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Ecological Economics 39 (2001) 449–462

ECOLOGICAL
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ANALYSIS

Why farmers continue to use pesticides despite environmental, health and sustainability costs

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Received 12 March 2001; received in revised form 6 August 2001; accepted 7 August 2001

Abstract

Use of chemical inputs such as pesticides has increased agricultural production and productivity. However, negative externalities from such use have increased too. These externalities include damage to agricultural land, fisheries, fauna and flora. Another major externality is the unintentional destruction of beneficial predators of pests thereby increasing the virulence of many species of agricultural pests. Furthermore, increased mortality and morbidity of humans due to exposure to pesticides are recorded especially in developing countries. The costs from these externalities are large and affect farmers' returns. However, despite these high costs, farmers continue to use pesticides and in most countries 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. © 2001 Elsevier Science B.V. All rights reserved.

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

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1. Introduction

Continuous use of chemical inputs such as pesticides has resulted in damage to the environment, caused human ill-health, negatively impacted on agricultural production and reduced agricultural sustainability (Pimentel et al., 1992; Pimentel and Greiner, 1997). Fauna and flora have been adversely affected (Pimentel and Greiner, 1997). Numerous short- and long-term human health effects have been recorded (Wilson, 1998). Human deaths are not uncommon (Wilson, 1998). The decimation of beneficial agricultural predators of pests has led to the proliferation of several pests and diseases (Pimentel and Greiner, 1997). Despite all these impacts and costs, farmers continue to use pesticides in most countries at an increasing rate, while biological methods of pest control have become limited. Many papers have highlighted this and drawn attention to issues such as pesticide productivity and host-plant resistance

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PII: S0921-8009(01)00238-5

(Widawsky et al., 1998), voluntary reductions in pesticide use (Lohr 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 remains why farmers continue to use pesticides, and in most countries (for example, Sri Lanka, India, China) in increasing quantities, despite all the adverse effects. In this paper, we show why farmers continue to use pesticides despite these adverse effects.

The plan of this paper is as follows: Section 2 of this paper discusses the use of pesticides in agricultural production and its relationship with agricultural sustainability. Section 3 discusses the human health effects of pesticide use. Section 4 examines the costs of pesticide use and Section 5 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[1] has reached 2.6 million metric tons. Of this, 85% is used in agriculture. Although the largest volume of pesticide use is in developed countries, its use is growing rapidly in developing countries (World Resources Institute (WRI), 1998). The quantity of pesticides used per acre of land has also increased (WRI, 1998). 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 (Chandrasekara et al., 1985; WRI, 1998). These trends are particularly noticeable in Asia and in Africa.

While the majority of pesticides used in developed countries are herbicides [which can be as toxic as insecticides (for example, paraquat, alachlor, atrazine, simazine)], the bulk of pesticides used in developing countries is insecticides which lead to insecticide-resistance by pests and cause most damage to human health (WRI, 1998). Furthermore, the insecticides used in developing countries often consist of organochlorines (for example, DDT, endosulfan, lindane, dieldrin), organophosphates (monocrotophos, parathion, methamidophos) and carbamates (carbofuran, thiodicarb, maneb) noted for their toxicity (WRI, 1998). It should be mentioned here that organophosphate and carbamate insecticides are less persistent than organochlorides but are potentially more toxic to farmers and field workers, especially if they are misused (Carlson and Wetzstein, 1993). Pyrethroid insecticides on the other hand could be applied at much lower rates and are effective against most foliar insect species. The lower rates and relatively low acute toxicity of these materials to mammals have made pyrethroids safer to farm workers, wildlife and food consumers than many other insecticides. However, the residues of some pyrethroid compounds have been found in ground or surface water (Carlson and Wetzstein, 1993). Some of the above-mentioned pesticides (for example, DDT, monocrotophos, parathion, methamidophos) 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, 1998). In Sri Lanka for instance, eight pesticides de-registered (for example, methamidophos, parathion, propanil) 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

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[1] According to the United States Environmental Protection Agency (US EPA) (1999), the term pesticide is a broad nonspecific term covering a large number of substances including, insecticides, herbicides and fungicides, 'though often misunderstood to refer only to insecticides'.

