SUBRATA GHATAK (*)

Comparative Analysis, Cost-Benefit Efficiency Ratio in the Use of Agrochemicals in Developing Countries(**)

Introduction

In Charles Darwin's characterization of the association between species and environment, the economic and technological nexus figured prominently. The survival of species is conditioned by the flexibility and appropriateness of bio-technology for different environmental conditions. Given that natural mutation processes were continually producing new genetic variations in living matter, i.e., new bio-technology, "there was a natural sorting out of the fittest for each environmental niche" (Evenson, 1984). However, mankind over centuries has created a social and economic system of plant and animal husbandry. The natural system has therefore been altered to create more wealth and "welfare". As new types of crops developed, pests and parasites had to find new environments in which to survive.

The process of developing new crops has been related to Research and Development (R/D) expenditure (see table 1). Developed countries (DCs) have large comparative advantages in most crop and animal production. For most crops at the beginning of the 1950s (when many Asian and African countries began to acquire political freedom), yields per acre of land were higher in temperate zone countries. This was due to two main reasons: (a) a higher proportion of spending on agricultural R/D (i.e., R/D expenditure as a proportion of the total value of the agricultural product) and (b) a significant difference in the use of agricultural chemicals (like fertilizers, pesticides, insecticides and herbicides) in producing crops between the DCs and less developed countries

(*) Economics Department, The University, Leicester LE1 7RH, England.

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TABLE 1 - Relation of World Expenditures on Agricultural Research to the Value of Agricultural Product, by Income Group.

Group	Per capita income (U.S. dollars)	Percentage of total and public research expenditures to value of agricultural product [a]			
		1971 total	(Public) [b]	1974 total	(Public) [b]
I	1750	2.48	(1.44)	2.55	(1.48)
II	1001-1750	2.34	(1.76)	2.34	(1.83)
III	401-1000	1.13	(0.86)	1.16	(0.92)
IV	150-400	0.84	(0.71)	1.01	(0.84)
V	150	0.70	(0.65)	0.67	(0.63)

[a] Total expenditures include: (1) national public agriculture. (2) national public agriculture related. (3) industry, and (4) international. Excludes People's Republic of China.
[b] National public agriculture (national public agriculture related is not included).
Source: Adapted from table 1.7 in James K. Boyce and Robert E. Evenson, *Agricultural Research and Extension Programs* (New York: Agricultural Development Council, 1975), 11.

(LDCs). In fact, even in the fifties, despite the availability of a menu of advanced agro-technologies, little of it was transferred to the LDCs.

In this paper, I will first examine the causes of the Green Revolution (GR) in LDCs. Next, I will analyse the need for new technology in tropical agriculture for achieving "sustainable growth". The concept of sustainable growth will be examined closely within a simple theoretical model. The case for using the Biotechnologies (BT) in tropical agriculture will be analysed. An attempt will be made to evaluate the economic use of azolla production in a developing country (i.e., Philippines). Then, I will discuss the use of BT in under-developed agriculture within an Integrated Pest Management programme. The case of using herbicides will also be considered. Some alternatives to chemical plant protection will be discussed. Finally, some constraints on the application of BT in under-developed agriculture will be indicated.

The Green Revolution in LDCs

The middle sixties ushered in the period of the Green Revolution (GR) in many LDCs in Asia and Latin America. The reasons for the GR are well documented (see Ghatak, 1986, 1987; Ghatak and Ingersent, 1984; Mellor, 1976; Ranadhawa, 1974; Hayami and Ruttan, 1984). Both demand and supply factors played important roles. On the demand side, population growth, rising income and demand for food were important in increasing the pressure on land. On the supply side, natural disasters like drought and flood, and the lack of modern inputs and water supply simply aggravated the all-too-familiar problems of decline in food supply, distribution, poverty and famine (Sen, 1981). In the end, "necessity became the mother of invention". The new technology that was successfully used in tropical agriculture encompassed: (a) "miracle" seeds, thanks to Borlaug and his team of researchers (e.g., IR-8 in wheat and rice; and dwarf varieties to withstand different types of environment stress); (b) chemical fertilizers (particularly nitrogen, phosphorus and potash); (c) pesticides and insecticides to offer protection from the attack of brown hopper pests; (d) machinery, tractors and harvesters. The yield curve in the agricultural sectors of less developed countries began to shift upwards in the late sixties and early 1970's.

However it was soon realized in the industrialised countries that all the 'know-how' of the DCs ("all the King's men and all the King's horses"), including most kinds of agro-technology (better seeds, modern agro-chemicals and capital equipment), could not simply be transferred without adjustments to alien environments. The process of growth in tropical agriculture has been accelerated temporarily but has not always been *sustained* as the law of diminishing returns began to set in. The initial impact of the intensive use of better seeds, chemical fertilizers and pesticides on specific crop yields began to falter during the 1970's.

The Need for New Technology for Sustainable Growth in Tropical Agriculture

To sustain a rise in food consumption for the masses in the face of a growing population, it became necessary to increase food production not only of principal crops like wheat and rice but also of other types of tropical crops. It is, of course, possible to import food from DCs, but given the balance of payment constraint on most non-oil LDCs, such imports of food, at the expense of other types of imports critical to the growth of the manufacturing sectors of the LDCs, are not always socially and/or economically desirable. Hence it has become imperative for most LDCs to achieve a sustained growth in agriculture. The desire to attain economic independence is an essential ingredient in a policy designed to achieve sustainable growth in agriculture.

