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ECONOMICS, ECOLOGY AND THE ENVIRONMENT

Working Paper No. 53

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environmental, health
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by

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WHY FARMERS CONTINUE TO USE PESTICIDES DESPITE ENVIRONMENTAL, HEALTH AND SUSTAINABILITY COSTS

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Abstract

Use of chemical inputs such as pesticides have increased agricultural production and productivity. However, negative externalities, too, have increased. The externalities include damage to the environment, agricultural land, fisheries, fauna and flora. Another major externality has been the unintentional destruction of beneficial predators of insects which has led to a virulence of many species of agricultural pests. Mortality and morbidity among agricultural workers, especially in developing countries from exposure to pesticides, are also common. The costs from these externalities are large and affect farmers' returns. However, despite these high costs, farmers continue to use pesticides and in increasing quantities. In this paper, we examine this paradox and show why farmers continue to use pesticides despite the increasing costs. We also emphasize 'lock-in' aspects of pesticide use.

Keywords: Pesticides; Agriculture; Environment; Human health; Sustainability;
Hysteresis

WHY FARMERS CONTINUE TO USE PESTICIDES DESPITE ENVIRONMENTAL, HEALTH AND SUSTAINABILITY COSTS

1. Introduction

Continuous use of chemical inputs such as pesticides have resulted in damage to the environment, caused human ill health, negatively impacted on agricultural production and reduced agricultural sustainability. Fauna and flora have been adversely affected. Numerous short-term and long-term human health effects have been recorded. Deaths are not uncommon. The decimation of beneficial agricultural predators of pests has led to the proliferation of several pests and diseases. Despite all these impacts and costs, farmers continue to use pesticides at an increasing rate while biological methods of pest control have become limited. Many papers have highlighted these issues and drawn attention to issues such as pesticide productivity and host-plant resistance (Widawsky et al. 1998), voluntary reductions in pesticide use (Lorh et al. 1999), willingness to pay for reductions in health risks associated with consuming pesticide residues in food (Fu et al. 1999) and valuing impacts of pesticide use (Foster and Mourato, 2000). However, the question that arises is why do farmers continue to use pesticides despite all the adverse effects of pesticide use? In this paper we show why farmers continue to use pesticides (and in increasing amounts) despite these adverse effects.

The plan of this paper is as follows: Section II of this paper discusses the use of pesticides in agricultural production and its relationship with agricultural sustainability. Section III discusses the human health effects of pesticide use. Section IV examines the costs of pesticide use and section V argues why farmers continue to use pesticides despite its effects on agricultural sustainability, the environment and farmers' health.

2. Use of pesticides and agricultural sustainability

According to Aspelin (1997) the worldwide consumption of pesticides has reached 2.6 million metric tons. Of this 85 percent is used in agriculture. Although the largest volume of pesticide use is in developed countries, pesticide usage is growing rapidly in developing countries (WRI, 1999). The quantity of pesticides used per acre of land has also increased (ibid.). In addition to the increase in quantity of pesticides used, farmers use stronger concentrations of pesticides, they have increased the frequency of pesticide applications and increasingly mix several pesticides together to combat pesticide resistance by pests (Chandrasekera et al. 1995; WRI, 1999). These trends are particularly noticeable in Asia as well as in Africa.

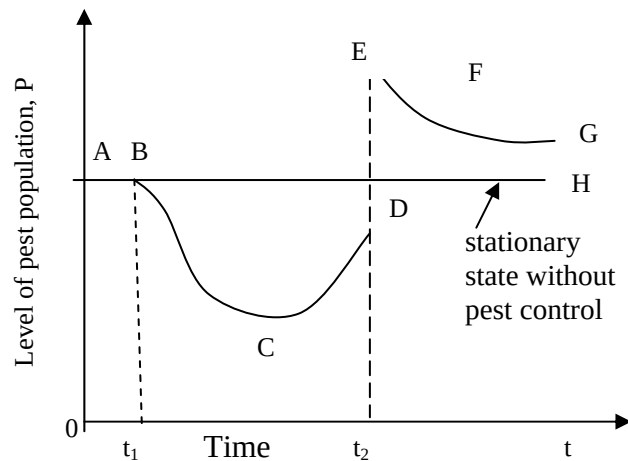
While the majority of pesticides used in developed countries are herbicides (which are less toxic than insecticides in most instances), the bulk of pesticides used in developing countries are insecticides which lead to insecticide-resistance by pests and cause most damage to human health (WRI, 1999). Furthermore, the insecticides used in developing countries are often of older types belonging to organophosphates and carbamates noted for their acute toxicity. Some of these are already banned or severely restricted, but are still used illegally because they are no longer under patent protection and hence are cheaper than newly invented pesticides (WRI, 1999). In Sri Lanka for instance, eight pesticides de-registered in 1995 because of their dangers to humans and the environment were still being used in 1996 (Wilson, 1998).

