

Reconnecting Agricultural Technology to Human Development

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Introduction

Human development has repeatedly been transformed by huge gains in food production; especially the 'Neolithic settlement', as former hunter-gatherers became farmers. However, even in Europe alone, this took many centuries to spread. Until about 1750, technical progress raised on-farm productivity too slowly, at national level, to achieve rapid increase in food availability or employment income. Yet between 1750 and 1914, new farm techniques (better crop rotations, plant and animal varieties, guano and fertilizers and, later, refrigeration and tractors) transformed human life in Europe, North America and Australasia. New farm opportunities meant more food, more labour income, and the conquest of mass rural hunger. Later, rising farm productivity released millions of farmworkers to higher-earning, mainly urban activity.

Between 1950 and 1990, an analogous process, the Green Revolution, brought unprecedented rises in food production, falls in poverty, and human development (including better health and education) to much of South and East Asia and Central America. These outcomes then fuelled more farm growth. However, this virtuous circle has become a crawl since 1990. Farm yield growth and poverty reduction have slowed right down — before even reaching most of Africa, uplands, and drylands. The farm changes of 1950–1990 were based on the adoption of mainly public sector research by smallholders, employment intensively and with irrigation or fairly secure rainfall. But agricultural research has shifted to the private sector; its results have become less smallholder friendly and less employment intensive; poverty has concentrated in rural areas with little water control; and rural water shortages are intensifying. The positive connections between agricultural research and human development have sharply weakened. This paper explores those connections, and how to revive them.

Agrotechnical progress is a three-stage process comprising:

- *research* by farmers and/or public or private providers;
- *invention*, discovery or development of a technique; and
- *adoption*, from innovation by early users, to diffusion by learning or extension.

Progress in human development is indicated by:

- increased consumption, especially by the poor;
- better nutrition;
- better health;
- better educational attainment; and
- participation in, or empowerment to influence, decisions affecting one's life or livelihood.

Agrotechnical processes of research, invention and adoption can improve human development by raising average consumption, nutrition, education or health, but can also affect their spread,¹ stability,² and sustainability.³ Health, good nutrition, education, poverty reduction and empowerment, especially of women, accelerate agrotechnical progress, and improve its structure in various ways. We review the two-way causal link between human development and agrotechnical progress.

This paper is divided into three sections. The first analyses how the five indicators of human development can be affected by the three stages of agrotechnical progress, and analyses the reverse causal sequence. The second section examines the issues of spread, stability and sustainability, while the third section concludes with some policy implications.

Types of human development, agrotechnical progress, and interactions

The interactions between human development and agrotechnical progress are summarized in Table 1. It reports the current consensus, if any, on how three main types of agrotechnology (animal/plant types, land management, and water management) affect the human development indicators, and *vice versa*. The signs indicate an expected direction of effects between average values. The entries show effects of 'types' of technical change on 'average' or 'total' human indicators (of health, etc.), in the short to medium term, in 'typical' cases. Any policy decision should also be concerned specially for the impact on outcomes of 'particular' agrotechnical options; on some 'non-average human effects', on the more vulnerable, less developed, less resilient; on the 'stability and longer-term sustainability' of effects on human development indicators; and on outcomes in 'locally relevant' conditions.

In the left-hand block of Table 1, all the 'research' and 'discovery' rows comprise nil entries. Until used, research and discovery alone has minimal impact on human development. However, long unused research, even basic science, can long afterwards prove a precondition for the final stage of adoption and spread. Mendel's discovery of plant genetics, neglected for 50 years, formed the basis of modern plant selection, with a huge impact on human development. Had this work been recognized earlier, the green revolution would have reached Asia sooner, providing much productive income for the poor and preventing many deaths. What of the opposite causal sequence? Health and nutrition affect adoption, but seldom do agricultural research and discovery. Education, however, normally improves all three.

TABLE 1. Interactions between agrotechnical progress and human development

Agrotechnical progress		Agrotechnical progress as CAUSE of improvement in:						Agrotechnical progress as EFFECT of improvement in:						
Type	Stage	Poverty via:			Poverty via:			PcPn/empwt	Growth	Distribution	Nutrition	Health	Education	PcPn/empwt
		Growth	Distribution	Nutrition	Growth	Distribution	Nutrition							
Animal/plant types/varieties	Research	Nil	Nil	Nil	Nil	Nil	Nil	Positive	Predominantly negative?	Nil	Nil	Nil	Very positive	Predominantly positive
	Discovery	Nil	Nil	Nil	Nil	Nil	?	?	?	Nil	Nil	Nil	Very positive	Positive
	Adoption/spread	Very positive	Predominantly positive	Predominantly positive	Nil?	Predominantly positive	Positive/negative?	Positive	Positive	Positive?	Positive?	Positive	Very positive	Positive
Land management	Research	Nil	Nil	Nil	Nil	Nil	Nil	Predominantly positive?	Predominantly negative?	Nil	Nil	Nil	Positive?	Positive?
	Discovery	Nil	Nil	Nil	Nil	Nil	?	?	?	Nil	Nil	Nil	Very positive	Very positive
	Adoption/spread	Possibly positive	?	Positive?	Nil	Positive?	Positive/negative?	Predominantly positive	Very positive	Very positive	Positive	Positive	Positive	Very positive
Water management	Research	Nil	Nil	Nil	Nil	Nil	Nil	Positive	Predominantly negative?	Nil	Nil	Nil	Very positive	Positive
	Discovery	Nil	Nil	Nil	Nil	Nil	Positive	Positive	?	Nil	Nil	Nil	Very positive	Positive
	Adoption/spread	Very positive	Predominantly positive	Very positive	Positive?	Predominantly positive	Positive/negative?	Very positive	Very positive	Positive	Positive	Positive	Positive	Predominantly positive

Note: Nil shows no or very small impact. ? shows lack of that type of agricultural research, or of 'research on research', or on that sort of causal linkage between research and human development. Predominance of a positive or negative effect signifies that effects vary among types of change in (say) water management, or experiences in different places. For example, the left half of entries in the bottom row report that adoption and spread of techniques for more or better water management' will, in the short-to-medium term, have good effects on improving average levels of poverty via extra output (with unclear effects via distribution) and of nutrition; two-way effects on health and participation/empowerment; and perhaps small positive effects on education.

The effect of agricultural research on human development

Growth, distribution and poverty. Over one-third of international variance in the rate of reduction of absolute consumption poverty is associated with variance in the rate of growth of consumption per person (International Labour Office, 1998).⁴ In low-income countries, agricultural growth is normally more conducive to poverty reduction than growth in other economic sectors, because:

- agricultural growth is usually associated with greater local reliability and affordability of food, especially staples; these comprise, respectively, over 70% and over one-half of the consumption of those in dollar poverty, far higher proportions than for the non-poor;
- the poor are more likely to be engaged in agriculture and the rural sector than the non-poor; and
- the poor depend mainly and increasingly on labour income; compared with other economic sectors in low-income countries, extra farm output is more labour intensive, has lower capital cost per workplace, and creates more demand for other labour-intensive products (especially rural non-farm services).

The expectation that faster agricultural growth is relatively pro-poor is borne out by Indian data for 1957-1989. Both among states and over time, faster farm growth is associated with considerably faster rural and urban poverty reduction, which is not the case for growth in other economic sectors (Datt and Ravallion, 1997). Indonesian and other data confirm that agricultural growth is far more strongly linked to poverty reduction than growth in other sectors (Hanmer and Wilmshurst, 2000; Eastwood and Lipton, 2001).

Improved agricultural technology has dramatically improved growth of farm value added (Alston *et al.*, 2000). Economic growth, especially farm growth, tends to reduce poverty. But it does not follow that all agrotechnical progress reduces poverty — let alone all forms of poverty. If new technology raises farm labour productivity faster than farm output, farm employment falls. Then, if most of the poor are landless and if the landed do not use their extra income in ways that create more employment than is lost on the farms, poverty among labourers can rise.

