatly accelerates farm improvement and rural poverty reduction but also sharpens an age-old conflict between two needs of the rural poor: biological improvement and biodiversity (Box 4.2).

Soil enhancement by manuring, to increase yield, is as old as varietal selection by farmers. But modern agrochemicals (fertilizer, herbicides, pesticides) are barely older than modern plant breeding, which began about 150 years ago. They often complement the yield-enhancing properties of HYVs and make them pay better, but biological HYVs can also substitute for agrochemical paths to higher, more robust yields. Farmers gain if they can keep seeds that incorporate pest resistance or high response to plant nutrients, so avoiding loans at interest to buy pesticide or extra fertilizer. Poor farmers gain most, because it is harder for them to borrow or repay loans. Also, wrapping up fertility and pest resistance in the seed rather than in agrochemicals, if feasible, helps sustainable management of natural resources.

But reducing inorganic fertilizer use is harder than reducing pesticide use. Even the Chinese, with their long experience of organic farming, have increasingly used inorganics as new varieties demanded more from the soil. If such varieties are more pest-resistant, the farmer uses fewer chemicals; but if they are more responsive to nutrients, it may pay him/her to use more chemicals. Use of chemical fertilizers, with careful planning and control, will probably continue to increase in most places as plant varieties improve. Current low fertilizer levels in most of Africa make good agricultural yields or incomes very hard to attain. With careful management, especially the prevention of nitrate and nitrite pollution of drinking water, health gains will far exceed ill-effects, as the poor acquire more income and food.

Agrochemicals and HYVs, when wisely used, have proved their great potential for reducing rural poverty. However, the transition since 1850 from farmer-dominated to scientist-dominated bio-agricultural research, and since 1980 its increasing privatization, threaten to deny, to poor farmers and consumers, both gains from and control over technology. If technical progress excludes the poor, poverty will be little reduced even by improvements in assets, institutions and markets. IFAD has supported participatory research methods that have potential to remedy this problem (Box 4.3).

The pace of varietal improvement in main food staples has been dramatic. Yields were expanded by maize hybrids, and even more by semi-dwarf rice and wheat varieties that turned nutrients into grain rather than straw and which could be heavily fertilized without lodging. These varieties were enhanced to deal with an increasing range of agro-ecologies, water conditions and pests (and pest biotypes). The Green Revolution was the main source of a more-than-doubled aggregate food supply in Asia in 25 years, with only a 4% increase in the net cropped area.[8] Tripled wheat and rice yields in that period were common over large areas of reliably watered cropland, in the Indian and Pakistan Punjab, Central Luzon, and the Muda scheme in Malaysia. By the late 1980s well over 80% of rice and wheat was planted to these high-yielding varieties, though yield gains in unirrigated areas were generally much smaller.

The Green Revolution kept food prices down and employment up. If an area doubled grain yields in the 1970s, as many did, employment per hectare normally rose by 40%, plus a further 30% due to extra farm demand for rural non-farm products.[9] Higher employment-based incomes meant extra food entitlements and cheaper food staples. Further, agriculture in the 1970s comprised 25-40% of GDP in the countries with a Green Revolution, which contributed substantially to their GDP and consumption growth. This typically accounts for 30-50% of international differences in speed of poverty reduction.[10] Without the Green Revolution, the continuation of the near-stagnant yield trends of 1955-65 would have induced massive intensification of production and expansion into previously forested areas and other environmentally fragile lands,[11] encroaching upon their use by marginalized rural people who were often ethnic minorities.

Nevertheless, in the early days of the Green Revolution, some argued that, although large farmers gained, poor farmers lost. Some of the new varieties of grains prospered only with high levels of input and involved high risks that poor farmers could not easily afford or manage. But poor farmers learned to manage the new varieties;

Box 4.3: IFAD-supported work in the CGIAR: focusing on poorer areas can succeed

Since 1979 IFAD has committed USD 99 million to research programmes at CGIAR-centres, focusing on input-output relations in marginal rainfed environments; institutions and incentives to maximize returns and conservation for smallholder assets; and building local capacity for participatory research:

- In 1979-89 IFAD invested USD 8.32 million in a pioneering partnership of the International Centre for Agricultural Research in the Dry Areas (ICARDA) with a NARS (Egypt) that achieved big yield rises, and nutritional improvements, for faba beans.
- Research through ICARDA on wheat and barley for farming systems in the Near East and North Africa produced high-yielding varieties, tolerant to moisture stress, adopted by drought-prone farmers in t12 IFAD investment projects in the region in 1981-85.
- In 1980-86, IFAD financed USD 5.3 million of ICRISAT and International Centre for Tropical Agriculture research on maize-sorghum-legume mixed cropping, leading to sorghum varieties for highlands, including rotation with field beans, initially benefiting some 600 000 rainfed farmers.
- IFAD-supported research at ICRISAT led to ICPH-8, the first pigeon-pea hybrid specific to resource-poor conditions; improved lines led to 10-30% yield rises in eleven Asian countries.
- IFAD's USD 3.1 million leveraged USD 35 million donor support for International Institute of Tropical Agriculture work that developed successful biological control for the cassava mealy bug in sub-Saharan Africa. Millions of poor or near-poor African cassava growers benefited. Estimated benefit/cost ratio: over 200:1.

rural institutions learned to widen access to relevant inputs; and crop scientists developed new varieties such as IR-20 rice emphasizing robustness against main pests and yield enhancement even at low input levels.[12] The landless rural poor gained from HYV spread. First, nearby employment rose and stabilized across seasons and years, because HYV seeds tended to be planted in less risky irrigated lands and in the formerly slacker dry season, and from the early 1980s to be more robust than traditional varieties. Second, HYV production increased the availability and reduced the price of local staples, and reduced fluctuations. The poorest, who are usually net food buyers even in rural areas and the most likely to depend on hired work, gained much from such changes.[13]

Rural poverty in HYV areas fell owing to the use of HYVs. Yet even there, partly due to rising land values and returns, inequality seldom declined. Even in non-HYV areas of countries with substantial HYV spread, the landless poor sometimes gained more from cheaper food than they lost from reduced employment opportunities; and some non-HYV areas shared in the gains through labour migration for work in HYV areas.

The anti-poverty record of the Green Revolution was excellent. Nearby rural areas and cities in affected countries enjoyed the gains from the reduction of poverty.[14] However, yields have risen much more slowly in the 1990s than in the 1970s, though the timing of the downturn varied among regions and staples (Table 4.1). The anti-poverty gains from the Green Revolution in well-watered wheat and rice areas were restricted in their spread by five factors.

1. Public agricultural research expenditure has fallen sharply in Latin America and Africa, and international outlays have been static in real terms since 1982; and from the mid-1980s outlays have been heavily diverted from biological crop improvement to other goals.
2. Yield growth has been slower for maize millets, sorghum, cassava, yams and sweet potatoes – staples eaten and/or grown by most of Africa's rural poor, and by many of the poorest elsewhere – than for wheat and rice.
3. Yield has grown more slowly even for the same crop in sparsely watered areas and in Africa.
4. Even in lead areas, yield growth has been slower since the 1980s. It has become harder to achieve gains in biochemically-based yields. Conventional research in breeding remains essential, but is used increasingly for defensive purposes: to select varieties less for higher yield *per se*, than for resistance against new pest biotypes, avoidance of micronutrient depletion, and adaptation to drought and more saline water.
5. The response of employment to a given yield enhancement in Asia is now about one third of 1970s levels owing to the increasing use of tractors and herbicides. This reflects, in part, rising real wage-rates and the retreat of poverty – but also the remaining subsidies on tractors, agrochemicals, fuel, or credit to obtain them.

Some of these trends are responses to the steady fall in global staples prices relative to fertilizer costs. Some reflect normal diminishing returns, as irrigation, improved varieties, fertilizers and research go first to the most promising areas and crops. These tendencies always slow down technical change, and are offset by extra demand for staples due to population and income growth and the livestock revolution.[15]

This does not explain why biological advance slowed down in the 1990s in the developing world more than elsewhere; or why it is less employment-intensive now than in the 1970s and 1980s. Two major factors are less emphasis on public research and its increasing need to be defensive. The success of the Green Revolution relied on the combination of international research developing improved varieties suitable for many conditions, and national agricultural research systems (NARS)

screening and crossing such varieties to suit local conditions. This partnership breaks down if NARS are denied funds, especially as the need for local adaptation of improved varieties for more diverse areas increases.

What are the priorities in bio-agricultural research to help the poor? Since the mid-1980s, CGIAR[16] has sharply reduced the proportion of its expenditure committed to breeding for yield and yield potential. This would seem to correspond to: many poor farmers' preferences; the need to concentrate effort in regions of high poverty, where crop yield is harder to increase; and the new development agenda, which stresses priorities other than yield or income, such as risk reduction, gender equity and concern for the environment. Yet staples yield and yield potential need increased emphasis, to attack rural poverty by expanding income based on employment, while the growth of the workforce continues.

The CGIAR and IFAD observe increasing concentration of low yields and poverty on ill-watered areas, usually under environmental stress, with increasingly hazardous life chances for some poor groups. Diverting research towards these areas requires participation with local farmers and research institutions, not uniform varieties of single crops to suit all circumstances. Where farmers are consulted about their priorities, they often select priorities other than yield.[17] From 1980 the CGIAR moved away from breeding for yield, especially yield potential, towards such issues as environment, gender and distribution, and towards less promising crops and areas.

Yet this has probably helped to reduce the growth in the yield of staples even for lead areas of the Green Revolution, and has been ineffective in delivering growth to some of the areas where the poor are increasingly concentrated. Farm and food yields and output-per-person have fallen since the late 1960s in much of Africa. Research must now be refocused on yield.

The funding of the ICRISAT indicated a shift towards poor people's regions and crops (millet, sorghum, chickpeas and pigeon peas). Returns on some of this investment have been substantial. In India and China some of the initially neglected rainfed areas now show better returns to research – and more poverty reduction per extra research dollar – than do irrigated lead areas. There are cases of successful outreach to smallholders through bio-agricultural research in non-lead areas, usually in conjunction with improved water management and, more rarely, in drought-prone areas with higher-yielding coarse staples.[18]

The case for expansion of research for poorer areas faces several problems.