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. Pimentel et al. (1992) give a striking example of such a development based on the work of Adkisson (1972) from northeastern Mexico and the Lower Rio Grande of Texas. As stated in Pimentel et al. (1992) 'extremely high pesticide resistance had developed in the tobacco budworm population in cotton. Finally, in early 1970, approximately 285,000 hectares of cotton had to be abandoned because pesticides were ineffective and there was no way to protect the crop from the budworm'. More recently in Sri Lanka (for example, in the Matale District), land has also been abandoned because pesticides have been ineffective in protecting crops (agricultural extension officers of the Department of Agriculture and farmers, personal communication, 1996; Wilson, 2000). This scenario can be illustrated in Fig. 1 (after Tisdell, 1991, 1993).

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 pests develop resistance to the chemicals used and beneficial predators of pests are decimated by the use of pesticides which creates a disequilibrium in the system (Pimentel and Greiner, 1997). Many pests have reached outbreak levels in crops such as rice, apples, cotton, soybeans, potatoes, onions and tobacco (Croft, 1990; Pimentel and Greiner, 1997). More examples of outbreaks of pest infestations attributed to pesticide use are discussed later in the article. At point t_2, the use of the chemical control is no longer economic and is discontinued. The population size of the pest suddenly increases, 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.

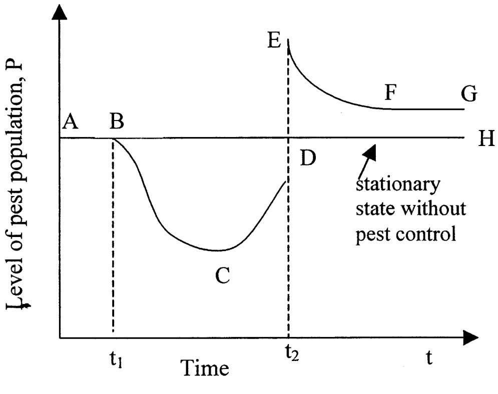

Fig. 1. Use of a chemical pesticide to control the population of an agricultural pest may prove to be unsustainable.

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; Pimentel et al., 1992; Teng 1990).[2] 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 (Kenmore et al., 1984; Litsinger, 1989; Rola and Pingali, 1993; Way and Bowling, 1991). 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 destroyed. Planthoppers are naturally controlled

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[2] Pesticide resistance by pests and weeds is ranked as one of the top four environmental problems in the world (United Nations Environmental Programme, 1979). World Resources Institute (WRI, 1994) notes that more than 500 insect and mite species are immune to one or more insecticides.

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 Barbier, 1990).

Apart from pests developing resistance to pesticides, there are other harmful effects of pesticides that affect agricultural sustainability, the environment and the health of farmers as well as those living near farms (Pimentel et al., 1992). These issues are discussed below.

Pimentel et al. (1992) point out that honeybees, which are vital for the pollination of crops including fruit and vegetables, are affected by most of the insecticides used. There are also agricultural losses due to reduction in insect pollination of crops due to pesticide use (Pimentel et al., 1992). It has been reported that recommended dosages of insecticides used on crops have suppressed the growth and yield in both cotton and strawberry (Instituto Centro Americano de Investigacion Tecnologia Industrial (ICAITI), 1977). The increase in susceptibility of some crops such as corn to insects and diseases after the use of 2,4-D and other herbicides has been demonstrated by Oka and Pimentel (1976). Keeling et al. (1989) show that when residues of some herbicides persist in the soil, crops planted in rotation may be affected. Herbicide persistence could even prevent farmers rotating their crops which could force them to plant the same crops (Altman, 1985). Crops are also lost when pesticides drift into neighbouring farms, even several kilometers away (Barnes et al., 1987). The problem is even worse when pesticides are sprayed from aircraft (Mazariegos, 1985). These agricultural externalities are also discussed in Wilson (1998), and are based on field work carried out in the summer of 1996 in Sri Lanka. Pesticides that easily find their way into soils become toxic to arthropods, earthworms, fungi, bacteria, and protozoa which ‘are vital to ecosystems because they dominate both the structure and function of natural systems’ (Pimentel et al., 1992). For a discussion on the effects/costs of pesticides on soils, microorganisms and invertebrates, see Pimentel et al. (1992). The effects on soils and microorganisms discussed above were in relation to pesticides. However, apart from pesticides, fertilisers used on agriculture, too, caused adverse effects such as the modification of soil bacterial ecology. For a discussion on the adverse effects of fertiliser on soils and human health, see WRI (1998).