In some cases, new technology raises farm output but causes larger proportionate price falls for farm outputs. This is especially likely to happen in (a) a heavily protected economy, or (b) a country with a large world-market share for a product with small price-elasticity of demand (i.e. where a big price fall is needed to induce consumers to buy even a modest extra amount of product supplied). The new technology of clonal teas in the 1970s raised output in Sri Lanka, but her large market share, and the low preparedness of tea-drinkers to raise consumption without large price cuts, meant that the technical progress actually reduced Sri Lanka's real income from tea.

Agrotechnical progress, even if it helps the poor via more farm output, can harm them by changing the product mix. If research raises productivity

of crops or animals that generate much less employment income, per hectare and per unit of capital, than others, or if research makes it pay to shift land and water from staple foods to luxury textiles or animal products, then the poor may lose despite higher farm output. Free trade and exchange make these ill effects less likely, provided transport costs are not too high. However, such negative effects of technology-based farm growth on poverty are exceptional (and avoidable), especially with open trade, good transport infrastructure, not-too-unequal access to rural land and water, and research policy that concentrates on outcomes that do not unduly displace labour, or neglect food staples, which dominate the diets of the poor (Box 1).

Box 1. What makes agrotechnology more pro-poor: a checklist

The 'dollar-poor' are much likelier than others to:

- (a) rely on labour income;
- (b) derive it from farming or farmwork, especially for food staples;
- (c) be risk exposed, uninsured and/or risk averse;
- (d) use most income to obtain staples;
- (e) be malnourished;
- (f) work where farm water is scarce, seasonal or risky; and
- (g) suffer from maldistribution of assets, especially land, water-yielding capital and education.

Techniques are likelier to be pro-poor if they:

- (i) demand labour;
- (ii) cut risk;
- (iii) raise access to cheap, reliable sources of energy and micronutrients;
- (iv) improve water use efficiency;
- (v) suit smaller and more asset-deprived farms; or
- (vi) help the poor to acquire key assets.

So, *subject to local conditions, scarcities and costs*, a farm technique is more pro-poor if, all else equal, it is:

- more productive of output per unit of input, i.e. cuts unit cost — unless (with falling labour costs) poor employees' loss exceeds poor farmers' and consumers' gain;
- more labour intensive (uses more labour per unit of land or fixed capital);
- but better 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;
- favouring products mainly made and/or used by the poor — but, as these change, the poor gain if research shifts to other products providing them farm or labour income;

- increasing availability or cutting or stabilizing prices of staples, the main sources of *nutrients* in which the poor are deficient: calories, iron, vitamin A and iodine; and
- more sustainable in terms of land, water and biodiversity, because the poor are most harmed by sudden falls in the productive capacity of farm environments.

There is often a trade-off between the features of the checklist in Box 1, but wise agrotechnology policy can reduce it. For example, land sustainability may be enhanced with higher labour/capital ratios by incentives to install vegetative barriers (which yield some quick income for the needy poor) rather than contour bunds (which do not). All features in Box 1 (except biodiversity) were advanced by the spread of high-yielding cereals in 1950–1990, leading to unprecedented poverty reduction. The relative importance of items in this checklist varies with local agro-ecologies, institutions and preferences; but farm growth, induced by agrotechnical change, normally helps the poor, and with good policy can do so even more. But is research good for growth? A recent ‘meta-analysis’ of all the 1852 available studies of returns to research provides the most reliable answers so far (Table 2).

Few types of investment show median returns of 40% or better. Returns were even higher for ‘pure’ agricultural research than for extension (including mixed research/extension) activities.⁵ These levels and patterns of returns to agricultural research are confirmed by a Food and Agricultural Organization (FAO) study (Evenson in FAO, 2000, p. 264). Plainly, excellent growth impact is being achieved from public investment in agricultural technology, especially since the ‘average’ return on public research funds in developing countries is about 40% above the return that can be expected from the ‘median’ study. These studies find no evidence of falling returns, even in the 1990s. On top of the high growth returns to agricultural research, countries, districts, and crops with rapid research progress, above all in staple food

TABLE 2. Real rates of return to median public sector research activity, 1958–1998

	Number	IRR* (%)		Number	IRR* (%)
All with known locations	1809	44.0	All with known products	1772	41.9
(Developing countries)	(683)	(41.0)	Multi-commodity	436	44.9
Sub-Saharan Africa	188	32.7	(Field crops)	(916)	(41.6)
Asia and the Pacific	222	47.8	Maize	170	45.1
Latin American/Caribbean	262	40.9	Wheat	155	38.1
West Asia/North Africa	11	34.3	Rice	81	48.9
Developed countries	990	43.9	Livestock	233	50.5
Multi/international	136	35.0	Tree crops	108	31.7
			Resources/fish/forestry	78	15.7

Source: Alston *et al.* (2000, pp. 58, 62). For the 1652 studies (p. 56) stating whether real or nominal returns were used, 351 were nominal; their higher returns overstated real returns for the sample by 1.049. The rates have been reduced accordingly.

*Internal Rate of Return.

crops, have been those with rapid 'poverty reduction' (Lipton and Longhurst, 1989; Kerr and Kolavalli, 1999; Hazell *et al.*, 2000; IFAD, 2001). Irrigation also appears clearly poverty reducing, via increased average income and reduced fluctuations (Rao *et al.*, 1988).

It is in less-favoured regions, hitherto thought to offer few prospects for agricultural research, where poverty has persisted. Yet such regions can gain from research, if they have well-developed local adaptive research systems, or high labour mobility. In Indonesia, the Philippines, parts of India and elsewhere, the gains of Green Revolution lead areas in rice have been, in part, transferred, through migration and remittances, to poor labourers from less favoured areas (David and Otsuka, 1994). In both China and India, some rain-fed areas (including some with low initial productivity) now show higher rates of return to agricultural research than the traditional 'lead' irrigated rice and wheat areas (Fan *et al.* 2000a,b).

Why, if its growth and poverty impact are good (even, or especially, in some 'backward' areas), has public agricultural technology development and diffusion stagnated in the international system, and contracted in Africa and Latin America? Why have both yield growth and rural poverty reduction slowed in the 1990s, and not expanded significantly to 'problem areas'?

First, the successes of public agricultural research, which benefited aggregate growth by increasing farm output per person in the 1970s and 1980s, are now increasingly 'preserving' it, in face of mounting pest, water, soil and nutrient problems. Annual yield growth in main food staples in the developing world has slowed from about 3% in the 1970s to just over 1% in the 1990s. Without research to maintain resistance against evolving pests, and to improve water and nutrient use efficiency, growth would have slowed down more; but such returns to research (even if still high) are less obvious. And they may indeed fall in the long run, if research itself generates steadily increasing bio-uniformity, increasing the vulnerability of crops and animals to pest attack. If future research is forced to become more 'defensive' by the very successes of past research, the returns to each piece of research are high before the event, but only because the 'growth costs' of the switch to defensiveness in subsequent research are not netted out, as they should be.

Second, price signals to public paymasters have not favoured research expansion despite its high return. World prices of main farm products have steadily fallen, relative to the prices of non-farm products. This means that 'successful' new farm technology merely raises the amount of crop, surplus to requirements, that taxpayers subsidize farmers for growing! Consumers are even less likely than farmers to thank politicians for financing such agricultural research, or to return some of the benefits readily, in product costs or in research fees or taxes.

Third, land-water research shows less attractive returns, and has had no scientific breakthroughs comparable with the Green Revolution in plant breeding. Yet land and water resources are under growing environmental pressures.

Fourth, and most fundamentally, the increasing defensiveness of research (and hence, in large part, the lack of political appeal of its still high rate of return) is a natural result of the steady using-up of the great impetus given by past, within-species plant and animal selection, especially for size and biotic resistance. New science is needed to replenish the 'cupboard' of innovations, by expanding the gene pool of major agricultural species. Fortunately it is available, but much more locked into private sector and profit-seeking research now than in the heyday of the green revolution in the 1960s and 1970s.