- Crops such as sorghum are selected to thrive with low, fluctuating moisture and nutrient inputs; but harsh environments punish plants with high input requirements. It is unsure, slow and costly to seek high-yielding yet safe varieties by breeding within the genetic range of these crops.
- Using marginal, low-humus lands to grow high-yield, continuous crops may be unsustainable, for example if adequate nutrient replacement is uneconomic.
- While well-watered deltaic or irrigated areas have many common features, rainfed – and especially rain-underfed – areas are diverse. A particular HYV or hybrid is therefore likely to have a limited range of usefulness.
- Although conventional breeding in HYV lead areas brings dwindling yield gains, it remains vital to defend yields against new pests, water scarcity and micronutrient shortage. Yet given the high proportion of staples output and employment in lead areas, the sharp slowdown of yield growth – probably due in part to a shift of research priorities elsewhere – harms the poor.
- Finally, growth in yield everywhere depends ultimately on increasing yield potential.

How can one reconcile the needs of the poor in three areas of bio-agricultural research: helping

neglected groups in diverse drylands; revive yield growth in the breadbasket areas; and developing new technology to raise yields and yield potentials?

Bio-agricultural innovation can aim to increase conversion efficiency; partition efficiency (the proportion of the plant or animal comprising food or other economically valuable materials); or extraction efficiency (the capacity of plant or animal to find and use up nutrients or water). Extraction efficiency for a nutrient is exhaustive and not sustainable in soils that release little to the plant. Partition efficiency has been pushed near the limit with wheat and rice, but can still be improved by breeding in some crops, and perhaps animals, for less favoured areas. But the main emphasis for bio-agricultural research in less-favoured areas has to be on improving plants' or animals' conversion efficiency – especially if they are to be sustainably manageable by the poor.

Improving conversion efficiency has proved difficult within the range of genetic material of some species concentrated in less favoured areas: species can be adapted to robustness but at the cost of high yields. The possibilities made available by the ability to insert genetic material into crop and livestock species are vital. Wide crosses can achieve this within conventional plant breeding. For example, West African red rice (*O. glaberrima*), adapted to upland and swamp farming in parts of West Africa, is robust, of short-duration and weed-competitive, but gives very low yields. It has successfully been crossed by the West Africa Rice Development Association (WARDA) with Asian paddy (*O. Sativa*). Another example is triticale, which Borlaug produced by crossing high-yielding wheat with cold-resistant rye, producing a new crop that has substantially raised food yields on millions of hectares in cold climates.

Successes such as these are rare, because these approaches are technically difficult, inaccurate as regards gene transfer, and slow. Most developing countries can apply and develop usable varieties from genetic modification (GM), but not all have the resources on their own to do so. Increasingly the findings of research into GM are locked into patents held by a small number of powerful research institutions. Some companies may occasionally provide free information to low-income regions. More often, GM research is steered towards fields where those companies can gather most profit.

Moreover, although food safety and biodiversity issues raised by GM are in principle the same as those raised by other biological or chemical routes to farm product improvement,[19] GM has been a catalyst in public concern about these issues. Genetically modified crops have the potential to reduce the poverty of the poor by increasing their supply of food from difficult land, but it is only with the full participation of civil society and institutions that the technology can be shared and applied. The effects of ignoring new approaches to poverty, nutrition, hunger and survival could be very damaging.

Micronutrient enrichment of food staples illustrates how GM is a powerful weapon in the armoury of breeding. The extent of the poor's micronutrient deficiencies and the resulting deaths are well documented: cures need not wait until much higher incomes permit all to escape the problem through diverse diets. Medium-term progress is possible through food fortification (especially with iodine). But iron anaemia has not retreated globally; anaemia and Vitamin A deficiency remains widespread. Conventional non-GM plant breeding can address some of these issues; for example, an experimental rice variety rich in iron and zinc, IR-68144, has induced a leap in serum ferritin in an anaemic population in the Philippines. However, only by GM, Vitamin A could have been introduced into the rice endosperm. Both breakthroughs have been made available free to developing-country research insti-

tutions. If successful varieties can be developed for relevant agro-ecologies, they will contribute towards saving millions from blindness, mostly among Asia's rural poor. Only bio-agricultural research currently promises micronutrient benefits of comparable speed, spread and cheapness. Nevertheless, as is the case for any new variety, there are risks. These should be identified and judged against the expected benefit.[20]

Bio-agricultural research for crop-water response is crucial to the rural poor, both because the poor are most harmed by tightening water scarcity, and because they are most exposed to risks of drought and least able to bear them. Already in 1972, the International Rice Research Institute (IRRI) identified moisture stress resistance as the main rice breeding priority. For the poor in many arid/semi-arid borderline areas, there is a critical research choice between two goals, neither so far successfully pursued[21] but both more credible with GM: breeding much better yields into robust but low-yielding millets, or better moisture stress resistance (especially capacity to delay anther formation if rain is late) into fragile but higher-yielding hybrid maize.

Increasing water scarcities require breeding (and managing) plants and animals for water economy – that is, high yield per litre, including capacity to return reusable water to ground or surface sources. As responses to water involve many genes, knowledge of specific gene functions in each host plant or animal type (functional genomics) is needed for major progress with transgenics. Timed response to local water conditions and needs is essential. These are issues for joint land-water and bio-agricultural design, management and research, not for isolated and unconnecting studies. Few crop research agencies outside CGIAR employ economists or hydrologists; if they do, specialists are seldom involved in decisions on research priorities.[22]

Bio-agricultural research and its extension are crucial to pest management. Pesticides can stimulate new, resistant pest biotypes, requiring ever more expenditure on ever less effective chemicals. This pesticide treadmill harms poor farmers most: from pesticide-polluted drinking water which poisons many farmers,[23] to endangering of economically important non-targeted species, including pest parasites. Bio-agricultural research can reduce pesticide contamination by plant selection and breeding, and can control pests by introduced parasites (Box 4.4).

Overwhelmingly the main source of biological pest control, even within integrated pest management (IPM), will continue to be selection and breeding of host crops and animals. This can become defensive, to limit harm from new pest biotypes. The rural poor, being most risk-averse and least able to buy the right pesticides on time, gain most from this. Rice bioscience had to shift from TNI, IR8 and others – winners of yield competitions that proved to be museums of insect [and other] pests – to today's rice varieties, which are better than traditional varieties at coping with the six major rice pests. A series of IRRI varieties were crucial in providing more stable resistance to emerging biotypes of brown planthopper. Uganda's success in breeding cassava resistant to the new (UGV) strain of cassava mosaic virus combined frontier plant genetics, important national research, donor support and skilful local extension in reversing huge economic and nutritional losses from this strain.[24] In 1997-99 GM research proved necessary to provide resistance to devastating rice yellow mottle virus in West Africa.

While safer than pesticides, some aspects of pest-resistant plant breeding could be safer still. First, most new varieties unduly stimulate emergence of new, virulent pest biotypes. These can be reduced by seeking: moderate resistance that allows the pest to damage, say, 5-10% of plants; tolerance, aiming not to destroy or avoid pathogens but to permit affected plants to survive damage; or horizontal control, using several plant

Box 4.4: Integrated pest management in Indonesia

In the early 1980s, Indonesian lowland rice was infested with the brown planthopper *Nilaparvata lugens*. Farmers applied pesticides intensively and IRRI conducted trials to breed plant resistance, but the scale of the problem prevented small farmers from controlling it economically. In 1986, the government (supported by FAO) announced its IPM policy, prompted by evidence that pesticide use was no longer increasing rice yields, and, by destroying natural-enemy populations, was destabilizing production systems. The main components of IPM were: banning many insecticides; reducing or removing pesticide subsidies; and strengthening crop protection and related research and extension institutions. By 1992, over 150 000 farmers had been trained to observe and understand the local ecology of the planthopper and its natural enemies and to follow simple threshold rules.

During 1987-90 the quantity of pesticides used on rice was halved. Yields increased by 15%. Extra net profits were USD 218 per IPM-trained farmer per season. The government saved USD 120 million a year (85%) of subsidies, which was partly used for the IPM initiative. Several lessons can be extrapolated to other high-potential rice-producing areas:

- Successful IPM requires access to education.
- Understanding the ecology of the rice field is a critical issue for IPM training.
- IPM training instructors must be aware of the local farming experience in the region.
- IPM should be part of extension worker training; farmers are the best candidates to be IPM trainers.

In high-potential areas, management-intensive IPM techniques offer low external input (and consequently low material cost) options for poor farmers. Through training in IPM and involvement in local initiatives to eradicate pests, farmers learn that they can jointly manage and improve their environments. Reduced health risks improves the livelihoods of rural farmers and farmworkers.

Whatever the IPM methods, natural selection implies that pests hit back with new biotypes. Hence an essential long-run component of IPM is a steady succession of improved pest-resistant varieties, such as IR-26, IR-36, IR-64 and IR-76, against evolving biotypes of the brown planthopper. This requires NARS in the field, working with farmers, to test, adapt and sometimes cross these emerging varieties.

Sources: Kenmore 1991; van Veen 1997; USDA/ARS 1993; van de Fliert *et al.* 1995; Hazell *et al.* 2000.

genes against the pest instead of a high barrier from just one. Second, in some crops and areas, breeders' very success has seriously lowered the biodiversity of farm populations: good, pest-resistant, profitable species and varieties drive out others. Although individual modern varieties tend to be more resistant to main pest species than traditional varieties, a population dominated by one such variety can be very vulnerable to virulent new pathogens, as with the resurgence in 1972 of southern corn blight (*H. Maydis*) in the United States and tungro rice virus in the Philippines. In each case researchers developed new resistant varieties in only two seasons.

Delays in research on plant breeding can harm the poor. How long can the poor wait without severe harm? And will research respond to new biotypes of pest, when they attack the new maize hybrids spread in Ethiopia, or adapted HYV rice in West Africa?

Lessons for pest management are:

- to improve biodiversity of modern plant and animal populations;
- to improve and duplicate both *ex situ* collections and *in situ* 'gene parks', so that a wide range of varieties remains available as a source of genetic material;
- to shift bio-agricultural research and extension towards horizontal, tolerant and/or moderate-resistant varieties;
- to assist in this, to stimulate genomics research to find pest-related roles of host and non-host

genes, and to improve pest management via inter-species gene transfer;[25]
- to see host pest resistance and tolerance in the context of IPM, including biological controls and appropriate pesticides; and
- to improve farmer participation (in pest research as well as reporting new pest problems: see the IFAD-supported example in Box 4.5).

Agricultural research and extension should focus on varieties that both suit the conditions of small and labour-intensive farmers, and that demand and reward workers rather than tractor-owners or herbicide manufacturers. Raising demand for labour, especially in slack seasons, is most needed where the rural poor rely mainly on employment for income. The researchers' main task is to enhance and stabilize yield; but their varietal choice affects the demand for employment and whether farmers demand more labour or more machines or chemicals. Publicly subsidized research should not develop or improve tools or varieties that, without raising yields, cut employment for poor hired workers. Research policy should normally shift farmers' inputs towards labour and away from other inputs.