The initial use of pesticides, has been very effective in reducing pest infestations and increasing agricultural production and productivity. However, over time targeted pests have developed resistance to pesticides necessitating increasing applications or resulting in rising populations of pests or both. After a point, resistance of pests may grow to such an extent that application of pesticides is no longer economic. Once application stops, the population of pests may climb to levels in excess of those predating the use of pesticides. They may remain permanently above levels prior to the use of the pesticides.

This can occur because the pesticides have eliminated the beneficial predators of pests. This scenario can be illustrated in Figure 1.

FIGURE 1

USE OF A CHEMICAL PESTICIDE TO CONTROL THE POPULATION OF AN AGRICULTURAL PEST MAY PROVE TO BE UNSUSTAINABLE



In the absence of the use of pesticides the population of pests might remain stationary at OA or follow the stationary or equilibrium path AH. Now suppose that the chemical pesticide is used at t_1 and that applications of it increase. The population of the pest may now follow the path BCD. The population at first declines but begins to rise again later as resistance to the chemical develops. The use of the chemical control creates disequilibrium in the system. At point t_2 , the use of the chemical control is no longer economic and is discontinued. The population size of the pest suddenly explodes, and may then decline, moving along path EFG. A new stationary equilibrium is established along FG and the stationary population level is now higher than before the use of pesticides. Not only has the control been unsustainable but it has exacted an environmental penalty.

Pest infestations affecting agricultural production are a common occurrence. Increases in pesticide use to control pests that easily attack commercially grown high yielding

varieties have led to an increase in the virulence of many species of crop pests due to the destruction of non-target species, which include natural predators of pests and parasites (Litsinger, 1989, p.235; Teng 1990; Pimentel, 1992)¹. Excellent examples are the brown planthopper (*Nilaparvata Ingens*) and the rice gall midge (*Orseolia oryzae*) pests. There are many more species that have proliferated with the destruction of natural predators which earlier were not serious (Sogawa, 1982; Kenmore et al. 1984; Litsinger, 1989, p.235; Way and Bowling, 1991; Heong, 1991; Rola and Pingali, 1993, p. 15-19). Kenmore (1980) reported that nearly every epidemic of brown planthoppers (BPH) in the tropics has been associated with prior use of insecticides. Reissig et al. (1982) found that 16 of the 39 insecticides tested caused BPH resurgence. Hence a pesticide treadmill has been created. Severe outbreaks of the brown planthopper occurred on rice in the 1970s, 1980s and the 1990s in Asia causing millions of hectares of rice to be destroyed². Planthoppers are naturally controlled by wolf spiders and a variety of other natural predators and parasites which are destroyed by many of the pesticides commonly used on rice (Conway and McCauley, 1983, p. 288; Conway and Barbier, 1990, p. 22).

Apart from pests developing resistance to pesticides there are many harmful effects of pesticides that affect agricultural sustainability, the environment and the health of farmers as well as those living around near farms. Furthermore, it has been pointed out that pesticides can adversely affect paddy soils (Greaves, 1984, p. 14). Declining soil fertility adversely affects productivity and increases the need to apply larger quantities of chemical inputs to maintain productivity, thus further increasing the costs to farmers. For a discussion on the effects/costs of pesticides on soils, microorganisms and invertebrates, see Pimentel et al. (1992).

¹ Pesticide resistance by pests and weeds is ranked as one of the top four environmental problems in the world (UNEP, 1979). Today more than 500 insect and mite species are immune to one or more insecticides (WRI, p. 113, 1994).