Nevertheless, there is large, favourable poverty impact from bio-agricultural research, and from much irrigation expansion (although with substantial differences among types).⁶ Mechanization of agriculture, if a normal response to rural labour shortage, assists labour transfer to more rewarding occupations. However, if induced by subsidy (to tractors, or the credit to buy them, or fuel to run them), mechanization displaces labour without compensating additions to output. Especially in labour-surplus, land-scarce economies, any gains from such technical change are unlikely to raise farm output, but likely to increase poverty. In such circumstances, subsidized public research on such things as mechanical rice transplanters or weedicides needs to be carefully vetted for poverty impact in main areas of application. Occasionally, greater speed of cultivation (sometimes allowing double cropping) outweighs losses in employment per season, but only seldom (Binswanger, 1978; Farrington and Abeyratne, 1982). Erosion and water impacts associated with deep ploughing also need review. However, the shift towards zero, chemical or minimal tillage, currently under way in South East Asia and on larger farms in parts of Africa, is double-edged for poverty reduction, sometimes raising yields and improving sustainability but also tending to cut employment.

For poverty reduction, important research options concern biotechnology. The policy goal must be the redirection of plant genetic modification (GM) research and development towards the crops and traits of key interest to poor farmers, labourers and consumers: main staples of humans rather than (as now) farm animals, and yield enhancement and moisture-stress resistance rather than (as now) compatibility with commercial herbicides that replace labour. Care and openness regarding biosafety, food-chain effects, and environmental impacts are needed, but GM plants present no greater (and in some ways fewer) hazards in these respects than do conventionally bred plant varieties.⁷ Such hazards should be far better understood and monitored for all introduced plants.⁸ Against such hypothetical risks of action must be set demonstrable risks of inaction: worsening poverty from not reviving rapid yield and employment growth in food staples production; and foregone or delayed specific benefits, such as development of GM rice enriched with provitamin A to reduce child blindness (Nuffield Foundation, 1999; Royal Society *et al.*, 2000).

Implications of water-economizing technology for human development. Both technology and extension policy and basic science have advanced

enormously in improving farm seeds and nutrient application. But the Green Revolution, so crucial to human development, has achieved far more in water-controlled areas. A prior scientific revolution, that of Darwin, Mendel and Crick and Watson, was a necessary precondition for the Green Revolution. However, water science (for farming as for domestic water use, for water exploitation as for water economy) has not had its Darwin. The world awaits, needs, but is doing little to pay for, its 'Blue Revolution'. The last basic scientific breakthroughs in irrigation and water-economy (timed dam use, artesian wells, etc.) are thousands of years old.

Africa has mainly rainfed agriculture, some promising and neglected. And it is often claimed that technology policy in Africa should eschew big irrigation, preferring traditional, farmer-controlled water-management techniques: no more large dams, but sandriver extraction, molapo stream diversions, rainwater catchment and other approaches to improved rain management (e.g. through supplemental irrigation⁹). However, the spread of such methods has been heartbreakingly slow. Only 3–5% of cropland in Africa is irrigated or water controlled (mostly on biggish farms), as opposed to over 35% in South and East Asia.¹⁰ Moreover, 'improving' traditional irrigation techniques has often meant mechanistic transfer across hydro-ecologies, sometimes with disastrous results, as with most so-called 'swamp development' in West Africa (Richards, 1985). Without new, including large, irrigation, little of Africa will achieve adequate growth (either in total farm-factor productivity or in employment-based food entitlements) to cut poverty rapidly.

Sustainable irrigation practices need to suit topography, water availability, soils, terrain, labour availability, crop needs, area cultivated and social organization. Many factors impeding adequate performance on older irrigation projects in Africa (subsidized water, underpriced crop output, corrupt settlement decisions in over-large units, reliance on monopoly foreign contractors) are much less strong now than in the 1980s. Nevertheless, given the controversy regarding large projects, already established, locally applicable small-scale water-control techniques should be used wherever economic, and attention should be given to maintenance of older irrigation schemes — although there is no presumption that this is always better than new works (traditional or modern), especially if the old schemes are severely saline or otherwise degraded.

Box 2 identifies some of the implications of better water management for human development.

The effect of agricultural technology on health and nutrition. Technology affects not just command over food,¹¹ but also food quality. Measures improving soil content of key micronutrients, notably zinc, probably help both plant growth and human nutrition. But for sustainability, varieties, crops or cultivation methods (e.g. water management) may need to increase the plant's conversion efficiency or partitioning efficiency for the micronutrient, or else add the micronutrient (by manure, fertilizer or rotation), but not raise extractive efficiency. However, the problem of extraction/exhaustion is much

Box 2. Implications of better water management in agriculture for human development

- Diversion of water for other uses, notably domestic consumption, can occur without threatening food production. Agricultural management practices that reduce chemical inputs also have a positive impact on drinking water supplies in both urban and rural areas.
- The presence of irrigation wells can greatly affect women who have greatest responsibility for collecting water for domestic use. In most rural areas where wells are sunk, drinking water takes priority over irrigation, resulting in substantial time saving for women and health benefits for rural households.
- If more water-efficient rice production is practised, those who plant rice will be spared exposure to leeches and other dangerous organisms living in water.
- Where water is priced, if farmers have access to technologies that enable them to use water more efficiently, they can save money and hence increase profits, reducing income poverty.
- Ability to use water more efficiently can reduce dependence on irrigation systems that might be inequitable, thereby empowering poor farmers. Moreover, much current research into pro-poor water-efficient technologies encourages participation by farmers themselves. Investments into developing traditional techniques, such as porous pot technology, contribute to human development through valuing past developments by poor farmers.

less serious for metals like zinc than for vitamins. There are huge prospects of GM for human micronutrient enhancement such as provitamin A rice, but conventional breeding can do better in other cases, such as iron enrichment of rice.

We now explore the impact of some agricultural technologies on human health. The intention is not to criticize past technological developments in agriculture through listing their side effects, but we badly need to identify effective ways of monitoring and reducing the hazards and developing treatment. However, health benefits from improved farm production and employment (and hence from technological development) can improve nutrition, shelter, and access to water, possibly far outweighing the side effects.

Human consumption of irrigation water. For families living near irrigation projects, this more convenient source of water may reduce disease through cleaner water, or greater availability, facilitating better hygiene. But drinking such water can sometimes spread infectious diseases such as cholera, and chemical poisoning through surface or groundwater transfer of agricultural

and industrial chemicals. For instance, the Gal Oya Project in Sri Lanka caused health problems through use of the water for drinking (Imbulana *et al.*, 1996).

Vector-borne diseases. Stagnant water is a breeding ground for disease vectors, especially insects (above all, mosquitoes). Surface irrigation, badly managed systems (resulting in seepage pools) and sometimes paddy fields increase mosquito populations. Furthermore, human resettlement on large-scale irrigation schemes (such as Gal Oya in Sri Lanka, Aswan dam in Egypt, Gezira in Sudan) compounds the problem, since incoming populations may have no natural immunity to the diseases. Schistosomiasis is another vector-borne disease, carried by snails that reside in stagnant water. In 1999, there were 14 000 deaths due to the disease, primarily in Africa (World Health Organization (WHO) data).