It is important to mention here that the desire to attain sustained growth in tropical agriculture in the face of a population explosion has led to over-grazing, deforestation, desertification and soil erosion in many LDCs. Indeed, if the short-run drive to increase agricultural production causes severe ecological imbalances like soil erosion (through deforestation) in the long-run, then such an attempt is very likely to be self-defeating and certainly not sustainable. Hence, from the technocentrist position the search for new technology including bio-technologies (BT) becomes both urgent and necessary, if the conflict between the short-run growth objective and the long-run ecological disorder is to be mitigated. It is indeed a pity that the rainforests of Brazil, Malaysia and India have been considered as "terrestrial whales". Their output has been harvested with no consideration given to sustainable yield potentials. But rather, extraction has been driven by the desire to maximise the return to capital in the short or medium term (Ghatak, 1985; also Dasgupta, 1982).

It is, however, necessary to clarify the concept of *sustainable growth* at this stage of our analysis. I shall presently argue that the concept implies living within means. It is also an inter-temporal and relative concept. Whether the growth level of a variable can be sustained or not depends significantly on what happens to a few other related factors. It will also be argued that the growth in tropical agriculture may not be sustainable if it violates seriously the principle of equity. In this sense, the concept of sustainability in production and consumption is not independent of problems related to the justice or 'fairness' of income distribution patterns. Finally, it will be argued that the use of new technology which includes BT is crucial to usher in the Second Green Revolution. But public policy should play an important role in regulating the transfer of technology to the LDCs and in minimising the inequality in the distribution of new resources. At the same time, for LDCs interested in the sustained development of agriculture, it is crucial that they spend more scarce resources on programmes designed to boost research and development work in tropical agricultural crops.

In the tropics, farmers (particularly small and marginal ones) should also be encouraged to adopt the new BT to sustain a target level of growth of agricultural income and output. This requires appropriate economic and social reforms to provide the right incentives to farmers and is influenced by whether or not they behave "rationally", responding "correctly" to appropriate socio-economic signals. However, even a strongly growing economy may not be sustainable over time if it creates extreme polarisation within the society, which can eventually lead to violent conflagration. The "Green Revolution" could easily turn "Red". Such conflagration might not occur in the classical Marxist-Leninist way, but it would be a violent and chaotic revolution all the same. It is thus necessary to minimise the degree of inequality in the distribution of gains from the introduction of new technology.

The Concept of Sustainable Growth in Tropical Agriculture

Despite some recent attempts to analyse the concept of sustainable growth (presumably in the macro-sense of some measure of output or consumption), it is not very clear whether such a concept can be easily and readily defined (Redclift and Porritt, 1986). In theory, such a concept should imply the steady state value of a target variable, e.g., real growth rate of output or consumption. It is useful to add a *time dimension* to the growth of the target variable. A diagram should clarify the problem (see Figure 1). Let the target variable be the growth rate of agricultural output in the tropics: $z = (\dot{y}/y)$. Then, if *over time* such a rate can be maintained, growth can be sustainable. But to achieve such a rate it may be necessary to shift from one production function to another (i.e., from $m \rightarrow n \rightarrow p$). It is interesting to point out that a sustainable growth rate is not

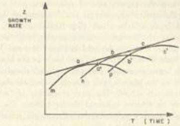

Fig. 1

always the combination of the highest points on the production function if a specific rate of rise of z values is to be maintained (see Figure 1). However, Figure 2 shows that with a given menu of technology, a sustainable growth could be the locus of the optimum points of production.

Whether such growth rates of agricultural output as given by the short-run production function can be *sustained* or not depends, *inter alia*, on: (a) the *availability* of a menu of technology; (b) the efficiency of that technology; (c) the price (absolute and relative) of such technology as compared to the rates of return; (d) risks and uncertainties arising out of market and climatic conditions and reflected in the mean and variance of yields and incomes from crop production; (e) the existence of a favourable "*environment*", physical, financial and managerial, for resource use. Violation of any or some of these conditions will prevent the attainment of sustained growth in production. (We will see later that a *sustainable* growth rate of consumption will depend upon the movement of other macro variables, e.g., population growth and income distribution).

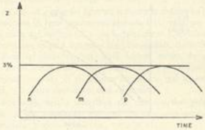

Fig. 2

To illustrate how the growth rate of agricultural production may not be sustainable in tropical agriculture, cases of actual differential agricultural growth rates in India and Japan will be cited. (See Ishikawa, 1967, 1977). Consider the impact of the use of chemical fertilizers on rice production per hectare in Japan and in two Indian states as depicted in Figure 3(a) and 3(b). The growth of crop output in both West Bengal and Tamil Nadu in the late 1960's and early 70s, when the GR began to spread, rose and then fell sharply. In Fig. 3(b) in two Japanese districts, the growth rates of crop output are shown to be clearly sustainable. The reason is simple. The mere availability of "miracle" seeds plus fertilizer is unlikely to achieve sustained results without the availability of a timely and adequate water supply. Further, the simple transfer of technology into an alien environment without due regard to economic and institutional constraints is unlikely to stimulate sustainable growth. In this sense, there is no such thing as a Japanese or an American lesson, as the success of new technology is conditional upon the existence of an appropriate host environment.

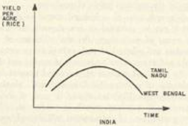

Fig. 3 (a)

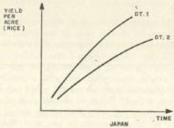

Fig. 3 (b)

The choice of a target growth rate should be potentially sustainable and it is a matter of national strategy. All that we can say is that such a choice is usually constrained by a number of factors. In the context of the growth of the tropical agriculture, it is very likely that growth of crop output at a steady rate may not be sustainable if some other conditions do not hold. Indeed, the important target variable could alternatively be a sustainable rate of growth in farm incomes.

The problem of attaining a sustainable rate of growth of farm income can be stated with the aid of the following simple model.