Allocating funds within research or extension requires economic analysis, both of benefit-cost ratios and of the distribution of benefits. This is still rare in NARS. The persistent absence of congruence between allocation of research among products and their importance for employing and feeding the poor means that poor people's products, such as sorghum and goats, are still under-researched, especially in traditionally neglected regions. Such species as sorghum and goats are under-researched at national level because they are written off as low-potential, yet are often low-yielding partly because under-researched, despite high returns to research. Seeking congruence makes no sense if the under-researched crops or animals

Box 4.5: Collaboration between farmers and researchers

- Better varieties can stimulate revival and adaptation of traditional pest management methods. Worldwide, over USD 300 million of pigeon pea, mostly grown by poor farmers, are lost yearly to pod-borer. In India by 1993, costly chemical controls predominated. At a farmers' meeting organized by an NGO (Research in Environment, Education and Development Society), an elder showed the defunct method of shaking larvae gently on to a plastic sheet and feeding them to chickens. In 1997 IFAD supported evaluation in a 15 ha watershed by ICRISAT. By 1999 the method had spread to thousands of farmers. It is a key component of the IPM strategy for pigeon pea.
- Farmers creolise research-station releases; ICRISAT millets and International Centre for Maize and Wheat Improvement maizes are crossed with landraces to suit local conditions and preferences, even at the cost of losing hybrid vigour in maize, as in the late 1990s by smallholders in Chiapas, Mexico.
- Farmers experiment with new plant types, as with the spread of cocoa in Ghana, or new combinations of plant type and land management, as in the indigenous agricultural revolution of mangrove rice in Sierra Leone.
- In many countries, a small subset of farmers, often on frontiers among agroecologies – e.g. for rice in Bumpeh village, Sierra Leone – specialize in selecting new varieties, planting out in various conditions, and selling – with advice – to others, often from hundreds of miles away.
- With appropriate amendments (testing larger populations of fewer alternative varieties), introducing collaborative even more than consultative farmer participation into breeding staples improves returns, biodiversity, speed and local relevance, especially in drier areas, as with rice in India and beans for women farmers in Rwanda.
- Where there is something worth extending, formal extension has substantial, documented returns. But farmers often get bio-agricultural advice from other farmers and/or migrants.

Sources: ICRISAT 2000: 5-6; Bellon and Risopoulos 1999; Hill 1957; Richards 1985; Witcombe 2000; Witcombe *et al.* 2000a, 2000b; Virk *et al.* 2000; Sperling and Berkowitz 1994; Evenson 1999; 2000: 264.

are unpromising for research; but new research methods offer new hopes. Even now, in Pakistan, if research outlays were in proportion to outputs, poor farmers' benefits would rise significantly.[26]

What about regional congruence? Current under-emphasis on some rainfed or less-developed regions harms output and efficiency, as well as the poor. In China, returns to extra agricultural research and development in the poorest (Western) region are 15% above the (already high) country average, and 140 people are brought out of poverty per 100 000 yuan of extra research investment, as against 34 nationally. In India in 1994, the impact of extra research on agricultural production in the sixth most fertile of 12 rainfed regions is double the impact in irrigated areas, and each million rupees of extra research investment takes 13 people out of poverty annually, as against one.[27]

The IRRI-supported Eastern India Rainfed Rice Project involved 'local scientists who had never conducted on-farm research' in learning as well as teaching improved management practices and farming systems in areas previously 'all but overlooked by advances in rice science'. Since 1996 these six States have produced all India's extra rice production, by shifting resources to the neglected area with future potential; better rice varieties, robust in rainfed conditions; and participatory research.[28] Box 4.5 provides evidence of the gains from linking formal research to farmers' own methods and experiments.

Farmer-researcher collaboration is needed to remedy another serious lack of congruence. Of formal non-commercial pest-control research, well below 10% goes to countering weeds, birds and rats. Yet these probably cause over half the poor's crop losses. A side-effect is that controls are over-dependent on agrochemicals. Only a large new research thrust, by farmers and formal systems together, can remedy this.

Participation is the ally, not the enemy, of formal research in benefiting farmers. But farmers are not the same as the rural poor in needs, tastes or preferences. Both participatory and conventional research give little say – less than most market research and much less than market demand or political action – to non-farmer food consumers or workers, or even tiny farmers who buy most of their food. Where such people comprise most of the poor, neither participatory nor top-down research, in current form, sufficiently involves the poor as agents.

Nevertheless, farmer participation in agricultural research usually raises poor people's welfare, for example, by stimulating choices that deal effectively with local problems, spread labour peaks, cut risks and improve or cheapen food. That impact will improve if indigenous research and extension are better integrated with the formal system. Issues relating to local farmers' priorities are still seldom considered in experimental design, especially in NARS; yet they are crucial, especially for the poor on marginal lands, in risk diffusion and labour and food planning.

IMPROVED LAND MANAGEMENT TECHNOLOGY (ILMT): LAND AS A NATURAL RESOURCE

ILMT is sorely needed to raise or maintain the quality of natural resources. Examples include range management to reduce overgrazing; the restoration of soil humus through the application of composts, rotational grazing, crop rotation, agroforestry[29] and fallow systems; land reclamation; and earth or vegetative barriers against erosion. ILMT can cut serious losses of farmland, which in developing countries around 1970 amounted to 200-300 000 ha a year from salinity and waterlogging alone, plus large areas to urban expansion. As for the loss of land quality, by 1990 about one fifth of land in developing countries (excluding wastelands) was affected by soil erosion or nutrient loss, two thirds of it badly enough to destroy or greatly reduce land usefulness for agricultural production. Every year the average cropped hectare in Africa loses over 30 kg

of nitrogen, phosphorus and potassium. Land degradation in the late 1980s cost 3% of GDP each year in Java, 4-16% of agricultural GDP in Mali, and 10% of annual agricultural production in Costa Rica. Such estimates are controversial and may be somewhat too high, but the poor lose proportionately more, having fewer options or defences and being concentrated on poorest quality land. Land degradation is worst in hotspots, such as the foothills of the Himalayas, sloping areas in Southern China, South-East Asia, and the Andes, forest margins of East Asia and the Amazon, rangelands in Africa and West and Central Asia, and the Sahel.[30]

Bio-agricultural research seldom provides much of a remedy for this on its own. That makes a powerful case for ILMT. But unlike the adoption of fertilizer, new varieties, or many crops, ILMT innovation normally requires extra fixed capital and a time lag before benefits gradually accrue, which is not an attractive option for poor farmers. The rural poor may thus be slow to embrace ILMT. They need their scanty income for consumables now; they cannot afford sacrifices to invest in long-term land stability, and have more difficulty in borrowing money, especially for ILMT with perhaps small and distant returns. Moreover, poor rural people often interact with land in ways that give few incentives for long-sighted management: as labourers or short-term tenants, often with little security, supervision or extension.

ILMT is essential to prevent land degradation from threatening the poor's chances to improve employment incomes and food entitlements from the dwindling land remaining. However, the cause of ILMT is ill served by claims of large or fast gains in yields, employment, or the income of the poor, especially through low-external-input farming; because there is a weak empirical base for such claims.

Farmers know the problems of land degradation, but are reluctant to allocate resources with high opportunity costs for remote, uncertain or insecure benefits.[31] In India ILMT investments decrease where time spent in other activities has higher returns, or benefits are vulnerable to water use or drainage upstream – or insecure land tenure, as in Morocco, Mali, Tanzania, Ethiopia and Ecuador. There is much evidence that farmers take sensible conservation measures if they pay, limiting overgrazing[32] and maintaining forest islands and galleries.[33] The task is to ensure that incentives and institutions stimulate conservationist ILMTs.

To attract poor farmers, ILMT should not conserve at the expense of production, and preferably should itself be productive (for example, construction of vegetative bunds which provide fodder).[34] Pure conservation, even by simple methods, is seldom attractive to farmers.[35,36] Further, adoption of new techniques must suit the timed labour availability of the household (Box 4.6), and take

Box 4.6: Labour availability and new technology in land management/conservation

Timing construction to coincide with the slack season is desirable where feasible (when the soil is not too wet, hard or compacted) and if local labour remains available. However, vegetative barriers must usually be planted at the start of the rains. In the slack season many men in Africa migrate for funerals or weddings, or to seek work in the mines.

Male migration, which is often a consequence of past land degradation, means that many smallholder households become female-headed (30% in Malawi). Women have difficulty in finding replacement heavy labour, for example, to make stone bunds. In the Calicanto watershed, Bolivia, widespread migration to non-farm work, while desirable to raise and stabilize labour incomes, impeded labour availability for ILMT works. Research and extension should examine timing and needs, and match labour to techniques.

Sources: IFAD 1992b; Mangisoni and Phiri 1996; Zimmerer 1993; Reij *et al.* 1996; Chaker *et al.* 1996; Shaka *et al.* 1996.

account of other needs. Indian small farmers favoured boundary bunds over contour bunds as they could be used to demarcate property.[37]

Many disincentives to conservation by ILMT arise from public policy. Deforestation and use of lands for possibly unsustainable cropping in north-west Brazil have been stimulated by tax incentives and publicly subsidized roads.[38] Conservation activities are impeded if a farmer must share benefits with others, and institutions to ensure shared effort are weak, inequitable or costly to engage with; projects concentrating on individual users are more successful than wider efforts.[39]

ILMT and conservation seek to use labour to save land, but indigenous ILMT typically uses little labour. Farmers are not interested in a more labour-intensive approach proposed from outside. They see more rewarding uses for their time and need the income from labour quickly. But where a proposed new ILMT is moderately rewarding, safe and swift, farmers, including poor ones, use it – as in Ethiopia, but only where it does not reduce current yield, unless they have low discount rates or special incentives.[40] Most successfully extended ILMTs for conservation involve biological intervention enabling some swift, direct gain to be achieved as well, such as vetiver hedge barriers to erosion, and eucalyptus.

Conversely, inducing conservation ILMT by subsidy has sometimes diverted farmers' and public resources from better uses, whether because the works would have been done anyway or because they are not worth doing.[41] It makes sense to subsidize people to carry out ILMT conservation only if social benefits are sufficiently high relative to cost, while benefits to private conservation investors are not, except with the subsidy. This in turn requires at least one of three things. Net benefits, accruing to and not recoverable from other people, may be sufficiently large. Future losses, risks or thresholds, in the absence of conservation, may be insufficiently discounted, because poverty requires high preference for quick income, or because of high credit costs. Or there may be distributional gains for the poor from the conservation ILMT not readily achieved otherwise.