Use of chemicals. In Concepcion, Paraguay in 1990–1991, some children living within 50 metres of a cotton crop suffered paralysis 2–3 weeks after the crop was sprayed with monocrotophos. The average recovery time was 6 months. By 1990, 1500 workers on Costa Rican banana plantations had become sterile since the 1970s through the use of the pesticide DBCP. In addition to the inability to have children and the consequent impact on social and economic status, one-half of the workers suffered depression and many became divorced or separated due to impotence. Clinical examinations of potato farm workers in Ecuador found that 93% had skin lesions compared with 81% in the control sample. Chronic dermatitis was twice as common among the farm workers as among the controls. A study of tobacco farm workers in Malaysia found that hazardous pesticides were used on 96% of farms and nearly one-half of the knapsack sprayers were leaking. The workers each applied the pesticide for about 18 hours over a 10–12-week season, with each spraying time lasting between 20 minutes and 5 hours. As a result, one-third of the workers had more than two symptoms of pesticide toxicity such as headaches, dizziness and facial burning. The children of female Colombian flower cultivators are likely to experience birth defects as a result of past pesticide exposure of the mother.¹²

Farmers' unawareness of the dangers of agrochemicals, combined with poor legislation and enforcement, often leads to poisoning. There are around 1 million severe occupational poisonings with 20 000 deaths, 99% of these in developing countries each year (WHO/UNDP, 1990). Two to 10% of agricultural workers reported previous pesticide poisoning in Bolivia (Aguilar *et al.*, 1993); in Indonesia, 9% of farmers had experienced pesticide poisoning in 1994 (Kishi *et al.*, 1995). More can be done to ensure safe and appropriate use of pesticides. In the Mekong Delta, Vietnam, pesticide use in paddy cultivation was higher than optimal for profit maximization (Dung and Dung, 1999). Reduced pesticide use often improves health impact, and usually cuts production costs. Indonesia (with IFAD support) has achieved major pesticide use reductions through integrated pest management (IFAD, 2001).

Fertilizer use also affects health. Nitrates and nitrites from fertilizer are among the most common contaminants in drinking water (World Resources Institute, 1999); nitrate contact with mouth bacteria causes nitrate poisoning. Babies fed formula milk mixed with nitrate-polluted water experience reduced oxygen carrying capacity of the blood, inducing 'blue-baby' syndrome, which can be fatal. As with pesticides, production costs as well as health suffer when fertilizers get into drinking water instead of crops; in China, only 30% of fertilizer applications reach the crop, much of the rest reaching watercourses. In Northern China, over one-half of groundwater monitoring sites had nitrate levels above the allowable limit. In some areas, drinking water plants had been closed (Maurer *et al.*, 1998). This harms health through inadequate water quantity and/or increases women's time and labour burden in finding alternative water sources.

Information about how to use chemicals safely may be less accessible to farmers than the chemicals themselves. Farmers need information about reducing the dangers of chemical use in agriculture through less frequent spraying, proper equipment and protective clothing.

Physical injury in farmwork. Casual labourers in rural India lose 5% of work time for men, 6% for women, to ill health, plus 1% in chronic disability. Much of these losses are due to snake/scorpion attack in fields, back injury (especially in transplanting), dehydration or inferior water quality (Lipton, 1983, p. 11).

In a progressive village in Bangladesh, 80% of female users of modern threshing technology suffered pain in their waist and legs for a few hours after threshing. However, 20% of the farmers said that traditional threshing technologies (e.g. dhenki) that had previously been used caused similar problems. Overall, investment in the new technology was felt to be worthwhile, since it made the job easier (Sarwar and Karim, 1988).

Most physical injury incurred in agriculture is preventable. It is largely ignored, but probably causes more death, pain and work loss (with much less offsetting output benefit) than agrochemicals and irrigation put together.

The effects of human development on agrotechnical progress

Education as a cause of technical change. Education facilitates an increase in farm output by: (i) providing a farmer with the necessary skills to improve technical and allocative efficiency; and (ii) inducing an attitudinal change, which may accelerate adoption of new technologies. However, evidence of the relationship between formal education and technological adoption is mixed.

Being educated increases the chances of adopting a technology:

- *Chemical fertilizer.* Fertilizer use is higher among better-educated farmers. In Thailand, a farmer with 4 years' education is three times more likely to use new chemical fertilizers than those with less education. In Bangladesh, one additional year of education of the rural adult male population raises

per hectare fertilizer consumption by 184 taka. Fertilizer use among soyabean and rice cultivators in Brazil is higher among the better-educated. In Uganda, 4 years of primary education by farm workers raises purchased inputs by 9%, 7 years' education by 15%, and 14 years' raises inputs by 25%.¹³

- *Packages.* Educated Indian farmers are more likely to use irrigation, improved seeds, fertilizers and pesticides (Raza and Ramachandran, 1990). There is a significant relationship between education and package technology adoption among groundnut farmers in Adamawa State, Nigeria (Bzugu, 1995).
- *Traction.* In Shoa Province, Ethiopia, education increases adoption of single-ox technology, and fertilizer and pesticide use (Kebede *et al.*, 1990).
- *Crops.* Being educated also affects crop and varietal innovation. Educated households are more likely to adopt F₁ hybrid rice in Hunan Province, China. In Nigeria, education increases adoption of soybeans. In Bangladesh, rural men with 1 year's more schooling sow improved seeds on 7% more area.¹⁴

But agricultural gains from education are greater in advanced farming regions. That is where it most accelerates adoption of new inputs and farming practices in rural Peru (Cotlear, 1990), and where the output gains from innovation in many countries have proved largest (Lockheed *et al.*, 1980). Conversely, introduction of new crop varieties, insecticides, fertilizers and tractors is speeded by educated farmers, who adopt such technologies sooner.

Farmers apart, education of non-farming household members can accelerate farm adoption. In rural Ethiopia, secondary education of rural family members increases access to off-farm income, which can be used to finance farm improvements (Weir, 1999). Furthermore, diversification of the household's income sources reduces risk aversion from agricultural innovation.

Thus, even a little education can predispose a farmer to innovate. Literacy enables farmers to read about the technologies and to read instructions about how to acquire and apply them. Numeracy permits calculations regarding input application. Education also enhances farmers' ability to understand concepts and to assess risks of technology adoption.

In some cases, being educated does not necessarily influence technology adoption. Mukhopadhyay (1994) finds that schooling did not affect adoption of improved seeds in West Bengal, India. Informal education through on-the-job experience and availability of extension services was found to be more important, although formal education might motivate change. Among the Tawahka Indians of the Honduran rainforest, the educated Tawahka are the more sceptical about (and not more prone to adopt) chemical herbicides (Godoy *et al.*, 1998). However, education has provided Indians with language skills, which enables communication with Spanish-speaking extension workers and traders, which has influenced the adoption of rice. Education does not influence adoption of oil palm technologies in Imo State, Nigeria, but may influence a farmer's ability to weigh up the risks and benefits of adoption (Njoku, 1990).

Sometimes, it is up to a threshold that education accelerates farmers' adoption of agricultural technologies. Appleton and Balihuta (1996) for Uganda, and Weir (1999) for Ethiopia, find secondary schooling (as compared with primary) does not improve returns to agriculture. It has little impact on farming innovation in most studies — probably because secondary graduates can make more money elsewhere. Indeed, in Central Luzon, education of household heads appears to reduce farm production, increasing the prospects of finding greater, or less tiring, income-earning opportunities off-farm (Estudillo and Otsuka, 1999). Education is not a significant determinant of adoption among the Indians of the Beni region of Bolivia; the educated migrate or quit agriculture (Godoy *et al.*, 1998). If future food requirements are to be met, investments must be made in developing agricultural technologies to keep farming attractive.

Informal education (e.g. through dissemination of information and extension visits) can be as important in stimulating farm adoption as formal education; the two can be complimentary (Lockheed *et al.*, 1980). Informal education tells farmers about new technologies; formal education equips them to respond to such information. However, informal education alone, in addition to past experience, can increase farmer confidence, and hence probability of adoption: a non-cognitive, learning-by-doing approach. This can include the multiplier effect of one (perhaps formally educated) farmer adopting a technology, whose success influences the decision of other (possibly not formally educated) farmers to copy the innovation (Appleton and Balihuta, 1996).