A Simple Model to Attain Sustainable Growth of Farm Income

We know that farm income (= Y) is given by the product of yield (Q), average (A) and farm price (P). Thus, we have

$$Y = Q \cdot A \cdot P \qquad (1)$$

Differentiating (Y) with respect to time (= t), we obtain

$$\frac{dY}{dt} = AP\frac{dQ}{dt} + PQ \cdot \frac{dA}{dt} + Q \cdot A\frac{dP}{dt} \qquad (2)$$

or

$$\frac{1}{Y} \cdot \frac{dY}{dt} = \frac{1}{Q} \cdot \frac{dQ}{dt} + \frac{1}{A} \cdot \frac{dA}{dt} + \frac{1}{P} \cdot \frac{dP}{dt} \qquad (3)$$

Equation (3) can be written in terms of proportional growth rates (in lower case letters) as follows.

$$y = q + a + p \qquad (4)$$

Equation (4) implies that the rate of change in farm income is equal to the rate of change in yield (productivity), acreage and price.

Consider the case of a stagnant agrarian economy in the tropics (where $q = o$). Now, a sustained rise in farm income can emanate from only two sources: (a) a rise in the area under cultivation; (b) a rise in farm price. Condition (a) is difficult to satisfy in land-scarce tropical countries (e.g., Bangladesh, India, Sri Lanka, etc.). Even in land abundant countries, (e.g., some African states), the poor quality of the land must act as a real constraint. The fulfilment of condition (b) may not always be acceptable because of its adverse impact on real wages, costs, profits and the growth of industrialisation in dual economies.

The above analysis simply underlines the dilemma that policy-makers face in many LDCs. It also emphasizes the need for increasing productivity of land by using the available modern inputs (i.e., set $q > o$).

While the more efficient use of "miracle" seeds, chemical fertilizers, water and other agro-chemicals will enable the tropical agriculture to grow in the future, it is not at all certain that the technology which accounted for the first GR (or "the seed fertilizer revolution") will be adequate to meet the challenge of the 1980s. The first challenge continues to pose problems because of the falling arable land/man ratio in many South and South-East Asian countries. The second newer challenge emanates from the inevitable operation of the law of diminishing returns on the use of existing types of seeds and fertilizers. The major problem, in terms of technical fixes, is to develop the "Biotechnologies (new BT)". Technology is required which could be used in adverse and varied weather conditions. I will now discuss some major reasons for using the "new BT" in tropical agriculture in order to achieve a sustainable growth in yield for agricultural crops.

Use of Biotechnologies in Tropical Agriculture

The age-old scenario of underdeveloped agriculture in LDCs may not present a very favourable opportunity for the use of modern biotechnology at the outset. However, the increasing application of such techniques will have a very important impact on food production and consumption in developing countries. The major changes during the second GR phase might be as follows:

a) The use of biotechnology is likely to *raise* the trend lines of growth of many types of agricultural products. It is true that yields of some specific types of food, e.g., wheat and rice, have increased significantly in a number of Asian countries. It seems that an increasing use of BT will enable these countries to achieve growth rates which are sustainable in the short and medium term if (a) such technology is available at a reasonable price; (b) new BT may permit the development of varieties of maize, corn, soyabeans, wheat, etc., widely applicable in the African countries (see Kloppenburg and Kenney, 1984). Public policy may play an important role (via the manipulation of subsidies and taxes) in spreading the use of BT in LDCs as it did in the spread of the first GR.

b) The techniques of BT, including those of genetic engineering and tissue culture, are being applied in DCs in an effort to improve cereal crops. Genetic engineering also provides a method of raising food production in tropical agriculture by altering the genetic make-up of plants. It can include nitrogen-fixing genes into cereal crops and thus make them less dependent upon chemical fertilizers. Enhanced resistance of plants to insects will lower pesticide needs for a given amount of food production. The nutritional level of foods can be increased by including synthetic DNA to produce essential amino-acids such as lysine and methiomine (Steinkraus, 1982). Genetically engineered crop varieties adapted to low levels of fertility or tolerant of saline conditions could raise productivity in large areas of marginal land in Africa and Asia where traditional HYVs are not suitable.

Many multi-national corporations (MNCs) have acquired seed companies recently (Buttel *et al.*, 1985a, 1985b). The logic of such purchases lies in the crucial role of seeds in the food chain, in good profitability prospects and in the fostering of a better environmental image (compared with, say, direct involvement in pesticide production). Further inducement of commercial investment in plant breeding in the West is provided by effective legal protection. The world consumption of seed stood at £ 28 billion in 1982 (Dunnill and Rudd, 1984). The close association between seeds and agrochemicals has been acknowledged by the MNCs. It is also acknowledged that although plant tissue culture and later on recombinant DNA techniques will have significant effect on the growth of crops, conventional plant breeding skills are still important in field evaluation, as are the marketing strategies of companies. It is thus important for the governments of LDCs to devise appropriate "code of conduct" for the MNCs when they transfer and distribute the agricultural BT to the Third World.

c) To achieve a stable (and sustainable) level of food consumption, it is important to strike the right balance between food production and consumption. The use of tissue culture for micro propagation of plants can allow the production of large numbers, of essentially identical superior specimens (Bhalla and James, 1986). However, consistent embryogenesis in cell suspension culture and the handling of many propagated plants may cause problems. Subsequent planting requires special techniques, which may be important in terms of the prior screening of chemicals for agricultural use, since pesticides and other chemicals influencing nitrogen fixation must all be properly tested.

d) The use of hydroponics in *semi-arid agriculture* needs to be strongly emphasized, given the present environment in sub-Saharan Africa. Its increasing use will largely depend upon greater international cooperation and judicious use of government fiscal policy.

e) A mixture of different kinds of BTs can increase crop yields substantially. It can also raise the ratio of edible material to waste matter (National Academy of Sciences, 1976, 1982). The growth of BT has enabled the "fermentation industry" to use agricultural waste materials to produce vitamins, vaccines, alcohols, organic acids and single cell protein (SCP) or fodder protein. It has been argued that by the use of SCP instead of grain in animal (and also human) feeds, large amounts of grains, legumes, hitherto consumed by animal and human beings can be released (Bhalla and James, 1986). The economics of the SCP production is quite interesting. It is estimated that the price of SCP compared to conventional protein (i.e., milk, eggs, meat) is quite low. It is also argued that "one SCP plant making 100,000 tons per year can produce about as much protein as that which could be extracted from 120,000 hectares (= 300,000 acres) of soya beans, or as much beef (cattle) as could be grown on 2 million hectares (5 million acres) of grazing land" (Heden, 1979). However, it is worth noting that "SCP is not a panacea that by virtue of its greater efficiency will displace conventional agricultural and animal sources of protein. The methods of the past will continue to be needed. Improvements of the old ways and adoption of the new will go hand in hand, complementing each other" (World Bank, 1981).