² For example, the brown planthopper causes considerable crop damage in Indonesia. From 1977 to 1979, over two million hectares of rice were lost due to brown planthopper damage. Again from 1984 and 1986 BPH outbreaks reduced rice yields nationwide (Whalon et al. 1990, p. 156). The estimated loss in just a two year period was 1.5 billion US dollars (FAO, 1988). Pimentel et al. (1992, 1993) show that the costs of decimation of natural enemies in the USA which run into millions of dollars each year.

No one knows for certain the extent of the damage done to wildlife from the use of pesticides. However, many species have been affected, especially animals³ at the top of the food chain, and according to Bramble (1989, p. 228), the natural balance of predators and prey has been disrupted, particularly in the insect world⁴. Birds, too, have been a casualty from pesticide poisoning⁵. Beasley and Trammel (1989) point out that farm animals and pets are also affected by the use of pesticides. For a discussion on the effects/costs of pesticides on wild bird populations in North America and Europe and for relevant references, see Pimentel et al. (1992).

In addition to the damage caused to the environment and to agricultural land, pesticides impact directly on other production processes. For instance, fisheries production has been adversely affected. Many pesticides are highly toxic to fish at normal rates of application (Grist, 1986, p. 318)⁶. There is increasing evidence for this from India as well as Bangladesh. In Bangladesh, fish production over the years has shown a noticeable decrease. Among the many factors that have been cited as a cause for decline in fish production is the presence of pesticides in fresh water as well as in crop fields (Bangladesh, Ministry of Finance, 1992, p. 32). Alauddin et al. (1995, p. 242) point out that in Chittagong and Durgapur districts (Bangladesh), fish production in paddy fields has declined by 60-75% over the last decade following the Green Revolution. In addition to fish, shrimps, prawns, crayfish and crabs are also known to suffer from pesticides, but detailed studies of pesticide poisoning are not available. Greaves (1984, p. 15) states that there is evidence that pesticides, particularly insecticides, can cause mortality in crabs and fish. Pesticides, not only affect the quantity, but also contaminate the harvests of fish, shrimps, etc. posing a serious health hazard to consumers (ICAITI, 1977). For a discussion on the effects of pesticides on fishery losses and their costs in the USA, see

³ For pesticide poisoning of mammals in Britain and elsewhere, see Mason et al. (1986, pp. 656-66); Blackmore (1963, pp. 391-409).

⁴ For a discussion on the impact in bees, see Shries (1983, pp. 118-20); Murray (1985, pp. 560-64). For a discussion on costs resulting from a decline in bee populations in the USA, see Pimentel et al. (1992, p. 754).

⁵ For evidence of pesticide poisoning of birds in UK and North America see Lincer (1975, pp. 781-93); Peakall et al. (1976, pp.392-4); Newton and Bogan (1978, pp. 105-116); Lundholm (1987, pp.1-22).

⁶ In the Philippines and Malaysia farmers have linked declining fish yields in rice fields to pesticide poisoning (Sudderuddin and Kim, 1979, Dinham, 1993, p.69).

Pimentel et al. (1992, p. 756). Other externalities have also been observed. For example, Wilson (1998, p. 156) notes that herbicides used on onion plots to destroy weeds when spread to neighbouring farms due to strong winds affected other crops which were not resistant to the herbicides used. In Australia, Endosulfan (a very toxic organochlorine insecticide) used on cotton crops has contaminated beef production and has affected exports in recent times (Williams, 1999, p. 11). Rural water supplies, too, have been affected (Callinan, 1999, p. 1). In USA, beef, milk and eggs have been negatively affected (Pimentel et al. 1992). For a discussion about similar externalities and their costs in the USA, see Pimentel et al. (1992, p. 755). In addition to the above mentioned adverse effects, the health effects arising from pesticide pollution are large.

3. Human health effects of pesticide use

The use of pesticides have not only influenced level of agricultural production and their sustainability but have also affected the health of users (mainly farmers), those living near farms and consumers of food products. Deaths from exposure to pesticides are not uncommon. Each year tens of thousands of farmers, especially in developing countries, are affected by exposure to pesticides. World Health Organization (1990) estimates that between 50 million and 100 million people in the developing world may receive intensive pesticide exposure, and another 500 million receive lower exposures. As a result it is estimated that these exposures may result in some 3.5 million to 5 million acute pesticide poisonings per year with a much larger number of people suffering subacute effects. Even in developed countries, despite the strict regulations and the use of safer pesticides, occupational exposures may be significant (WRI, 1999). It is believed that in developing countries the incidence of pesticide poisoning may even be greater than reported due to under-reporting, lack of data and misdiagnosis.