The effects of human health on agricultural technology. Seasonality is a major issue here. Often, illness is seasonal. Temperature and rainfall determine survival and breeding patterns of mosquitoes, and thus malaria. The rainy season also sees a greater incidence of diarrhoeal disease. Such threats to human health often coincide with times of high farm labour requirements, causing labour bottlenecks. This might stimulate adoption of labour-saving agricultural technologies. But households facing labour shortage due to illness cannot afford health care (due to poverty and loss of income through illness) (on Burkina see Sauerborn *et al.*, 1994), let alone investments in technologies that ease labour constraints, unless they have access to credit, which is best used in getting better. Where external inputs are already used, money might be diverted away from these towards paying health care expenses. Illness during the slack season can reduce the use of agricultural technologies, such as conservation techniques, because households seeking to reduce labour input are likely to target activities that give the least or latest returns. Nutrition in pre-harvest seasons also tends to be worse, compounding the seasonal effects of ill health and increasing susceptibility to illness.

How can agricultural technology be adapted to seasonal health variations? In the Nigerian savanna, farmers intercrop commercial crops such as yam and rice with traditional crops and stagger the cropping of staples so as to spread labour needs more evenly throughout the year (Stone *et al.*, 1990).

This works less well where households have alternative activities in the other seasons such as migrant labour. In addition, this is not favourable to human development if children are taken out of school to help on the farm during an extended cropping season. Irrigation development and spread to poor households may also be needed to enable households to spread their agricultural activities beyond the wet season. Alternatively, breeding for drought tolerance is a policy issue. In Northern Mali, Tuareg pastoralists experience labour bottlenecks in milk production. Timing of milk production is linked to the biology and breeding patterns of the animals which agricultural research could address (Swift, 1981).

Another major issue is AIDS. The intensity of the impact of AIDS on agriculture is dependent on a number of factors, each with consequences for agricultural technology.

- *Seasonality of labour demand.* The longer the rains, the more room there is to adjust cropping practices to available labour supply. Yet seasonality also means migration, the women that remain on farms being vulnerable to spread of AIDS from seasonal migrant husbands (FAO/UNAIDS, 2000). Seasonal labour bottlenecks and illness during certain seasons can have implications for agricultural technology, either in stimulating its adoption or in reducing investment in agricultural technologies as household expenditure is diverted to health care. In East Africa, the increase in banana weevils may be attributable to shortage of labour to control them by traditional means, or shortage of cash to buy pesticides, both worsened by the AIDS crisis (FAO, 1995).
- *Specialization by gender and age.* In many farming systems, men, women and children often do different, specific tasks. Most African farmers are women; and in Africa women are about three times as likely to contract HIV, given the exposure, as men (Gregson, 1994). If a farmer dies without passing on knowledge and skills needed to maintain agricultural production, or leaves no male family members to ensure household access to land, credit, etc., this may result in abandonment of farming, as with widowed female farmers in Uganda (FAO, 1995).
- *Diversion of workers.* This occurs due to illness or to look after the sick or orphans. This perversely stimulates labour-saving technology (in particular, long-lasting machinery such as tractors) even where capital and savings are scarce, seasonal underemployment rife, and long-run workforce growth, allowing for AIDS, over 2% yearly (United Nations, 1998).
- *AIDS-related expenditure.* Household income is diverted for expenses such as medical assistance and burial. Productivity-enhancing inputs can be foregone, as opposed to fixed assets, especially as the labour used to apply such inputs might not be available due to death, caring for the sick, attending funerals, etc. Twenty-three percent of surveyed farms in Masaka and Rakai districts in Uganda in 1991 reported a reduction in land use over 4 years due to HIV/AIDS (Hunter *et al.*, 1993). In Tanzania, 29–43% of previously available labour in AIDS-affected households had been devoted to the AIDS crisis (Tibaijuka, 1997). In Gwanda village, Uganda,

the coffee–banana system has been abandoned due to lack of labour and capital to control against weevil infestations (FAO, 1995).

- *The relationship between labour and the technology.* Labour-saving technology is less likely to be affected by ill health than labour-intensive technology. Vulnerability to AIDS in the agricultural sector is primarily through loss of labour incurred by the condition, either through sickness, caring for the sick — a greater issue in Uganda (FAO, 1995) — or death. Even if households short of labour could afford to hire it, if AIDS has hit a locality, the hired labour pool is affected. Thus, if AIDS-stricken rural households are to ensure that their livelihoods are not threatened, they often invest in labour-substituting technologies (Barnett and Blaikie, 1992); this response, correct or inevitable in its place and time, impedes labour-intensive development more widely, harming workers, by reducing demand for labour.
- *Impact on agricultural extension services.* In Rakai District in Uganda in 1995, up to one-half of working time of the extension service team was lost due to HIV/AIDS. When villages have up to 15 deaths per month, scheduling meetings at a time convenient for both farmers and extension workers is difficult. Since the AIDS epidemic leaves farmers unable to devote resources to the long term, the European Union's Farming Systems Support Programme, to revive coffee production in Uganda through better seeds, failed (FAO, 1995).

Participation as a cause of faster, or more appropriate and successful, adoption of farm technology. While some farmer participation in agricultural research is required to ensure that proposed innovations are appropriate and hence 'adoptable', too much or ill-designed participation is counterproductive, delaying or warping applicable results, and/or making farmers feel they have wasted their time. One needs to assess the goal of participation. If it is simply to improve farming methods, then cost-effectiveness during problem identification and experimentation is paramount. Success in devolving responsibility to farmers to test and adapt agricultural technologies has been mixed. Often, as farmer participation in on-farm experimentation increases, the reliability of the data collected decreases (Baker, 1991). Cost-effectiveness is also at stake if supervision costs for scientists are high, and quality is compromised if data sets collected by farmers are heterogeneous and difficult to decipher (Ashby and Sperling, 1994). In participatory plant breeding, breeders suggest that farmers cannot take part in every part of the breeding process due to low levels of numeracy and literacy (CGIAR, 2000). Yet there are many examples of where participation in agricultural research and breeding has been very successful, both for cost-effectiveness and empowerment of the farmer (IFAD, 2001). Despite difficulties in working with female bean farmers in Rwanda, their inclusion early in the breeding process resulted in faster and cheaper research, and locally appropriate bean varieties. This success stimulated farmer participation in public bean research in DR Congo and Tanzania (Sperling and Berlowitz, 1994).

Even where farmer participation in varietal selection does not much reduce cost, it can greatly improve distribution because seeds are more user friendly. Farmers in the Western Hills of Nepal were given several rice varieties to test in the field, and selected for early maturity, medium to tall plant height, easy threshability, good cooking quality and taste. Thus distribution of the selected seeds was successful due to the use of farmer networks and because the seeds were adapted to local needs (Joshi *et al.*, 1997; cf. Weltzien *et al.*, 1997). Other Nepali farmers selected rice varieties mainly by post-harvest evaluation; there, too, participation speeded adoption, which was substantial within 2 years (compared with 7 years for conventional varietal selection) (Sthapit *et al.*, 1996).

Technology, stability and sustainability

Technical change is better for human development, other things equal, if its benefits are stable (i.e. evenly distributed over time)¹⁵ and sustainable (i.e. can be maintained at current levels (or replaced) at acceptable cost, without loss to other regions). There are choices. Research, invention/discovery and innovation can be structured to maximize poor people's likely income gains, their smoothness over years (or months and seasons), or the length of time during which the gains are enjoyed, but not all at once. After good rains on drylands, surface irrigation can be used to increase peak-season yields further, or stored to secure next season's or next year's. Pests can be managed to eliminate short-term attacks at the cost of stimulating new biotypes that threaten sustainability later on.