The use of waste materials in the acquaculture of algae or plants is presently being investigated. The use of micro-organisms in waste treatment processes can produce the following goods (see, e.g., Bhalla and James, 1986):

(a) production of fodder yeast on spent liquor;

(b) mushroom production of rice, straw and compost.

Applications of Bio-Technology to Agriculture

The following applications of BT in tropical agriculture need to be specially emphasized:

1) To foster and enhance desirable agricultural traits in plants, e.g., better disease resistance, salt tolerance.

2) Plants with increased levels or modifications of storage compounds: e.g., high polyunsaturated oils.

3) Pest control: e.g., microbial insecticides, fungicides.

4) Plant genetic manipulation and breeding: e.g., plant growth regulators for modifying leaf abscission, loosening fruit, improving photosynthesis and affecting ripening: e.g., gibberellins.

5) Hydroponics in semi-arid agriculture — the technique of growing plants in dilute aqueous nutrients without soil.

6) Fostering desirable traits in animals — e.g., better disease resistance, better feed conversion.

7) Animal feed and growth promotion — e.g., SCP: single cell protein, amino acids.

8) Vaccines: e.g., foot and mouth, pig scours.

9) Azolla — an aquatic fern that lives symbiotically with nitrogen fixing blue-green algae — a green manure and/or intercrop with rice (for example, in China and Vietnam). Evidence suggests its growth path is as follows:

$$A_t = A_m / [1 + e^{-(a+bt)}]$$

where

A_t = the biomass per hectare at time t

A_m = the asymptotic maximum attainable biomass

a, b = parameters which define the initial stock and the growth rate.

Azolla's use has been recommended in order to insulate rice production from the effects of possible energy (and fertilizer) price shocks and balance of payments crises in LDCs. But one study suggests that where urea is available (at world prices), adoption of azolla is unlikely as the cost of producing nitrogen through azolla is higher than the price of nitrogen. Azolla as a *green manure* is also rather cost-inefficient under nearly all types of irrigation. Only with very good irrigation is the effective cost of nitrogen from the azolla intercrop less than the cost of nitrogen from urea. (See Tables 2 and 3). However, given the water control regulations, azolla will tend to benefit farmers who already have high quality irrigation. The income distribution implications are therefore likely to be regressive Rosergent, Roumasset *et al.*, 1985).

A different evaluation of azolla use as a green manure in rice production, however, shows considerable biological and economic benefits. (See Kikuchi, Watanabe, Haws, 1984). Under favourable experimental conditions, a layer of azolla covering a 1 hectare rice field releases 20-30 kg organic N. Azolla can be cultured more than once. The application of azolla raised yields of rice by 0.4-1.5 ton per hectare over control plots (see Tables 8 and 9). It has also been shown that the economic return from azolla adoption, including *cost savings in chemical fertilizers* and *weed control*, is more than 10% of the total non-land cost of rice production in areas where environmental conditions favour azolla growth (see Table 10).

Some major constraints on the adoption of azolla are as follows:

a) P content of the soil;

b) the danger of insect and pest attacks, which can raise the cost of pest control;

c) increase in the wage cost due to a rise in labour requirement.

From the basis of the evidence available so far, we can thus conclude that the potential economic and social benefits of azolla use will be high in those LDCs where the opportunity cost of labour in terms of foregone marginal productivity of labour and real wage is low. The adoption of azolla could thus depend considerably on the level of real wages and the cost of pest control.

Insecticide Resistance, Integrated Pest Management (IPM) and the use of BT in Tropical Agriculture

The agricultural use of synthetic insecticides generally protects crops but imposes strong selection pressures that can result in the development of the resistance. The chief resistance mechanisms are enhancement of the capacity to metabolically detoxify insecticides and alterations in target sites that prevent insecticides from binding to them. Insect control methods must incorporate strategies to reduce resistance development and conserve the utility of the insecticides. The most promising approach, the integrated pest management (IPM), includes the use of chemical insecticides in combination with improved cultural and biologically based techniques.

Three major factors that can influence the rate of resistance development in agricultural pest insects are as follows:

(a) genetic,

(b) biological,

(c) control-related factors.

Genetic manipulation of some insects is theoretically possible but practically

Table 2 - Estimated Costs of Azolla Production in the Philippines.