No one knows for certain the extent of the damage done to wildlife from the use of pesticides. However, there is evidence to show that many species of mammals (Mason et al., 1986), insects (Murray, 1985) and birds (Lundholm, 1987) have been affected. An example of wildlife being affected is the death of 1200 Canada Geese killed in one wheat field that was sprayed with a mixture of parathion and methyl parathion at a rate of 0.8 kg/hectare in the USA (White et al., 1982). United States Environmental Protection Agency (US EPA, 1989) estimated that Carbofuran results in the death of 1–2 million birds each year in the United States. Stickel et al. (1984) note that exposure of birds, especially birds of prey, to chlorinated insecticides has caused reproductive failure, sometimes attributed to eggshell thinning. However, it must be stated that most birds affected by DDT poisoning have recovered since its ban but remain a concern, especially for wintering birds in developing countries. Beasley and Trammel (1989) point out that farm animals and pets are also affected by the use of pesticides. For a further 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). Pesticides enter aquatic ecosystems by water runoff, soil erosion, leaching and wind (Clark, 1989; Pimentel and Greiner, 1997). Pimentel and Greiner (1997, p. 66) state that:

> Once in aquatic systems, pesticides cause fishery losses in several ways. These include high pesticide concentrations in water that directly kill fish, low-level doses that may kill highly susceptible fish fry, the elimination of essential fish foods like insects and other invertebrates, or the

> reduction of dissolved oxygen levels in the water due to the decomposition of aquatic plants by pesticides.

Pimentel and Greiner (1997), based on United States Environmental Protection Agency (US EPA) (1990b) state that each year large numbers of fish are killed by pesticides, and from 1977 to 1987 the number of fish kills due to all factors (including fertilisers) has been 141 million fish per year, out of which pesticides are responsible for the death of 6–14 million. They state, quoting US EPA (1990b):

> these estimates of fish kills are considered to be low for the following reasons. First, in 20% of the fish kills, no estimate is made of the number of fish killed, and second, fish kills frequently cannot be investigated quickly enough to determine accurately the primary cause. In addition, fast-moving waters in rivers dilute pollutants, so that these causes of kills frequently cannot be identified. Moving waters also wash away some of the poisoned fish, while other poisoned fish sink to the bottom and cannot be counted. Perhaps most important is the fact that, unlike direct kills, few, if any, of the widespread and more frequent low-level pesticide poisonings are dramatic enough to be observed, and therefore go unrecognised and unreported.

As stated by Pimentel and Greiner (1997), in addition to pesticides, there are other substances such as fertilisers that result in fish kills. For a detailed discussion on the effects of pesticides on fishery losses and their costs in the USA, see Pimentel et al. (1992).

Pesticides also contaminate drinking water and food crops, especially fruits and vegetables receiving the highest dosages of pesticides, thus posing a possibly serious health hazard to consumers (Pimentel et al., 1992). According to the Food and Drug Administration (FDA) (Food and Drug Administration 1990) approximately 35% of the foods purchased by consumers have detectable levels of pesticide residues and 1–3% of the foods have pesticide residue levels above the legal tolerance levels. Kegley and Wise (1998), based on many studies that have been conducted on sample extracts, report that many vegetables (for example, cucumbers, carrots, turnips, radish, tomatoes) and fruits (for example, strawberries) exceed the allowable tolerance limits of pesticide residues (organochlorines, organophosphates, carbamates) in the USA. The National Research Council (NRC, 1993) points out that infants and children are more vulnerable to organophosphate and carbamate induced cholinesterase inhibition and related effects. In North America, aldicarb contamination of crops has resulted in widespread outbreaks of food borne pesticide toxicity (Goldman et al., 1990). Goldman and co-workers investigated more than thousand cases of illnesses caused by consumption of aldicarb contaminated watermelons and cucumbers. For many case studies showing pesticide contamination of foods with examples from many countries see NRC (1993). Water is also contaminated with pesticides. For example, Osteen and Szmedra (1989) point out that in the United States the three most common pesticides found in ground water are aldicarb (an insecticide), and alachlor and atrazine (two herbicides). It is reported (US EPA, 1990a) that 10.4% of community wells and 4.2% of rural domestic wells have detectable levels of at least one pesticide of the 127 pesticides tested in a national survey. For more studies detailing out pesticides in ground water and their dangers, see Pimentel and Greiner (1997). Other externalities have also been observed. For example, 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). Rural water supplies, too, have been affected (Callinan, 1999). In USA, beef, milk and eggs have been negatively affected (Pimentel et al., 1992).