Policy choices determine whether farmers use, and whether researchers develop, sustainable and stable techniques. Research choices can stimulate varieties with vertical resistance that eliminates today's pest biotypes — or horizontal resistance, or tolerance, that permits modest crop loss now but does not stimulate the build-up of virulent pest biotypes later. Researchers can use resources to select and breed for short-duration crop varieties, permitting more double cropping and smoother income flows, instead of maximizing yields per season (Lipton and Longhurst, 1989). However, seeking sustainable and stable varieties, water uses, or farming systems requires multi-site, multi-period research and is expensive. The sharp drop in yield growth, and in yield potential growth, in the 1990s may partly reflect the 'environmentalization' of cereals research objectives without corresponding resources. Also, the poor often need income immediately as they cannot borrow for capital works to protect against soil erosion or to conserve water, or have insecure tenure that reduces their concern with next season's income, let alone the next decade's. In Zimbabwe, poor herders knowingly select depleting, unsustainable grazing technology because they have too little land to survive from farming otherwise (Drinkwater, 1991). Reduced inequality in land access may increase the sustainability orientation of both initially poorer and richer farmers.

Specific issues of sustainability and stability arise with water resource management and pest control.

Water stability and sustainability

Irrigation, which covers over one-third of cropland in Asia but below 5% in sub-Saharan Africa, is the most credible way of stabilizing water supply to agriculture, allowing for seasons or years of low rainfall. Around 1990, developing countries had irrigation potential of a further 110 million hectares of land (World Bank/UNDP (1990) cited in FAO, 1996). Even a fraction of that would greatly stabilize output, employment and income (apart from feeding up to a further 2 billion people). Perhaps only 25–40% of such extra irrigation might be economic, at existing prices of products and factors. Yet the economic potential for irrigation to stabilize human welfare is clear.

Barriers to increased irrigation are, above all, efforts to release for urban domestic and industrial uses the 80–95% of water offtake in low-income countries now used by farmers. The heavy subsidization,¹⁶ wasteful use, and poor drainage associated with much farm water use is indefensible; the stabilization (and output) benefits of much farm water use are available with less water, used more efficiently. Over and above removing inefficiencies and subsidies, however, it may be misguided further to impede farm water use and thus worsen rural water instability. Water used by farmers is not necessarily used up; much is available downstream, or after the groundwater table is recharged. It is hard to see how the appalling instability of much African agriculture can be reduced without a substantial increase in formal irrigation.

Apart from the thrust to reduce agricultural water use, other barriers to this include construction and maintenance experience and skills for a whole range of traditional and modern irrigation equipment. Better market access, better seeds to raise returns to irrigation, better extension and microcredit, and much else can make it pay even better to acquire these skills.

Despite gains in safe water and sanitation coverage over past decades, one-sixth of the world's population still lack access to water. Groundwater is being mined beyond its replenishment capacity; surface-irrigated land is going out of use due to salinity and waterlogging, especially in older, worse managed systems, and urbanization, industrialization and undesirable agricultural practices (Lipton, 1999).

Governments' economic choices also affect stability and sustainability. In Brazil, inappropriate tax regimes encourage erosion of forest margins (Binswanger, 1991). Policy uncertainties raise rates of interest and time preference; then, market outcomes give a high weight to income yields in the short term, and little weight to long-term sustainability.

Government choices on redistribution and land reform also affect the stability and sustainability of farm technology. When market demands for new technology are very unequal, with big farmers making the running, there is pressure to deliver new farm technology to maximize income, but less so for stability and sustainability. Worse, a growing majority of scientists concurs that 'global warming' is a serious and growing threat, is significantly increased by human action (especially carbon emissions), worsens freshwater scarcity in hot regions due to increased evapotranspiration, and, especially, is raising short-term rainfall variability and long-term freshwater uncertainty.

By 1992, 8% of people in sub-Saharan Africa and 53% in the Near East and North Africa lived in countries with water resources below 1000 m³ per caput per annum, suggesting 'severe constraint' (World Bank, 1992, p. 48). By 2000, 30 countries were water stressed¹⁷ as against only 18 in 1990 (Rosegrant, 1995). Seckler *et al.* (1999) suggested that, by 2025, over one-quarter of the world's population (one-third in low-income countries) will experience severe water scarcity. Semi-arid Asia and the Middle East will be worst hit, with groundwater depletion being of particular concern.

Who loses from non-sustainability? *The poor suffer more*: the richest income quintile 'in Peru, the Dominican Republic, and Ghana is, respectively, 3, 6 and 12 times more likely to have a house (water) connection' (World Bank, 1992, p. 47). *Rural quality is worse*: On WHO data in developing countries, 30% of rural and 18% of urban people lacked 'safe water'; respectively, 82% and 37% lacked 'adequate sanitation'. Bad maintenance, especially in rural areas, makes matters worse than these official estimates (Gleick, 1999). *The rural poor are worst hit*: being more reliant "on rivers, lakes, and unprotected shallow wells, and least able to bear the cost of simple preventive measures such as boiling water" (World Bank, 1992, p. 47). *And agriculture is the main water user*: 88–95% of annual water withdrawals (from rivers and aquifers) in China, India, other low-income countries, and sub-Saharan Africa overall, 69% in middle-income countries, and 39% in high-income countries.

Technical remedies. Development of water-efficient and robust seeds holds great promise for (a) facilitating more efficient use of farm water, (b) reducing instability of crops in face of bad rains or irrigation, and (c) making water use more sustainable in both irrigated and rainfed areas. For example, development of seeds with short growth duration or high latency¹⁸ can cut both exposure to periods of low or risky rains, and the amount of irrigation required. In Andhra Pradesh, India, chickpea varieties for rainfed farming have been developed that mature fast and avoid end-of-season drought (ICRISAT, 2000). Less drought-prone varieties of millet and sorghum are widely used in some semi-arid areas of India and modestly in Africa.

Breeders have developed more water-efficient varieties, but seldom with high yields. Seckler and Amarasinghe (2000) suggest that further advances are unlikely and that the current research output is uneconomical for the farmer, but biotechnology could change this radically. It could introduce latency from other species (millet or even cacti) into higher-yielding plants lacking it (e.g. maize); or high yields from maize, into sorghum or millet, whose plant genomes provide fewer yield-enhancing options but have root and shoot characteristics for robustness under moisture stress. Moreover, less drought-prone varieties improve stability even if they do little to raise yields — and may stimulate risk-averse, vulnerable farmers to be more entrepreneurial and risk-taking in search of higher yields in other farm technology decisions.

Not only new varieties, but also new seeding techniques, can save water. Dry seeded rice technology permits water use efficiency through

better use of the rains.¹⁹ A shift from transplanted rice to this method in Southeast Asia has meant substantial water savings.

Pests, instability and sustainable technical remedies

In well-watered areas, pests are the main source, and elsewhere the second source, of unstable income for farmers and farmworkers. Most farmers, especially in Africa and on uplands, identify weeds, birds and rodents as the three main biotic sources of crop instability and loss. Yet they enjoy only a minute proportion of scientific attention, and therefore of technical progress.

Pesticides have long been the standard technology to reduce losses and instability due to pests (and to weeds). Major short-term successes have been achieved, and the technology is constantly 'improving'. But that improvement is like running uphill in a way that steadily increases the slope of the hill! The 'pesticide treadmill' compels farmers to use an ever wider range of costlier pesticides, to keep up with new pest biotypes evolved to overcome the old pesticide, often (notoriously in cotton) ending up with lower usable yields, higher pest losses and higher pest control costs than before the treadmill was first turned.²⁰

Improved plant varieties have several effects on crop losses and instability due to pests.

- They provide more food for pests.
- When bred to grow year-round (e.g. tolerant of varying sun or cold) they provide year-round food for pests.
- They are increasingly bred for pest resistance. For decades (ever since IR-20), newly introduced rice semi-dwarfs have been more resistant, when introduced, to all six main rice pests (Lipton and Longhurst, 1989).
- But crops with rapid varietal improvement drive out others. So genetically uniform rice or wheat populations have, over large areas and often year-round, replaced diverse varieties and crops. If a new pest, or new biotype of an old pest, evolves to overcome a uniform plant population's uniform defences, devastation can result, as with tungro virus in rice in the Philippines in 1971-1972. This is less likely with an open-pollinated crop like maize but it happens, as with Southern corn blight in the US in 1972.