Conservation tillage (CT)

This involves reducing or eliminating ploughing, resulting in a protective mulch on the soil surface (the residues from previous crops). This protects soil from wind and rain erosion, encourages water percolation, and improves the physical and chemical characteristics of the soil by retaining more soil organic matter, moisture and nitrogen. Yields may be increased slightly, but the main benefit is reduced land preparation costs.[42] However, CT applies only to soils that do not become too hard to be sown without first ploughing or hoeing. CT illustrates the complementary relationship between so-called low-external-input farming and external inputs. For many lighter textured soils, conventional tillage is mainly a means of weed control. Replacing it with CT may require the application of herbicides, especially in the first year or two without ploughing. For CT to be really attractive to farmers, yields should also increase. This can be achieved by introducing leguminous cover crops into the rotation, extra mulch or extra inorganic fertilizer.

In Latin America, the Latin American Conservation Agriculture Network (RELACO), a network promoting CT, was established in 1992. By 1998 more than 14 million hectares were under CT, with seed planted by a specially designed chisel plough which cut the costs of land preparation (Box 4.7, Table 1). Production costs per hectare of soybeans could be cut by USD 12 million in Argentina and USD 5 million in Brazil.[43] But, since distribution of cropland there is very unequal, most cost-cutting would benefit large, non-poor farmers. Much, too, would correspond to reduced demand for employment of very poor tillage workers: note the

Box 4.7: Conservation tillage in Chiapas, Mexico and Ghana

On the steep hillsides of Chiapas, Mexico, soil degradation is exacerbated by intensive maize and bean cropping to meet most local demand for food (though perennials such as coffee can improve matters). Conservation tillage offers promise. It requires farmers to use the residues of previous crops as protective mulch for soil; to minimize tillage, to avoid destroying the mulch; and to replace manual weed control with herbicides. CT also conserves water (reducing risk from drought) and reduces burning of crop residues and thus risk of forest fires. Net returns are higher when both the low tillage and mulch components of CT are practised, as are labour productivity and returns per day (Table 1). CT seems efficient while promoting sustainability and food security.

Table 1: Budgets for maize-bean intercropping, 1993 summer cycle, Motozintla, Chiapas

	Non-adopters	Mulch only	No-tillage only	Mulch and no-tillage
Gross benefit mx USD/ha	1953	1941	1971	2210
Total var. cost USD/ha, inputs + labour	1291	1304	1227	1242
Total inputs mx USD/ha	358	370	450	446
Total labour mx USD/ha	933	934	777	796
Total fixed costs	326	539	326	539
Net benefit mx USD/ha	336	99	418	428
Labour productivity (kg maize/day)	28.0	28.5	32.8	36.1
Return/day (mx USD)	13.6	11.1	15.4	15.4

Source: Erenstein and Iniguez 1997.

In much of Ghana, slash-and-burn methods with traditional tillage are practised. This loses mulch and requires long fallow periods to allow for full land regeneration. These become less affordable as person/land ratios rise and shortening fallows degrade the land. Strategy to deal with this may include shifting to CT, with higher initial costs (and, even with hand weeding, some extra chemical inputs), but higher profits. This almost certainly permits shorter sustainable fallows. Labour costs (and incomes) are not recorded separately, but a fall might harm some of the poor.

Table 2: Costs and returns for three tillage systems in Ghana, 1997

Treatment	Variable costs (USD /ha)	Net profit	
		USD /ha	%
Slash and burn	56.25	360	100
Roundup + hand weeding	76.5	567	158
Roundup + Lasso + Atrazine	85.75	713	198

Source: Hazell *et al*., 2000, citing Ghana Crop Research Institute.

big fall in labour costs (employment income) from CT in Ghana in Box 4.7. Unless land is fairly equally distributed and few labourers are landless, the poverty impact from CT in such conditions is at best dubious. It would be more appropriate in areas where land is more equally distributed and where the proportion of cheap staples grown using CT would be higher, such as in parts of Africa.

Box 4.7, Table 2, shows the variable costs and profit of maize production under three tillage systems in 32 comparison plots. Farm income rises, and as less labour is used, returns per labour day

rise too; but the poorest may lose hired work. However, heavy weed growth is usually transient and herbicide and spraying costs fall with time. CT offers the advantage of early planting: farmers do not have to wait for the rain to soften the soil prior to ploughing. Nevertheless, conservation tillage on African smallholdings remains constrained by lack of credit and the absence of commercial input suppliers of herbicides. Other constraints relate to difficulties in maintaining the surface mulch due to grazing; fast breakdown of organic matter; the use of crop residues for fuel; and consumption by termites.[44]

Land reclamation

Two main forms of land loss seriously harm the rural poor. In lowland irrigated regions, salinity has caused large losses of prime farmland. Each year, globally, land abandoned due to salinity is about equal to land developed for irrigation.[45] The other source of loss is erosion, especially on slopes in arid and semi-arid areas, and above all in Africa, where in 1992, 4% of the area under vegetation was seriously degraded and 18% lightly degraded – about half of this due to overgrazing.[46]

Degradation of such lands does not reflect ignorance or recklessness, but lack of incentives and the indifference of institutions serving the farmers. Some land reclamation might indeed boost farm incomes and productivity.

It is difficult, expensive and often slow to improve saline or waterlogged land. Labour-intensive reclamation is more pro-poor, but viable only on suitable terrain, and with high population densities. Techniques for reclaiming lands commonly include moving soil and installing drainage pipes. Mulching to modify the hydraulic properties at the soil surface can address secondary salinization. Ploughing, with tractors or livestock-pulling wooden ploughs that can cultivate to 30 cm, can rehabilitate abandoned soils.[47] More employment-generating reclamation practices include freshwater harvesting from ponds that form in gullies by constructing simple earth check dams, digging pits and refilling with the same soil, planting vegetative barriers with leguminous species, and afforestation with salt-tolerant species.

These practices are most relevant to the rural poor, who lack mechanized equipment, especially as establishing permanent vegetative cover with salt-tolerant trees and grasses provides income (firewood and fodder) as well as rehabilitating saline lands. The grasses provide some income for the poor while the trees grow (though the pool's access to the trees needs to be assured). In India, *prospis*, *acacia* and *casuarina* are useful trees and produce organic matter that enhances soil productivity. Soil pH fell (10.3 to 8.9 after six years) when salt-tolerant grasses were intercropped. *Prospis* and grass grown together, producing poles, woodfuel and fodder crops, provided a net income of Rs. 4866 per farmer.[48] However, income and employment levels for the poor after reclamation seldom approach those before the land became saline, except from Casuarina. Box 4.8 highlights IFAD's experience with reducing soil salinity in the North China Plain (Hebei Agricultural Development Project), combining mechanized and labour-intensive techniques.

Labour-intensive reclamation and subsequent maintenance techniques are usually more successful in reclaiming overgrazed or eroded than saline lands, but working populations tend to be sparser and more seasonal. Such techniques include earth or stone contour bunds; water harvesting; digging and refilling pits; and planting appropriate vegetative erosion barriers or species that can compete successfully with the thorn acacia which otherwise makes the areas ungrazable. Contour earth bunds were promoted by colonial extension officers in Western India for decades, but seldom worked well. Success depends on all, or almost all, farmers maintaining their part of the bund; that is, on high levels of collective action. How can benefits to secure

Box 4.8: Community-led land reclamation efforts in China

IFAD responded to a soil salinity problem in the North China Plain by supporting the *Hebei Agricultural Development Project* (1982-89). The soils of Quzhou and Nanpi, the counties where the project operated, are coarse, light silt loams, well suited to maize, wheat and cotton when adequately drained. However, years of irrigation and poor drainage made about half the farmland in the counties saline enough to inhibit agricultural productivity, particularly for the rural poor, who live on the most marginal lands.

Low-cost labour-intensive technologies were largely used to reclaim saline lands, though tractors were used at times. Drainage works to lower the water-table and reduce surface pooling of stagnant water involved excavating 17.6 million m^3 for drainage systems by manual labour, far surpassing targets. Land levelling of 11 000 ha allowed salt to be leached from soils, simplifying planting. Most tree-planting was less successful (propagation was inhibited by residual salt) but some community orchards were successfully established, providing nutritional and income gains.

Conditions improved greatly during the project. Landholdings increased, as did production of wheat, cotton and maize. Salinity greatly decreased and seemed likely to stay low, although continued monitoring and evaluation by the communities affected was a key requirement for long-term sustainability. Large labour requirements associated with the project worked against households with low adult/child ratios and unable to diversify. The communal philosophy of assisting neighbours and extended family alleviated some of the emerging disparity. The economic rate of return for the project was 19%; 23 000 ha of land were reclaimed through the project and 35 200 households lifted from poverty.

Source: IFAD data and project documents.

this be made faster, clearer, less unequal? Stone bunds require advance capital commitment and yield no obvious income. Vegetative barriers are more attractive to the poor, yielding quicker direct income (fodder) and, if not in competition with main crops, net benefits from nutrient cycling, and sometimes nitrogen fixation. Hedgerows, as in IFAD's East Java Rainfed Agriculture Project, have been called 'the most promising technique for soil and water conservation'. Vetiver, widely used traditionally, has advantages that assist extension: breaches are less erosive than in earth or stone bund, maintenance is light and the crop is drought-resistant and provides thatching, mulch or fodder. In Katsina State, Nigeria, vetiver reduced erosion both in boundary hedgerows and as grass contour strips. Where erosion has gone too far, humus and water management, building on traditional techniques, can reclaim some land (Box 4.9).[49]

Several points about these small-scale, locally based ILMT techniques should be noted.