	Cost (P)
A. Nursery bed (40 m²)	
Azolla starter inoculum (8 kg, P 1.00/kg)	8.00
Land preparation (.25 man-animal day, MAD)	5.00
Superphosphate fertilizer (93 g P_2O_5)	0.50
Fertilizer application (.25 man-day, MD)	2.50
Seeding and tapping azolla (.25 MD)	2.50
Insecticide (20 g active ingredient, ai)	5.00
Subtotal	23.50
B. Multiplication bed (600 m²)	
Land preparation (.33 MAD)	6.60
Superphosphate fertilizer (1.3 kg P_2O_5)	7.50
Fertilizer application (.33 MD)	3.30
Seeding and tapping azolla (.5 MD)	5.00
Insecticide (30 g ai)	7.50
Subtotal	29.90
C. Azolla in rice field (one hectare)	
1. As green manure	
Land preparation and rotovation (8 MAD)	160.00
Superphosphate fertilizer (8 kg P_2O_5)	44.50
Fertilizer application (1.5 MD)	15.00
Seeding and tapping azolla (2 MD)	20.00
Insecticide (150 g ai)	37.50
Opportunity cost of land [a]	550.00
Subtotal	827.00
2. As intercrop	
Seeding and tapping azolla (2 MD)	20.00
Superphosphate fertilizer (8 kg P_2O_5)	44.50
Fertilizer application (1.5 MD)	15.00
Insecticide (150 g ai)	37.50
Incorporating azolla in soil (5 MD)	50.00
Subtotal	167.00
Total cost per hectare: [b]	
With azolla as green manure	880.40 (867.27)
With azolla as intercrop	220.40 (207.27)

[a] Farmer's profit foregone on the use of land from change in cropping pattern from azolla cultivation before rice transplanting.

[b] Figures in parentheses are total costs net of costs of phosphorus fertilizer assuming 20? recovery of phosphorus for rice production released by azolla upon incorporation in the soil.

Source: Rosergent, Roumasset *et al.* (1985), *op. cit.*

TABLE 3 - Expected Nitrogen Contribution and Effective Cost of Nitrogen from Azolla Used as Intercrop and Green Manure, by Quality of Irrigation

Quality of Irrigation	Expected Nitrogen Contribution and Cost of Azolla: Wet Season, Intercrop (kg/ha)	Wet Season, Intercrop (P/ha)	Wet Season, Green Manure (kg/ha)	Wet Season, Green Manure (P/ha)	Dry Season, Intercrop (kg/ha)	Dry Season, Intercrop (P/ha)	Dry Season, Green Manure (kg/ha)	Dry Season, Green Manure (P/ha)
Good	38	5.45	65	13.34	37	5.60	64	13.55
Average	33	6.29	57	15.22	27	7.68	46	18.85
Poor	32	6.48	55	15.77	10	20.73	17	51.02
Rainfed	29	7.15	50	17.35				

Note: For comparison, the cost of chemical fertilizer (including the costs of transportation, application, and credit) are P 6.23 and P 9.95 per kg. of nitrogen supplied by urea ammonium sulphate, respectively.

Source: Rosergent, Roumasset *et al.* (1985), *op. cit.*

difficult, though insect biology can be manipulated. For instance, pheromone lures can be used to attract susceptible insects to dilute a resistant gene pool. Control-related factors (those directly related to insecticide use) are generally available methods to reduce the insecticide selection pressure, the most important factor in delaying resistance.

The careful selection and exact application of chemical insecticides and their integration with other control methods consistent with the principles of the IPM hold promise for effective resistance management (Brattsten, Holyoke, Leeper, Raffa, 1986). The case of selected insecticide *mixtures* can reduce resistance development as it is more difficult for an insect to develop several adaptations simultaneously. Needless to say that mixtures should be used with caution, particularly in tropical agriculture.

Apart from mixtures, insecticide synergists showed good promise as their use inhibits enzymes involved in insecticide detoxification. But their application didn't achieve much, mainly because of these reasons: (a) their range of activity is too narrow and they are less effective against the general population than against metabolically resistant strains; (b) the additional cost is also a major barrier to their use in tropical agriculture; (c) it is difficult to choose a synergist to delay resistance, since different field populations of the same species demonstrate highly volatile responses to a given synergist.

To promote the utility of the insecticide and the susceptible gene pool, spray applications should be made only when economically determined threshold infestation levels are present. Such a threshold changes considerably, depending on crop growth stage. Crop, insect pests and region can be determined only by constant monitoring of population densities.

The Use of Herbicides in Agriculture

Several types of herbicides are now in use in agriculture in both DCs and LDCs. Paraquat is, perhaps, one of the world's most widely used herbicides. Following its introduction in 1962, it has benefited farmers in many countries and is now an important part of many crop production systems. Its use in the production of many crops (e.g., coffee, cotton, tea, maize, sugarcane, rice, oil palm and rubber, vegetables, bananas, etc.) has led to substantial rises in yields without much damage to the environment. The economic significance of the use of herbicides like paraquat and gramoxone is derived from the substantial time and labour savings in farming systems of many kinds and possible significant energy savings during the crop-production process (see Tables 4-7). It has also promoted the growth of "no-till" farming which, in addition to the already mentioned benefits, can lead to significantly less soil erosion and loss of moisture from soil.

Herbicides like paraquat have the characteristics that provide an improved type of weed control and growth in crop yield. Applied as an overall spray to emerged weeds, it is: (a) effective on a broad spectrum of weeds, e.g., grass and broadleaf species, (b) quickly applied compared with most mechanical and manual

TABLE 4 - Effect of Herbicide Treatment on Coffee Yield

Treatment	Mean Yield kg/ha
Hand cultivation	1585
Paraquat 0.2 kg/ha	1803
Paraquat 0.4 kg/ha	1712
Paraquat + hand cultivation	1816
Paraquat + diuron	1749
Paraquat + simazine	1867

Source: Mitchell H.W. (1974).

TABLE 5 - Rice - Pre-Planting Weed Control: Costs and Timing

Method	Unit cost ($/ha)	Time (days)
Buffalo power	114	28-56
Buffalo + mechanisation	89	25-30
Paraquat	68-75	5-10

Source: Paterson E.C. (1978).

TABLE 6 - Weeds in Rubber: Duration of Control and Use of Labour

Method	Control (days)	Labour (hours/month/acre)
Paraquat	55-60	0.64
Hand weeding	40-55	21

Source: Seth A. and Kappor J. (1968), Chemical Control from Planting Onwards, *Planter* 44: 641-4.