Unlike pesticides, new varieties can be developed to overcome these problems (to make stability sustainable), provided we seek tolerable and managed levels of crop loss, not elimination of the pathogen. That is, seek moderate horizontal resistance, in which pests have to overcome several genetic barriers, instead of single-gene (vertical) resistance that briefly avoids almost all crop loss to the pest, but by that same token compels it to survive by selecting new, virulent biotypes to conquer that gene. A complementary approach is to aim at tolerance — acceptance of some limited crop loss or damage (i.e. allowing some of the pest population to live rather than resistance that forces it to adapt or perish).

Such forms of technical progress are less spectacular than single-gene vertical resistance, and in the short run may be less saleable and competitive

in the marketplace. Hence, in North America, annual and regionally differentiated alternation (cycling) of maize hybrids and wheat varieties, each with different sources of pest resistance, has been imposed by governments to modify the effects of a vigorous seed market in creating a uniformity of the temporarily 'best', but unsustainable, single variety or hybrid. However, it is hard to see countries with millions of smallholders implementing that.

Until recently, horizontal, moderate resistance, and tolerance have been much harder to research, stabilize, prove, and develop than single-gene vertical, near-total resistance. Biotechnology could change that — if redirected to the crops, conditions, and pest resistances of interest to the world's mass of poor farmers, labourers and food consumers.

Integrated pest management. Integrated pest management (IPM) is an increasingly popular approach to sustainable stabilization of yields in face of pests. IPM seeks to maintain pest populations below an acceptable threshold, using a combination of suitable techniques: some (low and safe) pesticide use; varietal selection; manual interventions, often by methods learned from particular farmers or locations (e.g. location and treatment of insect egg masses); timing and mixing of crops; and, strongly emphasized, biological controls of pests with predator (including parasite) populations.²¹ IPM aims at human development via both 'sustainable stability' of income lost to pests and at avoidance of the quite serious poisoning problems associated with pesticides, especially in developing countries.²² There are notable successes with IPM; for example, in controlling brown planthopper in Indonesia (IFAD, 2001).

The biological-control component has often proved specially cost-effective. International Institute of Tropical Agriculture (IITA) carried out research in South America, where the cassava mealy bug originated, to address mealy bug problems in Africa, causing yields to be affected by up to 80%. It was discovered that the parasitic wasp uses the mealy bug for laying its eggs and then kills the pest. The wasp was introduced in 30 African countries, once it had been ensured that it would not adversely affect the new environment. Each dollar spent on the project brought returns worth around \$150 to the farmer (IITA, no date).

Most interestingly, some of the biggest successes of IPM have advanced human development through empowerment — learning from farmers. Biological controls in Honduras (Meir, 1999), communal baiting in Bhutan (van Schoubroeck *et al.*, 1999), and pigeon-pea pod borer control in Andhra Pradesh, India (ICRISAT, no date) all stemmed from approaches that learned from, as well as teaching, farmers — women as well as men.

IPM, as a route to improved sustainability of pest control, has worked best as a multi-pronged, participatory approach, in place of over-reliance on chemicals and top-down technology transfer. An analogous approach to nutrient sustainability is 'integrated nutrient management'. Nutrient enhancement, like pest management, is a central contribution of modern agrotechnical change. It builds on traditional organic manuring methods. These alone are certainly insufficient to achieve the food outputs (and employment

impacts) needed for adequate nutrition, but steadily rising enhancement of soils with inorganic fertilizers based on the three main macronutrients (nitrogen, phosphorus, potassium) faces serious risks and limits. Organic and inorganic soil enrichment are complementary, not conflicting — and jointly complement other methods of nutrient management, such as varietal improvement, and nutrient cycling through crop rotation, animals, and other methods (IFAD, 2001).

In general, improved land and water management techniques are required to advance stability and sustainability, as improved biochemical techniques have advanced yield. But land and water management techniques' science, discovery and innovation have advanced far more slowly than their counterparts in biological and chemical science. The weight of conserving and stabilizing soils, water and terrain has increasingly fallen on biological science. Yet stability and sustainability of agriculture depend on enhancing technical progress in soil and, above all, water use and maintenance to match the enormous progress in plant and animal biology and its applications.

Policy implications

This paper has examined two-way interactions between agrotechnical progress and human development. These interactions are historically recent. Only since 1750 was agrotechnical change a main engine of steady human development; only from the 1950s to the 1980s was it deliberately harnessed towards such ends, achieving unprecedented progress. Indeed, the irrigation and biochemical revolutions of the 1960s and 1970s, with all their imperfections, have led the world's greatest and fastest advance in human development. Since 1990 the engine has stalled.

What policies can enable agrotechnology to resume its thrust towards human development, despite the reversion to more typically profit-driven and nationality-driven modalities of farm science and technology?

1. Mutual effects of agricultural research–discovery–diffusion and health–education–empowerment matter for policy. Education (schooling and extension) can help farmers to interact with formal research systems, better articulating both farmer knowledge and farmer wishes, as in the highly-educated and highly participatory agricultural research environment of Sri Lanka. But education leads to faster diffusion only where gains of adoption are significant and clear. Health and empowerment also speed adoption and perhaps discovery. Rural health and education underprovisioning may reduce agrotechnical improvements.
2. Public agricultural research and innovation were historically significant in stimulating agricultural progress (Asian irrigation for 2000 years, plant selection and fertilizer research in nineteenth-century Prussia and Britain, etc.) and were necessary for the Green Revolution, but have slowed down (in funding, rate of discovery, and impact on yield expansion) before large parts of the poor have gained. This needs to be addressed, if poverty reduction, now slowed, is to revert to 1975–1985 rates.

3. New farm technology is found and used in the wake of 'new science'. The big impetus from the Green Revolution breakthrough is slowing down, and being redirected to yield maintenance against pests and water shortage — both themselves partly results of Green Revolution success. And growing soil and water pressures further limit continuance and spread of agrotechnical progress. Hence the need for public support of new science, at basic levels, promising relevance for poor people's crops, preferred traits, and labour-intensive methods (relatively unattractive to private research) to:

improve water use efficiency in agriculture; and understand the functions of genes in main staple crops, and the scope and limits for transferring genes to improve crop performance (yields per unit of land and water) while enhancing prospects for spread of such improvements to less well-watered and/or upland areas.

4. Plant type improvement on poor people's farms is almost unambiguously good for human development unless it accelerates the 'chemicalization of agriculture'. Genetic crop improvement may, but need not, reduce fertilizer use, and is likely to reduce pesticide use. Policy review of GM requires an effective and open public sector role, both to maintain confidence of health issues and to steer progress in environmentally desired directions. IPM and integrated nutrient management are the right contexts for GM approaches to pests and nutrients, respectively.
5. Sub-Saharan Africa's low degree of water control seriously inhibits crop improvement. In some areas, irrigation expansion is indicated. This can build successfully on farmer-managed microsystems. But the spread of such systems has been extremely slow. Despite the pressures to cut agriculture's share in water offtake, major irrigation schemes, in some parts of Africa, will be pre-requisites for rapid rural (and human) development. The environmental, cost escalation, and human displacement hazards, formerly associated with some such schemes, are increasingly being avoided. More generally, water stress increasingly limits farm improvement. New, faster diffusing water technology and basic science are important.
6. Modern, specialized provision of agrotechnical progress (research, discovery, diffusion) makes farmers' own needs and 'finds' less commercially important in determining the direction of such progress. Markets stimulate researchers to consult farmers, but seldom poor or dispersed ones. Furthermore, scale economies increasingly concentrate research into a few, very large providers, often monopolizing their knowledge — and this may be a needed incentive to scientific discovery. For small farmers (and labourers) to influence research decisions, governments need to develop: (a) institutions and incentives to such people's participation, and communication with the formal research community; (b) competition among private research providers; and (c) public research supply in cost-effective, but not readily 'priceable', activities that do

respond to farmers' needs but are unlikely to attract formal private research.