In addition to the short-term and long-term illnesses arising from exposure to pesticides, exposure to pesticides during handling and spraying on the farms also result in many deaths. For example in Sri Lanka hundreds of individuals die from pesticide poisoning

each year. Table 1 shows the number of deaths in Sri Lanka due to pesticide poisoning from 1975-1996. As shown, the number of deaths from pesticide poisonings in Sri Lanka are around 1,500 a year. Table 1 also shows morbidity figures, deaths per thousand and morbidity rankings for the whole country compared to other sources of deaths.

TABLE 1
HOSPITAL ADMISSIONS AND DEATHS DUE TO PESTICIDE POISONING IN
SRI LANKA, 1975-1996

Year	Total Pesticide Deaths	Total Pesticide Admissions	Deaths Per100,000 Population	Rank Order ⁷
1975	938	14,653	-	-
1976	964	13,778	-	-
1977	938	15,591	-	-
1978	1029	15,504	-	-
1979	1045	11,372	-	-
1980	1112	11,811	-	-
1981	1205	12,308	-	-
1982	1376	15,480	-	-
1983	1521	16,649	-	-
1984	1459	16,085	-	7th
1985	1439	14,423	-	4th
1986	1452	14,413	-	6th
1987	1435	12,841	8.8	6th
1988	1524	12,997	9.2	6th
1989	1296	12,763	7.7	6th
1990	1275	10,783	8.8	6th
1991	1667	13,837	11.3	4th
1992	1698	15,636	-	4th
1993	1682	16,692	9.5	5th
1994	1421	14,979	8.1	5th
1995	1581	15,740	9.5	6th
1996	1850	21,129	-	6th

Source: National Poisons Information Centre, General Hospital, Colombo, Sri Lanka, 1997.

The incidence and severity of ill health from pesticide-use are far greater in developing countries than in developed countries. While most farmers in the developed countries use pesticides from a closed environment such as an aircraft or a tractor, farmers (who are

⁷ Rank order shows the leading causes of deaths in the country. As the rank order shows, pesticide poisonings is a major cause of death in Sri Lanka.

largely small scale farmers) in developing countries use hand sprayers, thus increasing the incidence of direct contact with pesticides. Furthermore, as noted by WRI (1999) farmers in the developing world use those more insecticides⁸, use those more frequently and also apply insecticides that are more toxic than those used in developed countries. The protective gear worn by farmers in LDCs is inadequate or poorly maintained. This is due to their inability to purchase standard protective gear. There are no regulations that require the use of protective gear during the use of pesticides. Farmers in LDCs often spray pesticides on a regular basis and in warm tropical heat thus increasing the incidence and severity of health effects. Inadequate education, training and pesticide regulations in the use of pesticides leads to accidents, haphazard application and over-use. Access to medical treatment is limited and most farmers rely on home made remedies thus increasing the severity and duration of illnesses. Poor health and diet are other factors that are known to increase the incidence of illnesses from exposure to pesticides in developing countries (WRI, 1999). Inadequate or non-existent storage facilities, poor living conditions, contaminated water supplies also affect the health of families. Exposure to pesticides can also weaken the immune system and increase the vulnerability to illness or death.

4. Costs of pesticide use

The delayed costs from pesticide pollution are high as a result of damage done to agricultural production from the proliferation of pests, impacts on other production processes, the environment and human health.

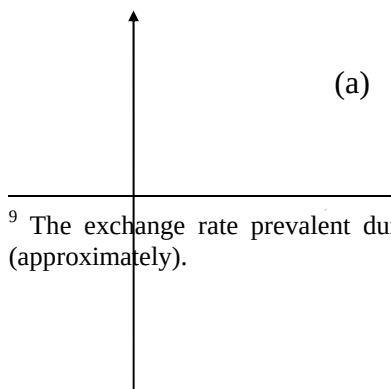
Farmers exposed to pesticides incur costs due to hospitalization, physician consultation and self-treatment. Some of the costs incurred are from hospitalization, costs of transport and costs involved with special diets and hired labour due to inability to work on sick days. The indirect private costs incurred are loss of working hours and days, loss of efficiency, the time a patient spends visiting hospitals or a physician and loss of leisure hours. Also loss of time for those members of the family involved in caring for persons

⁸ Interestingly, the bulk of pesticides used in developed countries are herbicides (WRI, 1999).