TABLE 7 - Fuel Consumption. Conventional (*) vs. No-till (**), New Zealand

	Fuel Consumption 1/Ha			
Technique	Spring 1973 (*)	Spring 1973 (**)	Autumn 1974 (*)	Autumn 1974 (**)
Ploughed	53	55	42	47
Rotavated	27	38	22	23
No-till	5	5	6	6

Source: Hughes K.A. and Barker C.J. (1977), *op. cit.*

methods of weed control, (c) rainfast: once the spray has dried on the leaf surface, its activity will continue irrespective of the ensuing weather, (d) fast acting: treated plant tissue shows signs of cellular disruption within hours and is killed within 3 to 7 days, (e) inactivated on contact with soil, and so is without herbicidal effect on crops established subsequently or on nearby untreated crops, (f) relatively safer in protecting the environment as paraquat becomes de-activated on contact with the soil and accidental spills on to the soil are similarly de-activated. Used as directed, it presents very few hazards to either the user, the consumer or the environment. In tropical, arid climates, the no-till technique promoted by the use of herbicides provides a water reserve which can carry a crop through periods of short-term drought and prevent the development of moisture stress.

It is now acknowledged that the main cause of soil-erosion is the unsuitable methods of land cultivation. Water erosion in many parts of the world is now much more serious than that caused by the wind. Water erosion can be significantly reduced by the major principles: (a) by maintaining the permeability of the soil surface, (b) by reducing the rate at which water can flow over the soil surface, i.e., limiting run-off.

The growth of "no-till" (or direct drilling which involves the elimination of ploughing and cultivation procedures prior to crop establishment) farming, in which paraquat has played an important role, has aided the application of these principles, much improving the prospects of soil conservation in the future.

Economists tend to estimate the *social* costs (C) and benefits (B) of projects by looking at the net present value (NPV = discounted benefits and costs) of any project by using the following formula:

$$NPV = \sum \frac{B_t - C_t}{(1+r)^t}$$

If the NPV > 0, the project is accepted. If NPV < 0, the project is rejected. In the formula r = rate of discount and t = time.

An estimation of a global sum of discounted benefits and costs of herbicide use in tropical agriculture is likely to be very hazardous and no attempt is made in this paper to make such an estimate. The valuation of net benefits is also likely to be influenced by the nature of objectives and constraints, say, in a labour-surplus or a labour-scarce underdeveloped "dual economy". It is also clear, however, that although the use of herbicides, as the foregoing analysis shows, has its advantages, it has also quite a few disadvantages in labour-*surplus* underdeveloped economies. Policy makers in such economies are unlikely to be persuaded by the benefits of considerable labour-saving devices, given the very low level of real wages for agricultural labourers and the presence of a considerable amount of "open" and "disguised" (i.e., marginal productivity of rural labour is very low or equal to zero) unemployment. Indeed, the objective function could easily be to maximise employment and consumption in such economies. It is possible to hypothesize a positive correlation between growth of consumption and productivity in LDCs as additional consumption is likely to increase the standard of nutrition, labour efficiency and thus productivity up to a certain degree. Such a relationship can be approximated by a logistic curve (see Fig. 5). If this line of argument is valid, then it is rather unlikely that on economic grounds the use of herbicides will be very encouraged in tropical "labour-surplus" agriculture (Ghatak, 1986).

Alternatives to Chemical Plant Protection; Biological Control

Alternatives to chemical plant protection are now increasingly available, thanks to the R/D activities in the biological controls. Strictly speaking, biological control means the use of one organism to control the population density of another, and it has a long history which dates back to ancient Egypt, where cats were kept to control mice.

Given the considerable loss of food crop in tropical agriculture due to the attack by insects, at least four methods could be suggested to control the insect population biologically:

(a) by specific natural enemies, usually parasites,
(b) by non-specific natural enemies, usually predatory species,

(c) by the sterile-male method, and
(d) by micro-organisms and sex attractants.

As regards the use of (a) and (b), the problem is that neither parasites nor predators will thrive unless there are already large numbers of the target insect in occupation of the crop. This implies that a farmer must wait until much damage has been done before the pests can be eliminated. This is a special problem with annual food crops (e.g., cereals), where huge losses can be suffered in the short run. The technique has more promise when used on long-term crops like timber. The other problem is that the predator or parasite that is introduced is likely to tackle only one insect pest and will be impotent against fungal diseases.

Sterile Males - This method involves sterilizing males of the species (e.g., American screw-worm) by means of gamma rays so as to reduce the population in the following generation. The technique has been successfully tried in the Caribbean, Central America and Southern U.S.A. However, it has been difficult to repeat the success with other insect pests.

Micro-organisms - Insect population can be checked by attacks from viruses and bacteria. But there is a serious difficulty in releasing into the environment large quantities of micro-organisms, whose future behaviour is hard to predict. Also, their release may kill off beneficial insects like honey bees. Note that the state of scientific knowledge on stopping viruses from multiplying is rather poor.

Bio-technical Control - In this method, biologically formed substances can be used to control insects; e.g., juvenile hormones can keep some insects in the larval stage so that they never hatch out and they never multiply. Pheromones (sex attractants) concentrate on freshly hatched males so that the grower knows that an infestation is imminent and can deal with it in time. These techniques have proved useful in giving early warning and are capable of development as parts of IPC management.