7. A checklist of features making agrotechnical change 'pro-poor' can be constructed (Box 2). Despite occasional conflicts between such features, staff of public agricultural research and extension institutions need to be aware of them and subject to incentives to provide them. For example, employment intensity is hardly ever a goal of researchers, who are trained to see labour cost like any other cost — to be cut. In a poor, labour-surplus country with heavy rural labour underutilization, this is a mistake.
8. For poverty reduction, by far the most important research options concern biotechnology. The policy goal must be redirection of plant GM research and development towards the crops and traits of key interest to the poorest farmers and consumers: main staples of humans rather than (as now) farm animals, and yield enhancement and moisture-stress resistance rather than (as now) compatibility with commercial herbicides that replace labour. Care and openness regarding bio-safety, food-chain effects, and environmental impacts are needed, but GM plants present no greater (in some ways fewer) hazards in these respects than do conventionally bred varieties. Such hazards should be better understood and monitored for all introduced plants. Against risks of action must be set risks of inaction: worsening poverty from not reviving rapid yield and employment growth in food staples production; and foregone or delayed specific benefits, such as development of GM rice enriched with provitamin A to reduce child blindness.
9. Farmer participation in agricultural research processes makes such processes faster and more efficient. Special measures are needed, however, if the poor, women, and labourers are to contribute their 'indigenous knowledge' or to share alongside large, male farmers in research benefits.
10. Vulnerability to AIDS in the agricultural sector is primarily through loss of labour incurred by the condition — either through sickness, caring for the sick, or through death. Even if households short of labour were to be able to afford to hire labour, if AIDS has hit an entire locality the hired labour pool is also affected. Thus, if AIDS-stricken rural households are to ensure that their livelihoods are not threatened, an appropriate response might be to invest in labour-substituting technologies.
11. The choice of what to research, diffuse and adapt is often insufficiently influenced by stability and sustainability, and therefore insufficiently attractive to poor people and to farmers in large/marginal environments. Water non-sustainability increasingly harms, especially, poor and rural people. Policy across the board, notably on credit, interest rates and land distribution, needs 'screening' for impact on technology, choice (and technology generation) as sources of water stability and sustainability. Varietal choice and development, seeding methods, and tillage, as well as irrigation systems, are relevant.
12. Neither pesticides, nor a stream of vertically resistant varieties —

even if temporarily improving stability under pest attack — is usually sustainable. Integrated pest management has proved a promising policy. Biological controls, physical pest removal, and varietal selection and sequencing, and (limited and selective) chemical controls are used jointly. This method has proved highly cost-effective — where farmers are participants, with training. But its sustainability is likely to depend on multigenic (horizontal) resistance or tolerance, bred into host varieties. Direct incentives to such breeding priorities, and financing of the genomics knowledge to advance them, are needed.

13. Public agricultural research and innovation has been historically significant in stimulating agricultural progress and was necessary for the Green Revolution. It has slowed down — in funding, rate of discovery, direction of research to yield expansion — before large parts of the poor have gained. This needs to be addressed, if poverty reduction, now slowed, is to revert to 1975–1985 rates. Yet the global bias of technical progress, driven by the needs and scarcities of the better-off with higher effective demand for it, is labour saving. A major effort is required to expand applied and basic agro-science in the international public sector and to introduce imaginative changes in incentives and institutions to enhance the private sector's scientific contribution to improving poor people's capabilities.

The central conclusion is to leave space in farm research systems for basic science. To point it, via incentives and institutions and civil-society pressures, to human development goals seldom fully expressed in either market or state values. And, to reward both success in research and discovery, and selection of topics and processes, that speed up adoption, spread, and impact on human development.

Notes

1. To hitherto disadvantaged groups, often including landless farmworkers, remote dwellers, women, and ethnic minorities.
2. Over time, with the poorest being least equipped to bear risks.
3. Administrative, financial, political and ecological.
4. This leaves the remainder associated with international variance in the distribution of consumption, either among persons or over time.
5. Median real returns were, respectively, 45.7 and 38.1% (Alston *et al.*, 2000, p. 55) (full sample data, deflated by 1.049 as above). However, this may attribute too small a share of the gains to extension, because returns to past extension are boosted by subsequent research success (Evenson and Kislev, 1976).
6. See Narain and Roy (1980). In India, dug wells appear to be most used by smaller and poorer farmers, and deep tubewells least, with surface water (tanks and dam/canal systems) in between.
7. For example, GM crops can encourage herbicide resistance, stimulate new virulent insect biotypes, or (in resisting or attacking pests) target unintended and beneficial insects. But all these things have also happened, and with far less breeder control or advance testing than for GM, to conventionally bred varietal improvements.
8. GM crops are far ahead of conventional crops in these respects.
9. All irrigation shifts water in space and time, or both — allowing, respectively, more land, more of the year, or both to be used for cultivation. 'Supplemental irrigation' is the

provision of farm water, insufficient for cultivation without rains, but available as needed if rains are late or short.

10. Ten to 15 years of costly, careful and determined efforts by a leading agricultural aid agency have spread traditional farmer-controlled micro-irrigation to, at most, 40 000 African farmers (IFAD, 2001).
11. That is, if labour intensive, more food entitlements for poor; if cheap staples producing, especially reliably or in hungry seasons, low food prices and reduced vulnerability.
12. See Dinham (1993) for Paraguay, Thrupp (1991) for Costa Rica, Crissman *et al.* (1994) for Ecuador, Cornwall *et al.* (1995) for Malaysia, and Restrepo *et al.* (1990) for Colombia.
13. See World Bank (1991, p. 57) for Thailand, Dev and Hossain (1996) for Bangladesh, Strauss *et al.* (1991) for Brazil, and Appleton and Balihuta (1996) for Uruguay.
14. See Lin (1991) for China, Olusi (1995) for Nigeria, and Dev and Hossain (1996) for Bangladesh.
15. More irrigation normally means more stability. So do more pest-resistant varieties. But irrigation expansion has slackened and is projected to slacken sharply. And increasing uniformity of crop cover — as (often closely related) leading improved plant varieties drive out other varieties and crops — increases vulnerability to pest attack. So the trends in output and income stability are at best unclear, in both developed and developing countries (Hazell, 1984; Singh and Byerlee, 1990; Kerr *et al.*, 1996; Naylor *et al.*, 1997).
16. 'Users seldom pay more than 10% of operating costs' (and no costs of capital or maintenance) (World Bank, 1992, p. 100).
17. That is, 1000–1600 m³ per caput per annum.
18. Latency allows the plant to delay critically 'water-requiring' periods of plant growth, especially flowering, for a few days until the rains arrive.
19. With dry seeded rice, farmers can use pre-monsoon rainfall for the early stages of crop growth, rather than waiting for delivery of canal water before planting, as with transplanted rice. As a result, there is more irrigation water available during the dry season. However, technologies need to be developed that address the greater weed competition associated with cultivation of dry-seeded rice (Guera *et al.*, 1998).
20. In cotton, notoriously, a season or two after a new pesticide is introduced pest populations are back to their original levels, compelling costly extra and/or new pesticide as they rise even higher if the pesticide is abandoned.
21. Such 'natural predators' of pests have often in the past been unintended casualties of pesticides — one of the reasons why these alone often prove unsustainable forms of pest control.
22. WHO estimates that up to 25 million agricultural workers suffer from pesticide poisoning each year and 22 000 deaths occur (Jeyaratnam, 1990). Although developing countries consume only 15–20% of pesticides used globally, one-half of poisonings and 80% of deaths occur there (Pimbert, 1991). This paradox arises, in part, to a higher incidence of pesticide-related suicides in developing countries; suicides account for up to 75% of pesticide-related deaths.

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