- They tend to succeed with low-input techniques in part of the approach only because of high-input techniques elsewhere (manure and/or mulch with fertilizers, labour-intensive reclamation with initial bulldozing).
- They often achieve good results for the intended conservation aims, but, in contrast to many improved plant or animal varieties, yield or output growth is localized, small or doubtful (Box 4.8 may illustrate an exception).
- Some current income gain, for example from vetiver as fodder, is required to provide an incentive to expand the scope of what are, after all, usually familiar methods.
- Pro-poor distribution of benefit is not automatic; conservation should not be about rich farmers securing cheap gains by mobilizing poor clients who gain nothing.
- IFAD experience suggests that ILMT gains are often sustainable only if followed up with means, such as herd taxes, to discourage overgrazing of commons or situations where 'the better-off herders… graze their cattle on the common lands [and later move them to] well-fenced individual plots'.[50]
- Without good crop and animal varieties, poor farmers seldom find it pays to divert resources to

Box 4.9: Land reclamation through soil and water conservation, Burkina Faso and Niger

Where large-scale erosion control had failed, the IFAD-funded Special Programme for Soil and Water Conservation provided current income, while improving or reclaiming about 5 800 ha of abandoned and degraded lands on the farms of some 6 000 households in 77 villages, through *tassas* (called *zaï* in Burkina Faso). The soils had been sealed by a thin crust, hardened by wind and water, preventing infiltration by water. Such areas are usually abandoned, without vegetation, scattered with outcroppings of iron crust. They are prime sites for surface erosion. *Tassas* are 20-30 cm dug holes, filled with manure since the soils normally lack organic matter. This also promotes termites in the dry season, further enhancing infiltration. When it rains, the holes fill with water and farmers then plant millet or sorghum. *Tassas* are normally used with bunds from stones that farmers remove from fields for planting. These methods were learned by farmers of Illéla on a visit to Yatenga in Burkina Faso where, on the central plateau alone, some 100 000 ha have been restored – each now producing some 700-1 000 kg of cereal per year. Yields of millet without *tassas*, demi-lunes and bunds are 150-300 kg/ha. They rise to 400 kg with manure in a poor rainfall year, and 700-1 000 kg/ha in a good year. Fertilizer raises yields to 650 kg/ha in poor years and 1400-1500 kg/ha in good ones.

Tassas have allowed the region to attain average millet yields of 480 kg/ha, reaching 700 kg/ha with fertilizer (still uncommon). Fields of similar quality without *tassas* produced only 130 kg/ha. Food availability in participating households rose by 20-40%, depending on local rainfall. The average family in Burkina Faso and Niger using these technologies shifted from an annual cereal deficit of 644 kg (six and a half months of food shortage) to a surplus of 153 kg.

Tassas are best suited to landholdings with family labour, or where workers can be hired. The technique has spawned a network of young day-labourers who have mastered it. Rather than migrating, they move among villages to satisfy farmers' growing demands. Some farmers, recognizing potential profits from *tassas* early, bought back land. Three factors were key to developing and disseminating the technology:

(1) an action-research approach that is flexible, open to farmer initiatives, and conducive to negotiation;

(2) a technology that is quick, simple, compatible with existing cropping systems, and replicable; and

(3) a technological package that can adjust to the changing local context.

Source: Pretty 2000, citing Mascaretti, pers. comm.; Reij 1996; Hassan 1996; IFAD project documents.

wide-scale, long-term conservation and reclamation. Yet without these, the land to support better varieties may continue to degrade.

- There must be progress on research on ILMT and bio-agricultural research together for either to succeed.

WATER TECHNOLOGY AND THE POOR

The World Bank[51] has identified the main single environmental problem for the poor, alongside water quality, as water depletion, particularly in the context of scientific consensus on global warming, with less reliable rainfall and higher evapotranspiration. Technical progress in farming since the mid-1960s dramatically cut rural poverty where there had usually been earlier improved water control. For two millennia, the rural poor have reached sustainable prosperity, if at all, mainly by applying known innovations that enhance water reliability and control, or through biological inventions which allow swift yield-enhancement in already well-watered areas. Rapid poverty reduction has long eluded people in large semi-arid tracts, especially in Africa. Even if transgenics bring gains in drought tolerance, without more water for crops and animals, rapid reduction in poverty will be difficult to achieve.

Technology can promote better plant types that raise each litre's output or poverty impact; ILMT is often inseparable from water conservation and development (Box 4.10). Raising water-use efficiency (WUE) is possible: a good benchmark is 50%, but typically only 40% is achieved (60% of field water fails to reach the crop root zone), mainly due

Box 4.10: Water efficiency: conveyance, field, use; economic and social

Water engineers concentrate on water-use efficiency (WUE), i.e. the proportion of irrigation system water that reaches the crop root zone. Conveyance efficiency (CE) is the proportion of irrigation system water that reaches cropped fields and field efficiency (FE) is the proportion of water applied to the field that reaches the cropped zone: so WUE = CE x FE. Even technically, these are not the only determinants of economic efficiency of water (EEW). The worth of a given FE depends on whether the water reaches, and is drained from, the root zone at the right times; and on how much of the water that does is absorbed by the crop, transpired to manage moisture stress, or diverted to weeds. The worth of a given CE depends on the quality (non-pollution) of the water before and after conveyance.

EEW is the value added to output by the water, as a proportion of the extra cost incurred to obtain it. WUE can come at too high a cost, actually cutting EEW; for example, sprinklers usually show higher WUE than gravity systems, but are more maintenance-intensive. Excessive emphasis on WUE in Zimbabwe has led to costly, possibly unsustainable, schemes (Heinemann pers. comm.).

Private and social EEW can differ greatly if some costs or benefits of water accrue not to the user but to the taxpayer, or to downstream free-riders – or victims, if water becomes polluted on its travels, or causes salinity or flooding due to poor drainage. Private and social EEW are enhanced by growing crops with higher returns to water. Finally, even if WUE, private and social EEW all improve, some poor water users might lose. Some means to improvement, such as centre-pivot systems, save water by using much capital not accessible to poorer farmers – who thereby become less able to compete – and displace poor workers.

So in principle more FE or CE need not raise WUE; more WUE need not raise private EEW; more private EEW need not imply more social EEW; and more social EEW might not help the poor. All these need checking. Yet in practice the big technical inefficiencies suggested by disparities in WUE – together with the known under-performance, mismanagement and sometimes corruption of some big irrigation systems – suggest scope for increasing WUE compatibly with gains in EEW and equity alike. This suggests focusing on irrigation techniques and technologies to increase WUE. Changed irrigation frequency and volume, rotational irrigation, cross-bunding, new drainage systems, canal lining, and other methods need evaluation. These complement bioagronomic ways to improve WUE, e.g. changing crops, varieties, or timings of operations, or improving weed control (Joshi and Singh 1994), or to improve CE, e.g. by control of water hyacinth in canals.

to spillage, leakage, infiltration and evaporation.[52] In sub-Saharan Africa WUEs are normally around 20-30%.[53] Conveyance efficiency (CE) can also be raised by reducing seepage (for example, through unlined or badly maintained canals), percolation and evaporation (Box 4.10).

If prices, institutions or environment[54] are not too hostile, water management techniques can improve WUE, raise economic efficiency of water and help the poor. Canal lining reduces seepage and leakage, raising WUE and CE respectively by 5-10%.[55] But lining field canals may not reward farmers; or appropriate materials, hired skills, or extension may not be available. However, seepage, evaporation and percolation are also due to excess water storage in the field. Poor farmers can address this problem by irrigating less frequently and making the best use of rains. Intermittent flooding in Asian paddies can reduce water requirements by about 40% with no significant decline in yields. However, while a farmer who cuts seepage and percolation enjoys more water, farmers downstream may then get less. In Northern Pakistan, overall WUE is only 30% due to mountains and coarse soil, but CE is 90% since downstream users benefit. In this case, greater upstream WUE – through technical progress or by water pricing – could cut CE, and thus water downstream.[56]

High evapotranspiration inevitably opens a gap between WUE and the benefit to the farmer in hot climates, but can sometimes be cut by cost-

effective techniques that create employment. Covering reservoir surfaces is expensive, but there are alternatives. The irrigated area of Ethiopia might rise 20-40% if irrigation sources are used fully at night and weekends.[57] Any measure which reduces exposure time to atmosphere, or mean exposure temperature of irrigation water, reduces evaporation: for example, pipes to convey water, or tubewell irrigation. In the North China Plain piping irrigation water results in 90% CE, compared with 50-60% for earth canals.[58]

However, it is costly capital, rather than (poor people's) employment, that is saving the water. How accessible are such techniques for the rural poor? Sprinkler irrigation allows water to be applied gradually to large areas of crop. This commonly leads to 70-80% WUE,[59] but usually at high capital cost for installation and spares. Though still expensive, lower-cost, easy-maintenance gravity-fed sprinkler systems proved attractive to some poor farmers in Lesotho. Drip irrigation often involves underground pipes, applying water direct to the root zone. This can give the same potato yield as furrow irrigation with half the water, and in Israel cut water use per hectare by one third. Nutrients can be applied to the crop with the water. Since drip irrigation wets the soil only in the root zones, access to the field is easier. Again, this is capital-intensive and costly per unit of water saved. IFAD has encouraged its use in Egypt, where conventional ways to raise WUE are unattractive to farmers due to lack of direct irrigation charges. In Israel and Jordan, up to 60% of irrigated area has been converted to drip systems. Tubewell irrigation, though sometimes more expensive than canal irrigation, can work more in favour of the poor due to its modularity which enables water to be more easily controlled. Poor farmers can access tubewells via markets; this gives tubewell owners direct incentives to raise CE, provided there is little distance between tubewell and field compared with previous water sources.[60]

While such techniques suit middle-income or labour-scarce environments, more labour-intensive methods would be more cost-effective to reduce poverty in the poorest regions, which often have labour surpluses, at least in slack seasons. But invention and innovation in irrigation techniques and water management that replace water use with employment are scarce and slow owing to lack of water use and management research resources, their weak integration with crop research and with farmers, and their relative neglect of simple gravity-flow methods. Cross-bunding is an obvious simple option. Less well-known is porous pot irrigation – an affordable, efficient method which has spread from North Africa to other countries. It involves a series of interconnected unglazed pots buried in the soil with openings exposed. Seeds are planted round the pots, which are then filled with water. As with drip irrigation, water is applied to the plants very slowly. The technique is best suited to those with low opportunity-cost of labour, such as the rural poor: small farmers and family artisans who make the pots.[61]

New techniques are also relevant to improving WUE where alternatives are sought to desubsidizing irrigation and drinking water, which, while desirable, is sometimes not politically, or occasionally even technically, feasible.[62] Relevant techniques include computer-aided scheduling of water allocation, based on forecast needs allowing for weather, crop-water requirements and area cultivated, as in the Mae Klong scheme in Thailand. Such techniques will improve and spread as information technology gets cheaper. Yet small farmers may be disadvantaged unless they can reap economies of scale, access equipment and software, obtain information and hire expertise through an appropriate water users' group. The Bali Irrigation Project illustrates the need to involve such groups in innovation and technical choice. External agents tried to replace traditional weirs with structures that could vary distribution

according to crop-water requirements. However, the technology was inappropriate to local needs and institutions, and drew management responsibility away from the water users' groups.[63]

Recycling can substantially improve conveyance efficiency. The Fayoum system in Egypt has WUE of over 60% because water unused by the crops, which seeps into the groundwater, is pumped up, increasing water availability on-site. Also downstream cultivators can collect run-off or pump groundwater which has resulted from low WUE up-stream. Conjunctive use of ground and surface water aims to optimize their joint use over time; one approach is to pump groundwater only in dry periods, and surface irrigation otherwise. In India, in theory, groundwater should normally be used for crops only from January to May, and rains plus surface irrigation should suffice at other times, especially for paddy.[64] But such rules of thumb are hard to enforce given power-structures, externalities,[65] downstream effects and sometimes corruption. They also allow too little for large local and short-term temporal variation in crop and other water uses and availabilities, in evapotranspiration rates, in preferences and costs, and in the needs of poor water users, who are less able to adapt to water failure or the resulting shortage of food or of employment income.[66]

There are many ways to improve the efficiency of both irrigation and drinking water delivery and use. The best way forward is often to work in partnership by combining rural people's own systems with technical expertise. This is shown by uses of water harvesting, sandrivers, valley-bottom systems such as *fadama* in Nigeria, and stream diversion methods such as *molapo* in Botswana. These systems were discovered by local farmers themselves, and are easily maintained by them. But without formal research and innovation, such systems spread and improve too slowly to reduce poverty enough. Most traditional methods have little application (without external scientific inputs) to rural management of drinking water, but bring dirty and dangerous water, stress and frequent water shortages.