Constraints on the application of new technology - There are various likely constraints to the adoption of new BT in LDCs:

(a) *Product Quality*: a new product may be preferred by consumers in DCs but not by consumers in LDCs (see, e.g., Bhalla and James, 1986);

(b) *Skill Requirements*: many LDCs do not have adequate skill and expertise to develop and apply the BT for promoting tropical agriculture;

(c) *Systems Dependence*: new technology is very information and R/D intensive. Such sophisticated technology is highly dependent on costly auxiliaries such as sensors, software and peripherals if it is to be truly effective. These forms of systems dependency may significantly constrain the adoption of new technology in LDCs;

(d) *Factor Costs and Market Size*: high capital and development costs will be problematic for smaller firms in LDCs, where the average size of the firm is relatively small;

(e) *High R/D costs* for LDCs to develop the BT relevant for tropical agriculture (see Table 8 and fig. 4). Here it is imperative to explore the possibilities of international cooperation;

(f) *Income and Employment Implications*: An important negative impact of the BT R/D in DCs is the development of derived products like enzyme-based sugar syrups and fructose sweeteners from maize. Such product development can pose considerable problems for those LDCs which produce and export sugar cane and sugar beet. In practical terms it means loss of employment and income of producers of sugar cane and sugar beet. It is obvious that the new BT will have far greater impact on the employment in the agricultural sector of the LDCs in comparison with the DCs (see Chart 1). Agriculture accounts for a very low proportion of employment and income in most DCs. Hence, the impact of the development of new BT on developed agriculture is likely to be marginal. However, as traditional varieties of agricultural products are replaced by new ones in LDCs due to the advent of the BT, the important factor to look at will be the relative labour intensities of new and old crops. Evidence suggests that the replacement of bananas by oil palms has caused considerable unemployment in Costa Rica as the same plantation now needs about one-third less manpower (Izurieta, 1984). The aggregate employment effect of the oil palm will depend on whether the country can produce and sell enough palm oil to offset reduced employment in the banana plantations without causing negative impact on the production and labour-intensities of other crops. However, the growth of the oil palm sector can boost employment in the secondary and tertiary sectors (Watanabe, 1986).

It is now acknowledged that many basic institutional conditions for a successful GR are missing in Africa. The mere availability of HYV seeds, chemical fertilizers and pesticides (the so-called "technical package") is unlikely to achieve much in the African or Caribbean countries as "the weak structure of organisation

TABLE 8 - Comparison of Costs for Pharmaceutical and Agrochemical Industry

	Pharmaceutical	Agrochemical
Research and development spending (as % of sales)	10-11 %	9.7 %
Average cost of research for and development of a new product (new single entity)	$ 7,500 000	$ 5,500 000
Number of compounds screened per product introduced	6000 to 7000	7430
Research time from discovery to market	7 years	6.5 years

Source: Marmet (at 1977 prices).

TABLE 9 - Economic Return (Cost-Saving) of Azolla Use per Hectare per Season, South Cotabato, Philippines.[a]

		Maximum		Minimum	
		Quantity	Value ($)	Quantity	Value ($)
1. N fertilizer saved[b]		50 kg	82.35	19 kg	12.35
2. Herbicide cost saved		—	2.94		
3. Weeding labor cost saved[c]		33 h	7.41		
4. Fertilizer application labor saved[c]		7 h	1.52		
5. Azolla application labor added[c]		3 h	0.70	3 h	0.70
6. Net return (cost-saved)			43.52		11.64
# 6/nonland cost[d]	(%)		11.6		3.1
# 6/output[e]	(%)		5.4		1.5

[a] For assumptions on maximum and minimum, see the text. US$1=P8.50. [b] Nitrogen price = $0.65/kg N. [c] Wage rate = $0.22/hour. [d] Sum of current input, capital, and labor. From Table 6. [e] A projected rice yield of 4.47 t/ha for no-azolla plots and a price of $0.18/kg unhusked rice are assumed.

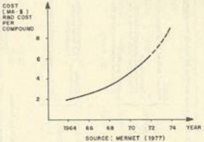

Fig. 4

could easily fail to deliver the goods. Even if genetic engineering reduces water and fertilizer needs for producing a certain amount of crops, a sound infrastructure in the tropical agriculture for seed distribution, product marketing and dissemination of related skill would still be required to achieve desired objectives". As Watanabe observes: "The same factor seems to have had much to do with the shift of palm oil production from Nigeria to Malaysia" (Watanabe, 1986).

Chart 1 - Possible Employment and Income Effects of New Biotechnology.

Main area of application	*Possible results*		*Possible income/ employment implications*	*Assumptions*
BIO TECHNOLOGY				
Chemical industry New synthetic materials	(DC + LDCs) Entirely new materials for entirely new products		(DC, possibly also LDC) New income/ job opportunities	No substitutions for existing products/uses
	(DC) Reduced imports of primary goods	(LDC) Reduced demand for primary export products	(LDC) Reduced income/ job opportunities	New materials are meant to substitute imports, or products based on imports from LDCs
		(DC) i) Home market a) increased economic stability b) increased funds for other use	(DC) Possibly more stable job opportunities	
		ii) Global market c) reduced export market in Third World	(DC) Reduced job opportunities in the longer term	
Pharmaceutical industry Improved medical care	Lower death rate	(DC) Aging of population → Increased burden of social security expenditure → Reduced funds for other uses	(DC) More constrained job opportunities	Constant patterns of employment (retirement age, working hours) and welfare scheme
		(LDC) Accelerated growth of labour force	(LDC) Need for accelerated growth of job opportunities	Constant birth rate and labour participation rate
Agriculture Improved varieties of animals and plants	a) Higher yields per hectare b) Wider crop zones	Increased demand / Reduced demand for fertiliser/ pesticides	(LDC, but also DC) Expansion of income/ job opportunities in the agricultural sector	No substitution for existing crops. Availability of complementary inputs
	c) Savings in fertiliser/pesticide consumption (imports)	Increased supplies of funds (foreign exchange) for other uses Increased demand / Reduced demand for fertiliser/ pesticides	(DC) Mixed impact on chemical industry in DCs	Chemical fertiliser/ pesticides are mainly supplied by DCs

Source, Watanabe (1986).