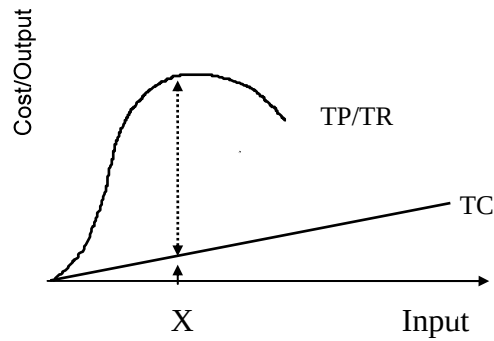
suffering from pesticide exposure. Wilson (1998) has estimated the private costs of farmers' exposure to pesticides in Sri Lanka. These are high. Using the cost of illness approach, he estimates that a farmer on average incurs a cost of around Rs 5,465⁹ a year (equal to about a month's income due to exposure to pesticides. On the other hand, use of the avertive/defensive behaviour approach estimates the costs to be around Rs 405 a year or about 12% of a monthly income of an average farmer per year. The contingent valuation estimates give a higher figure of Rs 11,471 or a cost of more than two and a half months income a year due to ill health resulting from exposure to pesticides. The contingent valuation approach takes into consideration the intangible costs as well as tangible ones. The estimates show that the country incurs millions of Sri Lankan rupees each year in costs due to exposure to pesticides. For a study that shows the true costs of pesticides see Pearce and Tinch (1998); Foster et al. (1998).

Apart from the health costs there are costs arising from crop losses due to proliferation of pests and effects on agricultural soils from pesticide pollution. When such a situation exists, not only is the total revenue from agriculture affected, but also the cost of production is increased. Such a scenario is demonstrated in Figure 2.

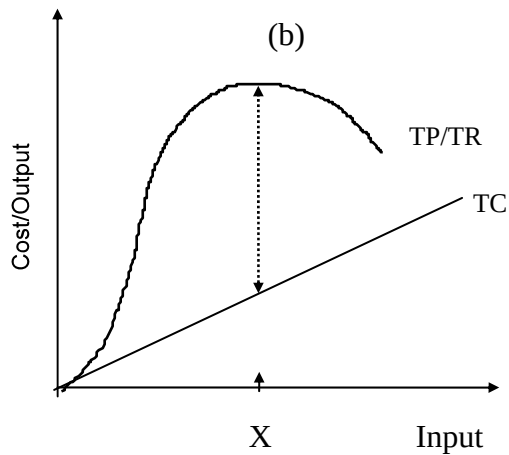
FIGURE 2
OUTPUT/COST RELATIONSHIPS BEFORE AND AFTER PESTICIDE POLLUTION



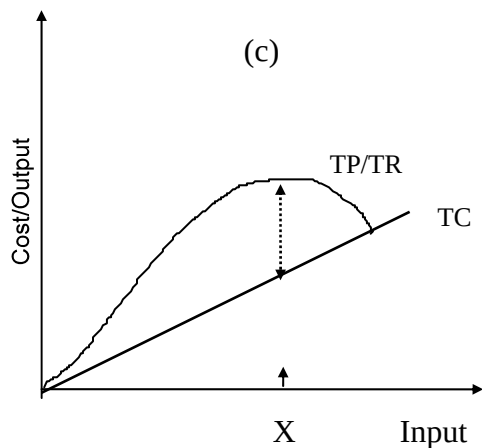
⁹ The exchange rate prevalent during the study period (June-September, 1996) was Aus\$ 1 = Rs 37 (approximately).



No pollution – limited use of chemical inputs and the assimilative capacity of the environment is greater than the pollution generated. The production system is sustainable.