What can water technology do to help eliminate rural poverty and address the problem of declining natural resources? There is much to be done to improve adequate rural drinking water for domestic and farm use. Old irrigation systems decline, and in large areas the lack of water precludes much benefit from improved seeds. Better plant and animal varieties have raised water demand by increasing the returns to extra water in well-watered areas, while doing little for parched areas. Rural water demand has also risen along with income, the livestock revolution with its higher grain requirements, and population. These pressures will continue, probably exacerbated by global warming. In spite of pressure to reduce agriculture's share in water use, water technology can be applied to offset these effects and reduce rural poverty.

More research is needed in developing countries on sustainable water use and supplementary systems, and for better integration of both with farmers' own techniques and preferences, and with bioagricultural research. Discovery in water technology has been slow, despite huge growth in irrigated area in 1950-90. It is unlikely that the problems of water can be resolved without faster technical progress in farm water location, extraction, recycling and drainage.

The World Water Council[67] sets out the urgent case and priorities for expanded water research funding for the CGIAR and nationally. The special water needs of the rural poor must be integrated into such research. Infant mortality for the rural poor is much higher than for the urban poor. Such deaths are swollen by disease due to dirty water. The poor's productive progress is frustrated by lack of water control. Their main resource, labour, can earn incomes by constructing better water systems, but only if appropriate research choices are made early.

More controversial is the need for much more irrigation, including major schemes, in sub-Saharan Africa. Yields, income and employment from most unirrigated areas, especially for main staples, have stagnated or fallen for three decades, and, without dramatic breakthroughs in suitable plant varieties, are unlikely to increase fast enough to make an impression on extensive rural poverty. Yet only 1-5% of African cropland is irrigated (depending on how we classify traditional water management) as against 30-35% in Asia. Typically yields and farm incomes per hectare are between two and four times higher on irrigated land, and their growth has been far faster.

Africa's low irrigation levels are in part due to donors' change in support to farmer-managed schemes, which, although beneficial, have lower outreach and may divert from large schemes. Some of these have been partly successful: Mwea in Kenya, Gezira and Managil in The Sudan. However, from the costly failures of the 1970s, especially in West Africa, the World Bank, IFAD and others concluded that 'large-scale projects have not yielded the expected results and did not principally benefit [the poor;] small-scale farmer-managed irrigation [is] more suited to their needs'. The 14 IFAD-supported projects in Eastern and Southern Africa with 'important water management components aim to support irrigated production on about 40 000 ha, about evenly divided between rehabilitation and improvement of existing farmer-managed schemes and construction of new ones'. Capital costs were USD 3 000 per hectare[68] – far below the USD 8 300 per hectare cost of major schemes (Box 3.10). However, even a large and determined donor such as IFAD over several years could support irrigation for only 30 000-60 000 smallholders, in this region with tens of millions, overwhelmingly unirrigated. 'Small on-farm irrigation only' will not greatly dent African rural poverty.

Large-scale irrigation techniques in Africa have faced many problems:

- high construction costs due to monopolistic and sometimes corrupt foreign contractors;
- settlement, not of smallholders, but of capital-intensive, inexperienced government clients;
- top-down imposition of cropping patterns;
- uncompetitive farming systems, with water and (inappropriate) crops heavily subsidized at the expense of other areas (for example, irrigated rice vs. rainfed beverage crops in West Africa);
- weak and badly maintained distribution systems, linked to spreading water-borne diseases; and
- weak marketing and extension arrangements.

Though returns to irrigation in Africa have been improving (Box 3.10), partly because market distortions are much less, not all these issues have been fully addressed. Large-scale irrigation will fail if public managers abuse it, whether to reward clients with subsidies rather than to enable farmers to work more profitably, or to centralize farm decisions upon water controllers, turning irrigated farmers into pieceworkers. Yet such lessons have been learned in many countries. In Eastern and Southern Africa, the Food and Agriculture Organization of the United Nations (FAO) estimates that, of 38 million hectares suitable for cultivation, some 17 million have good irrigation potential, but only 3 million (mostly in Mozambique or on large farms in South Africa) are water-controlled.[69] While medium-to-large irrigation will be economical only for a minority of these lands, it should not be assumed to be economically or environmentally unacceptable. National water stress is increased by denying smallholder irrigation to areas, like parts of the Eastern Cape of South Africa or many riverine and lakeside areas throughout the continent, with underused water not suitable for use outside farming. It is time both to accelerate the spread of small-scale water management in Africa and to reassess the conventional wisdom about large-scale irrigation.

Excuses are offered for the delay in addressing the problem of irrigation in Africa. 'African irrigation is made less attractive by general inferiority, water-unresponsiveness, variation, or fragility in soils, climates or terrains': this makes little sense, given the huge and localized variation within both Africa and Asia. 'Costs of construction in Africa are much higher than in Asia': the gap has narrowed, and is partly due to excessive reliance in Africa on ex-colonial contractors with market or political power. 'Traditional irrigation systems occur where appropriate; these alone should be spread': they do show good sustainability, but spread slowly, perhaps because on their own they seldom improve income, output or employment fast. 'Crop, animal, and land-management research must concentrate on rainfed areas': this is reasonable while they occupy 95-99% of arable land, but this is only a consequence of past neglect and lack of alternatives in both irrigation and appropriate research. This neglect of irrigation has done vast harm by denying the African poor a Green Revolution.

It is vital to place more emphasis on researching and spreading pro-poor water control techniques, instead of assuming that they already exist but that farmers refuse to adopt them, or that traditional methods already serve the rural poor well. Crop and animal farming can and should increase value-added per unit of water; and in some areas (near many African lakes and rivers) irrigate with farmer-managed systems or medium or even large-sized schemes.

In many cases, especially in semi-arid lands and where there is little water control, external support for its improvement and expansion with farmer and client participation is pro-poor, and a precondition of rapid growth. This has to accompany desubsidization of water for productive use, and recognition that, with urbanization and development, agriculture's share of commercially extracted water should and will fall.

PRO-POOR TECHNIQUES IN OTHER RURAL ACTIVITIES

Although much could be said about the application of technology to many natural resources, we focus on technology where its prospects are most important for where the poorest live, what they work in, and what they eat. For most of the world's poor, economic advancement will continue to depend on crops, especially staple foods. Yet livestock are the main income and employment source for many poor rural people, especially in arid areas of Asia and the Horn of Africa. Elsewhere cattle are integrated into the farming systems as sources of draught and manure, and as users of crop residues. Indeed, their competing uses, for meat, milk, manure, draught, transport, store-of-value and so forth, render technology improvement harder, and policy generalizations less useful, than for crops. In spite of valuable work, research and innovation globally have been much slower, and more concentrated on the needs of wealthy farmers and consumers, for livestock than for crops. Chapter 3 examines ways to improve the benefits to the rural poor from livestock assets. The implications for research and technology are: a shift from cattle to animals more likely to be owned and managed by the poor (sheep, goats, pigs, poultry, donkeys); and, within cattle technology, a shift (in research on both productivity and disease control) towards small herds and their uses and feed.

A special issue relates to draught power. The shift from hoes via draught animals to machines is often desirable, as in parts of South-East Asia today, because wage-rates and employment are rising and labour is getting scarce. Too often, however, the causality is reversed: mechanization, especially the use of tractors, has received open or hidden subsidy, has displaced labour, and caused employment incomes to fall, causing harm to the poor with negligible production benefits. Aid-backed research into mechanization of ploughing,

rice transplanting, reaping, weeding and so on for South Asia or sub-Saharan Africa reduces the incomes of the poorest, and is hardly ever justifiable. Despite such hidden subsidy to labour displacement, technology generation for animal draught (for example, better yokes and harnesses for animal traction in Africa), let alone hoe methods, is on a very small scale.

What of technologies for the rural non-farm sector? This sector is increasingly important, but the parts of it that can most effectively help the rural poor depend mainly on growing demand from nearby agriculture, and will prosper if farm technology drives ahead. As such, public rural non-farm sector research seems unlikely to succeed. In most developing countries, the rural non-farm sector, being much less homogeneous even than farming, lacks the professional organization, public-sector technical expertise, or common features that bring economies of scale and external benefits from publicly-supported research. In general, no overall technology policy for such a diverse sector makes sense (much less so than is the case for agriculture). State attempts to provide it often misperceive problems, build in inflexibility, and rest upon little public-sector expertise. It is more constructive to facilitate flexible sector growth, especially in trade, transport and construction, by providing training and stimulating the economic spread of relevant rural services while regulating monopolies.