TABLE 10 - Economic Return of Azolla Use under Different Price Structures and Different Assumptions of Cultural Practices

	1980 world prices [a]			1981 Philippine prices [b]		
	Quantity/ha	Unit price ($)	Total value ($)	Quantity/ha	Unit price ($)	Total value ($)
1. N fertilizer saved [c]	30 kg	0.50/kg	15.00	22 kg	0.64/kg	14.08
2. P_2O_5 fertilizer for azolla [d]	12 kg	0.42/kg	5.04	5 kg	0.89/kg	4.45
3. Return of azolla use (1-2)			9.96			9.63
4. Chemical for azolla: case 1, low use [e]	15 g a.i.	37/kg a.i.	0.56	15 g a.i.	46/kg a.i.	0.69
5. Return of azolla use (3-4)			9.4			8.94
6. Chemical for azolla: case 2, high use [f]	2 kg a.i.	37/kg a.i.	74.00	2 kg a.i.	46/kg a.i.	92.00
7. Return of azolla use (3-6)			−64.04			−83.37
8. Break-even quantity of chemical for azolla [g]	263 g a.i.			209 g a.i.		
9. Labor use for azolla: case 3, low wage [h]	5 days	0.63/day	3.15	5 days	1.87/day [k]	9.35
10. Return of azolla use for farmer (3-9)			6.81			0.28
11. Labor use for azolla: case 4, high wage [i]	5 days	14.58/day	72.90			
12. Return of azolla use for farmer (3-11)			−62.94			
13. Break-even wage rate [j]		1.94/day			1.93/day	

[a] F.O.B. prices at port of origin nearest to Asia are assumed. Data are from Palacpac (1982) except for carbofuran, for which price data are given by O. Mochida, IRRI entomologist. [b] Prices paid by farmers. Data are from same sources as in [a]. [c] Quantity of chemical N (urea) that could be replaced by use of azolla with optimum use of P_2O_5 fertilizer for azolla. [d] Optimum level of P_2O_5 (superphosphate) for azolla growth with given relative prices of N and P_2O_5. [e] Assume that 15 g a.i. carbofuran mixed with azolla inoculum for 1 ha can control insects and pests for azolla. [f] Assume that 2 kg a.i. carbofuran/ha is necessary for controlling insects and pests. [g] ⑧ 3/price of carbofuran. [h] Assume 5 days of labor requirement for azolla application net of labor saved due to azolla (labor for chemical fertilizer application and weeding), and assume a low wage rate that prevails in India. [i] Assume the same labor requirement above, but assume a high wage rate that prevails in Taiwan. [j] ⑧ 3/5 days. [k] Philippine wage rate in agriculture.

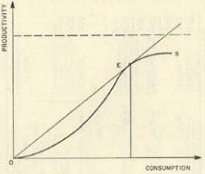

Fig. 5

It is hypothesized that the equation of the curve OS is: $y = \frac{k}{1 + be} - at$

It can also be written as

$$\frac{dy}{dt} = \frac{a}{k} y (k - y) \qquad \frac{d^2y}{dt^2} = \frac{a}{k} (k - 2y) \frac{dy}{dt}.$$

Consumption growth is supposed to add slowly to the growth of productivity at the initial stage of economic development of LDCs: its impact rises steadily and then it tapers of after the point E. [Johnston (1984)].

Conclusions

In this paper, I have mainly discussed the problem of the use of old and new BT in order to achieve sustainable growth in yields of tropical foodcrops. It is important to note that the process of sustained inter-temporal growth in yield needs continuous expenditure for Research and Development on new agro-technology. Clearly, a strong political will to promote such technology is a vital ingredient to maintain dynamic and sustained growth. It has been argued at the outset that growth without equity is unlikely to be sustainable in the long run. Hence, it is imperative to take proper steps to distribute justly any gains from increased productivity arising out of the use of new BT. It is equally important to induce the largest number of farmers to adopt the new technology, through the creation of an appropriate economic and social environment. Such inducements will probably require substantial land and other types of institutional reform and the development of suitable infrastructure which will facilitate an easier transfer of agricultural technology to the LDCs. Evidence suggests that the scope for raising crop productivity in many tropical areas of Africa, Asia and Latin America simply by better allocation of "old" BT is considerable (Borlaug, 1983). Hence, in such countries, it is necessary to use the new BT as a complement to the "old" BT after carefully assessing their relative costs and benefits. Such calculations should also include the income and employment effects of different technologies. Some "fermentation agro-industries" which use BT are looking increasingly attractive in the face of rising costs of oil and non-microbial protein. In the case of other BT used in tropical agriculture, e.g., azolla, it has been shown that the economic case for its use is not *always* overwhelming and the impact of its use on income distribution may not be more egalitarian. Hence, caution is needed before advocating the use of BT in tropical agriculture as LDCs in the tropics differ considerably in their level of economic development, growth of skill and infrastructure and resource endowments. Finally, it is useful to promote greater international cooperation (both public and private) in R&D in tropical agriculture not only to meet the challenge of new and rising demand for different types of agricultural products, but also to avoid waste of resources. Such cooperation should also enable us to minimise the technology gap between the rich and poor countries. If the fruits of such R&D could be quickly disseminated at a reasonable price, particularly for the large majority of small farmers in the tropics, then the problem of growing polarisation between the "haves" and "have-nots" could also be minimised. Perhaps it is worth remembering that "small is not just beautiful" in underdeveloped agriculture; it has proved to be quite efficient there as well.

However, it is imperative to develop necessary cooperation between the DCs and LDCs at different levels, even for selfish reasons which dictate promotion of national interests as the forces of inertia are immense, deeply entrenched in systems of value and socio-political structures (Rees, 1985). As Machiavelli reminded us in 1513, "There is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things. For the reformer has enemies in all who profit by the old order, and only lukewarm defenders in all those who would profit by the new order. The lukewarmness arises partly from fear of their adversaries, who have law in their favour; and partly from the incredulity of mankind, who do not truly believe in anything new until they have had actual experience of it" (Machiavelli: *The Prince*).

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