Increasing the use of chemical inputs to increase yields. The agricultural chemical pollution generated is greater than the assimilative capacity of the environment. The production system is unsustainable



Increasing use of chemical inputs have caused pollution. The pollution impacts on production. In order to boost production, increasing amounts of chemical inputs have to be used, thus increasing not only the costs of input use but also increasing 'pollution' related costs. The gap between TR and TC is smaller than in (a) & (b).

Figure 2 (a) shows output before pollution with limited input use (which may include pesticides) where a sustainable system of agricultural production is maintained. Any pollution that occurs is assimilated by the environment. The total costs (TC) of production are not large. Figure 2 (b) shows a system of production where increasing quantities of chemical inputs such as pesticides are used to increase and maintain yields. Productivity increases in the short-term and TC of production is large due to high

chemical input use. However, as production and productivity increase with high input use, the level of pollution too increases. The pollution impacts on production in the form of declining soil fertility and the proliferation of agricultural pests due to pesticide resistance and the decimation of beneficial predators of pests. As a result more and more chemical inputs have to be used to boost production and to protect crops from pests thus increasing the total costs of production. The costs include: the costs of increased use of chemical inputs, damage caused by the proliferation of pests and farmers' health costs arising from exposure to pesticides. Hence, the gap between TR and TC becomes smaller. This scenario is shown in Figure 2 (c). The figure shows that the TC of production has increased and that the level of production is declining. It must be pointed out that although total output can be increased by adding extra amounts of inputs, it only increases at a decreasing rate. In fact average product (AP) and marginal product (MP) are declining. Of course, using more of the inputs cause further problems, as the stock of pollution accumulates. In such a case the pollution impacts are multiplied and the private and external costs keep increasing. In other words the new technology has affected agricultural sustainability. For an early discussion on the benefits of new technology, their impact on farmers' incomes and national welfare see Duncan and Tisdell (1971); Akino and Hayami (1975); Lindner and Jarrett (1978).

5. Why do farmers continue to use pesticides?

As shown in the previous section, the agricultural, environmental and health costs arising from pesticide use are high. In such a case the question that is often asked is why do farmers continue to use pesticides? There are many reasons for this paradox. They differ widely across regions and countries and may not follow a similar pattern where the use of pesticides is common place.

According to neoclassical theory, farmers will use pesticides if discounted net present value of stream of returns from doing so is positive. This can support the use of unsustainable pest control strategies and are more likely to do so the higher is the real discount rate. This is usually considered to be higher in less developed countries (LDCs)

than in more developed countries (MDCs). Hence, to use less sustainable techniques are more likely in LDCs. It is also possible that farmers in LDCs are less informed about pesticides than those in MDCs.

Market systems encourage the adoption of biophysically unsustainable techniques such as the use of pesticides in agriculture. Such techniques lower current costs and boosts yields in the short-run, but eventually lowers yields and raises costs of production in the longer term as shown in Figure 2 (c). Initially, the use of pesticides could increase supply and reduce market prices thereby forcing non-adopters to adopt despite their reservations. In other words, farmers not using pesticides may be forced to use it to avoid economic losses. A type of prisoner's dilemma exists due to external effects. Defensive use of pesticides becomes necessary by non-users so as to ensure their economic survival. Once the new technique is used, it may be impossible to revert to the previous process, except at a high cost, even when the cost of production employing the new technique eventually rises above that of the old. Hysteresis is present.

Pesticides may be adopted for reasons other than the above. There may be ignorance about its long term sustainability - it may be believed to be more sustainable than is in fact the case. Pesticides are an integral part of commercially grown high yielding varieties (e.g. Green Revolution varieties). Without the use of pesticides, high yields may not be sustained. Furthermore, chemical companies selling the pesticides have an incentive to push its use by advertising and promotion and this may create a bias in favour of its use (Tisdell et al. 1984). Thus the use of chemicals in agriculture may be encouraged in preference to the use of natural ingredients available to farmers on farms (Tisdell, 1999). Agriculture research can also become biased in the same way as will be discussed later in this section. This market failure problem can result in the use and development of agricultural techniques which lack sustainability and which reduce long-term economic welfare (ibid.). Loans obtained by farmers for the purchase of inputs (e.g. pesticides and fertilizers) may also be a barrier to switching to other strategies. Damage to agricultural land from the use of pesticides occur over a period of time. Hence, costs arising may not initially look serious. Furthermore, farmers do not compensate for the

numerous externalities except in the case of production externalities. As shown by Wilson (1998), although farmers in Sri Lanka were willing to pay a higher price to use safer pesticides or adopt Integrated Pest Management (IPM) strategies which includes biological control of pests and diseases, such services are not easily available to farmers in these countries. IPM is practiced in many countries but has been on a small-scale for many reasons¹⁰. As the WRI (1994, p. 117) points out, IPM in developing countries is more the exception than the rule.