TECHNOLOGY, THE SECOND INDUSTRIAL REVOLUTION AND THE RURAL POOR: CONCLUSIONS AND IMPLICATIONS FOR RESEARCH ORGANIZATION

Technical progress increased farm productivity and released labour, capital, food and timber to fuel the first industrial revolution in northern Europe and the United States. Many decades later, the new technologies revolutionized agricultural growth. In the North this was mainly through labour-saving innovations, from tractors to herbicides, suited to the demands of developed economies. But these innovations spread labour-displacing methods even to poor economies with fast-growing workforces. More appropriate land-saving techniques emerged only in the Green Revolution around 1965-85, largely where they were supported by water control and fertilizers. As discussed above, this reduced poverty in many countries, but that progress has slowed, leaving large parts of the developing world little affected. Renewed progress is essential for adequate advance in food staples yields, employment and hence rural poverty reduction. Land and water management techniques, meanwhile, have improved and spread very slowly; despite limited effect on yields, their acceleration is essential to contain soil and water degradation in the face of population growth, agrochemicals, growing effective demand for water diversion from agriculture, and probable climate change. In view of the reduced support for *pro bono* agricultural research, and increasing privatization and patenting of much agrotechnical progress, this raises serious difficulties for new pro-poor techniques in developing agricultures.

The 1990s saw great advances in biotechnology and the delivery of information. So far, these advances raised farm productivity mainly through labour displacement, favoured larger farms, and in spite of growing more food were not necessarily pro-poor in agriculture. Yet biotechnology and informatics in principle raise productivity through skills and communications; are neutral in scale; and may help small farmers to move from traditional to new methods with less reliance on innovations from the intervening stage of capital- and chemical-intensive farming.

For this to happen, and for farm income growth to revive and spread to the neglected areas where the poor now concentrate, changes are needed in agricultural research organization and funding.

Partnerships need strengthening between:

- farmers' own research and formal research systems;
- private and public or *pro bono* research;
- bio-agricultural and land-water research;
- low-external-input and high-external-input farm techniques; and
- work for leading regions and for backward regions.

Historically, poverty reduction has rested on pro-poor technical progress that raised entitlements to food staples. Since 1950 rising numbers of workers seeking employment income and, recently, the threat of land and water degradation made technical progress more urgent. Progess took two forms: the innovation of irrigation and water control especially in 1950-80; and the invention of new plant and animal types especially in 1960-85. Both irrigation expansion and biological yield-enhancement, especially for drylands, have slowed down. Environmental challenges, especially water depletion, require new ways to save and manage land and water, yet land-water management technologies have been historically slow to change, spread, or raise output or employment, though they are often successful at conserving resources.

There appear to be three ways forward. Low external-input agriculture faces a stark choice. With low outputs, employment and food entitlements will be inadequate. If high output is obtained by extracting water and nutrients, these are mined unsustainably; if by converting them more efficiently, farmers have generally discovered the methods already, yet remain poor. Accelerating conventional agricultural research and extension for previously backward areas is starting to show high returns in some cases, but is limited by the need to revive growth of employment and food output in the breadbaskets, and by the fact that farm crops and animals in resource-poor areas have been selected – by farmers and by nature – for robustness, not for high yields, restricting the scope for improving such species by conventional breeding. Thus genetic improvement of the species themselves, for which transgenics is the most promising method (as long as potential damage to human health and the environment are avoided), seems needed to revive growth in tropical yield potential. Output from economic best practice for farmers will always lag behind yield potential, but as best practice from existing crop and animal varieties spreads among farmers, new varieties with higher yield potential are needed to keep farm output, employment and food entitlements moving forwards. Genetic improvement of species also seems the only way to achieve some goals (such as rapidly reducing death and blindness from Vitamin A deficiency in very poor rice-eaters).

Whether by conventional or by transgenic techniques, bio-agricultural research can help the poor by wrapping the benefits in the seed rather than requiring costly purchases of inputs. Carefully planned seed research has raised farm output even at low levels of agrochemical inputs. The Green Revolution has induced a massive reduction in poverty for labourers and small farmers by increasing employment and restraining food prices, and has reduced the pressure to grow food crops on fragile land-water systems; yet its slowdown, and crop and geographic limits, have become evident. Though not the only causes, internal research and technology issues are strongly implicated: cuts in funding for public research; its diversion from germplasm improvement; and, within germplasm research, increasing concentration on defence against crop pests at the cost of yield expansion. There is a hard choice facing bio-agricultural research: concentrating on the diverse, recalcitrant farm circumstances of growing proportions of the rural poor, developing many fine-tuned varieties; or re-addressing the potential growth in yield by developing a few varieties to fit a wide range of conditions.

Improving the nutrition, income and employment of the poor requires advances on both fronts.

An important bio-agricultural contribution can be made to improved environmental sustainability, through both biodiversity and varieties of crops and animals able to produce high returns with less polluting and depleting methods of land-soil-water management. Yet progress on both fronts will require not just major new funding, but also the addressing of an overriding issue of research organization: the drain of leading-edge work from the public sector into a few large firms. Their concentration of research on assisting large farmers and processors, and their development of techniques (e.g. the 'terminator') to impede farm-to-farm spread of new varieties, deflect interest from the needs of the poor. The increasing drive for profits from research, and the increasing use of patents, should not preclude attention to reducing poverty.

Integration of bio-agricultural research with other activities to improve the robustness, sustainability and yields of poor people's farming is a priority. Stable pest management requires breeding for horizontal, less-than-total resistance and/or tolerance, with awareness of farmers' own pest management procedures and experiments, while reducing the risks that reduced biodiversity will stimulate unmanageable new pest biotypes.

Institutions such as IFAD can help the CGIAR and NARS to recognize how pro-poor research can involve not just smallholders but landless workers. Workers with no land need time-specific employment income; that is not simply a farm cost for researchers to minimize like other costs.

Water technology problems and options carry similar lessons and implications for research organization. Water supply to agriculture is under increasing pressure from falling groundwater tables, deteriorating surface irrigation systems, and diversion to domestic and industrial needs (although often justified), accompanied in many areas by increased evaporation, and probably less reliable (and reduced) mean rainfall due to climatic change. Yet the main contributors to the reduction of rural poverty since 1950 have been the spread of new staples varieties, and the extra irrigation that assisted their success. With the spread of irrigation reduced by decreasing returns and increasing price disincentives, ways to alleviate the water squeeze become vital for renewed growth in the yield of staples, rural employment, and hence poverty reduction. Prices and markets, institutions and water-yielding asset distribution can all help. But better methods of water delivery, economy and control are vital.

There has been less research in the field of water delivery; what there was, was less successful than bio-agricultural research, and these two areas were not integrated. Technical improvements in water-use efficiency are attainable, but if this is to increase the economic efficiency of water, let alone the share of benefit flowing to the poor, plant scientists and economists must work together with irrigation researchers and, above all, farm users themselves. As with other technical choices, so for water: farmers' traditional micro-methods and, building on these, collaborative, participatory methods in extension, trials and formal research itself, are not a populist alternative to research-station work: each needs to support the other.

Incentives and institutions should ensure that timely and available labour, rather than capital, is used and rewarded to save and control farm water. But some changes seem inescapable as current subsidies to over-use of farm water are phased out. Expensive and complex irrigation systems will increasingly be used to grow high-value crops, increasing the pressure on both biological and water research for technical paths to increased staples output, per litre and per hectare, from cheaper irrigation systems and sustainable rainfed production. Despite the growing water deficit in many countries, most of sub-Saharan Africa seems unlikely to achieve sharp improvements in the growth in staples yield and in the employment

of the farmers growing staples without raising the proportions of cropland irrigated from the current 1-5% towards typical Asian ratios of 30-40%. Some progress is possible through small farmer-managed schemes, building on traditional methods, but improvement requires more expansion of implementation capacity in publicly supported domestic extension and maintenance, and in funds. For a large reduction in rural poverty, large formal schemes, as well as development of small farmer-managed water control, will be needed.

Technology and institutions ultimately determine not only the poor's access to assets and to local and global markets, but also to growth, distribution, and, in the end, poverty. This report on rural poverty places more than the usual emphasis on technical change. Many people see technical change as determined: by economic advantage as shown by crop and factor prices; by changing population or environment; or by institutions that set agendas for science and technology. But new science and technology affect economic, political, demographic and environmental outcomes, as well as being affected by them. New scientific breakthroughs, and new access to information, constantly change the boundaries of feasible technical progress in farming, and the cost and likelihood of different sorts of advances.

The CGIAR is the international agricultural research system with most effect on developing countries. Its funding has not improved since the early 1980s, while the number of member institutions reliant on its support has risen. Large and fast-growing proportions of CGIAR resources have been diverted from producing higher-yielding, less extractive and more robust germplasm towards new environmental and social goals;[70] yet the donors have failed to provide resources commensurate with such goals. (For example, the long-term experiments, needed to test environmental impact and sustainability of alternative varieties, farm systems, or watershed management, require longer-term and more resources than standard varietal trials). Research managers' ability to plan, or to move money where scientific success is most likely, has been further reduced by the growing propensity of donors to tie funds to particular goals. Despite continuing good performance and high rates of return, the CGIAR institutions have, under these conditions, been less and less able to compete with expanding private-sector research (especially biotechnology), and thus to keep sufficient leading scientists in institutions directed mainly to poverty reduction.

The CGIAR in the 1970s and early 1980s effectively advanced the concerns of the rural poor despite the tendency of much science and technology to serve the interests of the rich. The power of the CGIAR to do that is under threat. Renewed funding growth to meet new tasks is essential – as is a clearer focus on those tasks, a reversal of the tendency to tie them into special projects, and integration between bio-agricultural and land-water research and innovation. The most important issue is how donors, foundations, the CGIAR and developing-country NARS can work with private-sector researchers. If poor people's needs are to be met, biotechnology has to be redirected from its focus on the needs of the rich, and integrated into the environmental and food-safety concerns of developing countries. This can be done only with the cooperation of, and incentives to, the private companies involved, some of which realize the dangers, even to themselves, of their present isolation from the needs of the poor. Some are willing to contribute to remedies (in 2000 developing-country researchers obtained free seeds of provitamin-A-enhanced rice for crossing and trials; and Monsanto gave its working draft of the rice genome to the international public-sector group involved in this research). However, a wholly new public-private partnership is required. Such a partnership should: be led by the CGIAR (connected via its secretariat with both FAO and

the World Bank); involve agricultural donors such as IFAD, using its experience of participation to discover and respond to the requirements of poor farmers, workers and nutrient consumers; and be mediated principally by developing-country scientists and economists.

We make no apology for discussing these institutions of international agricultural technology beside the local, immediate needs of the rural poor. Not only are many of these issues inherently international, so the welfare of the poor depends on their effective voice in agricultural technology institutions; but also, if the institutions continue to lose funds and freedom of action, and (to the private sector) both key staff and access to information, basic inputs to NARS will be missing. NARS will not recover, or in many areas even acquire, capacity to stimulate growth in yields or rural employment. If biological and land-water technologies fail to improve, rural poverty reduction will be slow at best.