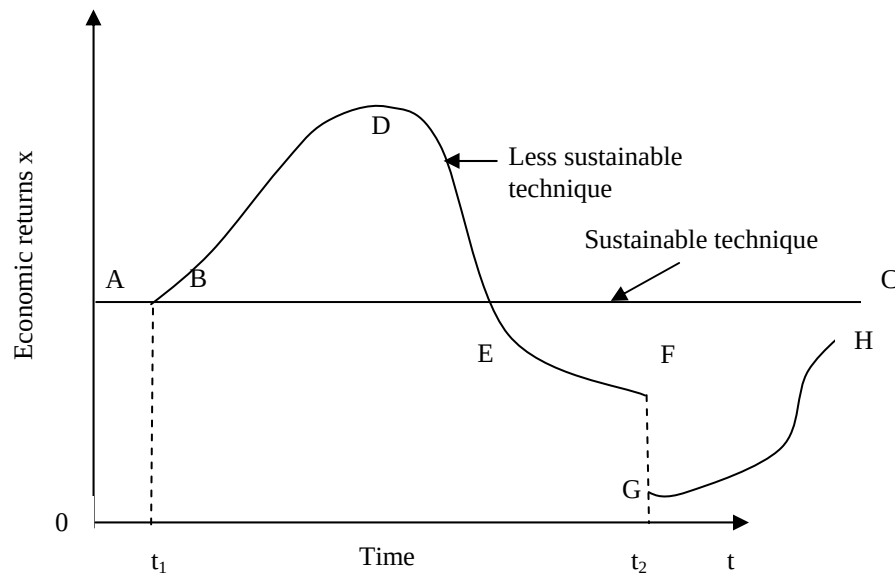
It is also likely that in the majority of cases, the short-term health effects arising from pesticide use and the disutility from that ill health are underestimated by farmers. This is because costs resulting from exposure to pesticides accrue over a period of time (e.g. one year) and include time costs as well. Furthermore, certain ill effects remain undetected and farmers do not necessarily die of pesticide pollution. Most often short-term and long-term ill health arising from exposure to pesticides are misdiagnosed partly because these symptoms can occur on non-spraying days. Lack of medical facilities in developing countries make the problem more complicated. As a result, lack of diagnosis attributed to pesticide exposure often ignores the dangers of pesticide use. Ill health then is attributed to another cause. The long term relationship between dose and effect are complicated and because of the time involved, is less easy to prove. Exposure to pesticides also reduces immunity against other diseases. People may not necessarily die of acute pesticide poisoning, but rather deaths could occur from diseases such as pneumonia, gastroenteritis or to complications of measles (Repetto and Baliga, 1996). Another reason is that farmers in developing countries have no easy alternatives to subsistence farming. Subsistence farming on the other hand requires very little capital and skill. Furthermore, subsistence farmers use some of their produce for home consumption, thus covering a large part of the family expenditure. Hired labourers using pesticides may not know the true health impacts of pesticide use until severely affected. Workers' attempts in Latin America to organise and assert their rights are known to have met with reprimands and dismissals, because replacement workers are easy to find (WRI, 1999). Enforcement of laws in LDCs is also often weak for institutional reasons.

¹⁰ See Cowan and Gunby (1996) for reasons why IPM has been slow to be adopted on farms.

As a result of one or more reasons mentioned, farmers become locked into 'unsustainable' agricultural systems once pesticides are adopted. This is because of the heavy initial costs of switching to more sustainable systems and the need for all to act simultaneously in the switching process if economic losses are to be avoided. This is illustrated in Figure 3.