Such improvement depends at least as much on NARS as on international research institutions. NARS in Latin America, sub-Saharan Africa and some of Asia have shown funding declines in real terms since the 1990s. Yet India, China, Brazil, Mexico and South Africa – with substantial world-class (bio)technology capacity that is responsive to the requirements of the rural poor – contain, between them, most of the world's rural poor. Many others inhabit agroscientific middle powers such as Indonesia, Kenya and Sri Lanka; the falling cost of transgenics, once a gene is identified, allows such countries to test and monitor these options themselves, provided they are not patented. But many rural poor inhabit countries with severely underfinanced research systems; some have proud research traditions and achievements, but through lack of resources cannot follow their research through;[71] and in others there is effectively no research capacity at all.

Last but by no means least, we have said little about extension, the importance of which we fully recognize. The potential returns to investment in agricultural extension are high, but unfortunately the responsible organizations are frequently weak or politicized with poorly motivated staff and serious gender and other biases. Similarly, complementarities with research[72] are frequently inadequate. It should be recognized that extension is a pipeline. If congested, it slows down the transmission of research, harming the poorest most, but is unlikely to prevent farmers from eventually selecting the technology that suits them best. In other words, the issue is, first, refilling the pipeline with innovations that suit farmers' needs and are useful for the poor; and second, ensuring their access to relevant inputs. IFAD has been instrumental in supporting moves towards more participatory extension methods; it initiated Lesotho's Client Demand System (replicated in Cameroon and Haiti), by meeting client preferences for technique and location. But for any extension strategy – and indeed for empowerment as a whole – to achieve the desired results, it will have to be matched by renewed progress in the techniques that really matter to the poor: techniques that turn their power over land and water sustainably into output, employment and income.

Endnotes

1 Their sustainability benefit derives mainly from reducing the further spread of farming into marginal land, which in their absence would have been essential to feed growing populations. To do this at constant levels 'if world crop yields had not been tripled [in 1950-92], we would have ploughed 10-12 million square miles of additional uncultivated land' (Avery 1997).

2 Evenson and Kislev 1976.

3 Fan *et al.* 2000a, b.

4 Lele 1992.

5 We use this term interchangeably with 'transgenics' (insertion of a gene obtained from one species into another) and 'genetic modification'.

6 Conway 1997.

7 Nuffield Foundation 1999; Brazilian Academy *et al.* 2000.

8 Rosegrant and Hazell 1999.

9 Hazell and Haggblade 1993.

10 Lipton 1998.

11 Avery 1997.

12 See Lipton and Longhurst 1989; Kerr and Kohlavalli 1999; Hazell *et al.* 2000. Typically of perhaps 80% of the hundreds of high-quality studies cited in these sources, Hossain (1988) reports from a sample of 639 farms in Bangladesh that those operating below 1 ha allocated 52% of land to modern varieties, as against 45% on 1-2 ha farms and 42% on larger farms. Farmers owning below 1 ha devoted 42.3% of cropped area and 51.7% of rice area to rice HYVs, as against respectively 32.5% and 42.4% for owned farms above 2 ha. Fertilizer use per hectare of cropland on below-1 ha operated farms was 33% higher than on farms above 2 ha; yield was also more, despite less access to irrigation.

13 Singh and Byerlee 1990; Lipton and Longhurst 1989; Hazell and Ramasamy 1991.

14 By the early 1990s, an extra million rupees spent on agricultural research (overwhelmingly biological) for irrigated areas in India produced an expected reduction in the numbers in poverty of only 0.76 persons per year – despite a rise in gross farm output of 4.4 million rupees, of course far less net of extra inputs of fertilizer, etc. Outcomes were much more favourable in some, but not most, rainfed areas (Hazell *et al.* 2000: Tables 6-7).

15 The shift of land to grain for feed. To provide a given calorie intake per person requires some 3-7 times as much cereals land if the cereals are filtered through cattle, rather than eaten by humans direct (Delgado 1999).

16 The CGIAR, founded in 1972, comprises leading international institutes for research on tropical and sub-tropical food crops (e.g. IRRI and CIMMYT) and livestock, plus some 'topic' institutes (e.g. food policy, irrigation management) and some regional institutes. The Secretariat is shared between the World Bank and the Technical Assistance Committee at FAO, with main financial and technical responsibility respectively.

17 IITA in Nigeria shifted from developing cowpea varieties for maximum monocrop yield because African farmers prioritized mixed cropping and fodder (Kingsbury pers. comm.).

18 Hazell *et al.* 2000; Fan *et al.* 2000a, b; Boyce 1987; Lipton and Longhurst 1989.

19 GM crops have spread from 1 million hectares in 1995 to 40 million hectares globally in 1999; some 60% of foods in US supermarkets contain them, with no known or recorded case of health damage. As with health, environmental risks are the same in principle as with other new plants (e.g. insect-resistant varieties can harm non-target insects), but GM crops are more carefully tested and screened. GM can be steered to increase biodiversity (e.g. the genetic similarity of many IRRI-based rice varieties has impaired field diversity, which should be increased following the insertion in 1999 of a dwarfing gene from wheat into rice). Environmental and health impacts of all introduced plants and foods should be screened, but potential benefits should be measured against risk (Nuffield Foundation 1999; Brazilian Academy *et al.* 2000; Lipton 1999).

20 On micronutrient deficiencies: FAO 2000; SCN Special Commission 2000. On iron-zinc-enriched non-GM rice: IRRI Press Release, Dr. R. Cantrill, 22/5/2000. On Vitamin A GM rice: Ye *et al.* 2000.

21 Hence 'do both' is unlikely to be a feasible way forward, even if funding constraints are somewhat relieved. Worryingly, the structure of international agricultural research (e.g. maize and millet are 'mandate crops' for independent institutions, respectively CIMMYT and ICRISAT) renders such choices hard to strategize or implement.

22 In crop/agronomic research to save water, an outstanding exception is IRRI's work in India, China and the Philippines on management to maintain rice yields under greatly reduced water use (IRRI 2000: 30-1).

23 Jeyaratnam *et al.* 1987.

24 Cockcroft 1997.

25 The main contribution of GM to pest management so far – inserting a gene expressing *Bacillus thuringensis* toxin into maize, soy and cotton – is single-gene, vertical resistance, intended to destroy as close to 100% of target pests as possible, and presumably as stimulative of virulent new biotypes as conventional breeding.

26 Byerlee 2000; cf. Mosley 2000, Lipton 1988.

27 Fan *et al.* 2000a: Table 6; 2000b.

28 IRRI 2000: 6.

29 These examples often involve mutual support between

bio-agricultural research and ILMT. More fodder-yielding cover crop varieties encourage the farmer to stabilize hilly land because they improve browse for cattle.

30 Lipton and Longhurst 1989.

31 Edwards 1995: 17 on Jamaica; IFAD/FAO 1999.

32 Drinkwater 1991; Tapson 1990.

33 Fairhead and Leach 1996.

34 Young 1998.

35 IFAD 1993.

36 Kerr and Sanghi 1992; Hudson 1992.

37 Kerr and Sanghi 1992.

38 Binswanger 1991.

39 IFAD 1992b.

40 Shiferaw and Holden 1997.

41 Lutz *et al.* 1998.

42 Erenstein 1999.

43 FAO 1998a.

44 Findlay and Hutchinson 1999.

45 Prathapar and Qureshi 1999.

46 World Resources Institute 1992; Yudelman 1993.

47 Prathapar and Qureshi 1999.

48 Singh, G. 1995.

49 On vegetative vs stone bunds: Kiepe 1995, Young 1998. On vetiver fodder: Grimshaw and Helfer 1995, Osunade and Reij 1996. Katsina: IFAD 1992b: 41.

50 Sidahmed 2000.

51 World Bank 1992.

52 FAO 1996.

53 Xie *et al.* 1993.

54 Seepage and percolation depend on soil permeability. WUE is around 70% in the Gezira Irrigation Scheme, Sudan, with impermeable soil. In Eastern India, rice irrigation reaches 85% WUE due to rock beneath shallow soils (Xie *et al* 1993).

55 Frederiksen 1992.

56 Paddy water: Tabbal *et al*. 1992, IRRI 1990, Hazell *et al.* 2000, IRRI 2000: 30-1. Pakistan: Wolters 1992.

57 Abate 1991.

58 Xie *et al.* 1993.

59 Wolff and Stein 1998.

60 On sprinklers: Wolff and Stein 1998; IFAD 1993. On drip: Stockle and Vilar 1993; Postel 1992; IFAD 1999h; Abu Taleb *et al.* 1991.

61 Xie *et al.* 1993. See Chapter 2 on ultra-low-lift and treadle pumps in Bangladesh – like bamboo tubewells in Bihar, India, also irrigation assets especially well suited for ownership, use and manufacture by the poor, whose main asset is labour.

62 For example, farmer-specific metering or other irrigation charging is often infeasible (e.g. if water covers, and flows between, tiny paddies). Similarly, standpipes for several households are often far more cost-effective and affordable than individually metered drinking water. User consensus on sharing a group fee is then needed for efficient desubsidization, but usually obtainable only if the group has 'voice' in securing reliable water delivery.

63 Thailand: van Vilsteren and Srkirin 1987. Bali: Horst 1996.

64 Chitale 1991.

65 A striking example is 'water mining' – the effect of deep tubewell pumping in lowering the water-table, rendering shallower tube-wells (usually used by poorer farmers) useless. If a deep tubewell is privately owned (which usually pays only on a single large holding – absent public ownership, or collective action by many nearby small farmers), it is very hard to prevent water mining by legally enforceable pricing. Equity and equality effects apart, water mining steadily raises costs of pumping and of new tubewells, and may exceed recharge and exhaust the groundwater. Yet publicly owned or cooperative tubewells have familiar and serious problems too.

66 On Fayoum: Wolters 1992; conjunctive use: van Tuijl 1993; India: Chitale 1991; corruption: Wade 1982.

67 World Water Council 2000: 64-6.

68 IFAD 2000b.

69 IFAD 2000b.

70 Lipton 1999.

71 For example, Ethiopia in 1996-98 widely introduced two successful maize hybrids under the GLO-2000 programme of the Sassakawa Foundation. Maize research, split among federal and provincial bodies, will surely be called on to deal with new pest biotypes that 'like' a new hybrid. Resources and leadership will be needed to respond swiftly – and such responses elsewhere have too often been slow or missing. The poor and remote then suffer most.

72 Evenson 1999, 2000.