FIGURE 3

**PRODUCERS MAY BECOME LOCKED INTO THE USE OF A RELATIVELY
UNSUSTAINABLE TECHNIQUE SUCH AS THE LESS SUSTAINABLE
ONE INDICATED HERE**



The line ABC represents economic returns with a traditional organic agricultural technique. This shows, say, sustainability. As an alternative, suppose that a modern non-organic technique, such as the use of pesticides is adopted. If this is adopted at time t_1 , returns might follow the path BDEF. Initially they are well above that for the traditional technique, but fall and eventually become smaller than with the traditional technique. However, to return to the traditional technique may not be economically possible for an individual farmer (unless produce from the use of this technique sells with a high price premium for pesticide free produce) because there can be high withdrawal costs. For example, if a switch is attempted at t_2 , the path FGH may be followed. If however, all farmers were to switch at t_2 , the price of the product would

rise normally and this would make switching easier from an economic viewpoint. The possibility of economic ‘locking in’ or hysteresis occurring as a result of the adoption of unsustainable economic techniques becomes real (Tisdell, 1991). As Tisdell (1999, 49-50) points out that reverting to the old technique might cause a downward jump in the welfare function (described as consumers’ surplus plus producers’ surplus), say from F to G due to mining of the natural environment by the new technique. Welfare gains may increase slowly, say along path GH. In some cases the net present value of the area under BDEFGH will be less than that under BC. This implies that net discounted economic welfare is lower for the new technique than for the old.

As Tisdell (1991, 173-174) points out that when chemical agricultural systems are adopted, agricultural yields or returns become very dependent on them despite the very high costs and thus impose an ‘economic barrier’ to switching to organic systems. In short, agricultural practices tend to become ‘locked into’ such systems once they are adopted despite being unsustainable (Tisdell, 1991, p. 173; Tisdell, 1993, p. 169). Cowan and Gunby (1996), too, point out that once a pest control strategy is adopted, then it becomes the dominant strategy as this has been the case with using chemical pesticides. They point out that once the chemical pest control strategy was adopted, the amount of money spent on R&D for further development of pesticides has increased while the development of IPM has slowed down. For example, they show that “ in 1937, 33% of the articles in the *Journal of Economic Entomology* dealt with the general biology of insects, 58% were devoted to testing pesticides. By 1947 these proportions were 17% and 76% respectively ” (p. 524). As a result, in a competition between two technologies, “ a lead in market share will push a technology quickly along its learning curve, thereby making it more attractive to future adopters than its competitor. A snow-balling effect can lock a market of sequential adopters into one of the competitors ” (p. 523). The use of chemicals can also affect biological pest control strategies by killing the predators of pests. Hence, even if some farmers decide to adopt biological pest control strategies, they would be affected due to externalities of pesticides arising from neighbouring farms. Therefore, despite the economic, social and ecological gains that could be derived from biological control of pests (see Menz et al., 1984; Tisdell 1987, 1990), pesticides once

adopted as the dominant pest control strategy will continue to be used in larger quantities despite the very serious negative effects that have arisen. For example, Cowan and Gunby (1996, p. 522) state that between 1964 and 1982 in the United States, the application of active chemicals increased 170% by weight. Since 1970, herbicide use has more than doubled. In Sri Lanka pesticide use increased by almost 110 times between 1970 and 1995 (Wilson, 1998, p. 36).

Therefore, despite the advantages of biological pest control strategies, farmers both in developed and developing countries continue to use pesticides at an increasing rate and hence become 'locked in' on one form of pest control technology which has resulted in their 'entrapment' in pesticides.

6. Conclusions

In the paper it was shown how the use of pesticides affects agricultural sustainability through several externalities. One externality that was shown to affect agricultural productivity was the development of resistance of targeted pests of pesticides. The manner in which pesticides reduce pest infestations and how chemical control creates a disequilibrium in the agricultural system was shown graphically. Not only does the control of pests become unsustainable, but it also extracts an environmental penalty. Several examples were provided. The health costs of pesticide use are also high. The private costs to farmers from exposure to pesticides in Sri Lanka, for instance, was shown to be high using three valuation approaches. It was then shown why farmers continue to use pesticides (often in increasing quantities), despite the high external costs. The possibility of economic 'locking in' occurring as a result of the adoption of unsustainable economic techniques was shown graphically. The prevailing agricultural system has 'locked in' farmers in the system of pest control technology which has resulted in their 'entrapment' in pesticides.

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