3. Human health effects of pesticide use

The use of pesticides has not only influenced the level of agricultural production and its sustainability but has 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. Recent estimates quoted by Food and Agricultural Organization (2000) from Pesticide Action Network (PAN) show that approximately three million people are poisoned and 200,000 die from pesticide poisoning use each year. The largest number of deaths are in developing countries. For example, hospital statistics in Sri Lanka show that on average 14,500 individuals were admitted to government hospitals and around 1500 individuals a year died from pesticide poisoning during the period 1986–1996 (National Poisons Information Centre, 1997). However, these figures should be interpreted with caution. It should be pointed out that not all hospital admissions and deaths were due to occupational poisoning but include cases of self ingestion (suicides), accidental ingestion and homicides. An examination of a limited number of bed head tickets by Wilson (1998) indicated that a considerable number of pesticide poisoning cases were due to occupational poisoning, but the majority of cases were due to self ingestion (suicides). However, it should be pointed out that most frequently occupational-related poisonings do not show up in hospitals and are mostly not recorded. Furthermore, even hospital outdoor treatment of occupational-related poisonings are not recorded. As pointed by an anonymous referee, in Guatamala occupational poisonings are a bigger problem than suicides.

Furthermore, there is evidence suggesting that some pesticides can produce immune dysfunction among animals when exposed (Thomas and House, 1989). One study (Fiore et al., 1986) showed that women who had chronically ingested groundwater contaminated with low levels of aldicarb reported evidence of significantly reduced immune response, although these women did not exhibit any overt health problems. However, it should be noted that the study of the immune suppression potential for pesticides is still in its infancy and that the evidence available is inconclusive (WRI, 1998; Repetto and Baliga, 1996). Even in developed countries, despite the strict regulations and the use of safer pesticides, occupational exposures may be significant (WRI, 1998). 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 (Forget, 1991).

The incidence and severity of ill health from pesticide-use are far greater in developing countries than in developed countries due to many reasons. While most farmers in the developed countries use pesticides from a closed environment such as an aircraft or a tractor, farmers (who are largely small scale farmers) in developing countries use hand sprayers, thus increasing the incidence of direct contact with pesticides. Furthermore, as noted by WRI (1998) farmers in the developing world use more insecticides,[3] use them 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 (many farmers are functionally illiterate and cannot understand instructions printed even in their own language), training and pesticide regulations in the use of pesticides lead 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 believed to increase the incidence of illnesses from exposure to pesticides in developing countries (WRI, 1998). Inadequate or non-existent storage facilities, poor living conditions and water supplies contaminated with pesticides also affect the health of families.

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[3] Interestingly, the bulk of pesticides used in developed countries are herbicides (WRI, 1998).

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 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 5465[4] 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 $2\frac{1}{2}$ 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.

Apart from 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 (TR) from agriculture affected, but also the cost of production is increased. Such a scenario is demonstrated in Fig. 2.

Fig. 2a 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. Fig. 2b 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 (including pesticides), 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 Fig. 2c. 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. Of course, using more of the inputs causes further problems, as the damage from pollution (such as pesticides) increases. In such a case the pesticide pollution impacts are multiplied and the private and external costs keep increasing. In other words the new technology has affected agricultural sustainability.

5. Why do farmers continue to use pesticides?

Despite the large increases in food production brought about by chemical inputs such as pesticides, the agricultural, environmental and health costs arising from pesticide use are high (Wilson, 2000). In such a case the question that is often asked is why do farmers continue to use pesti-

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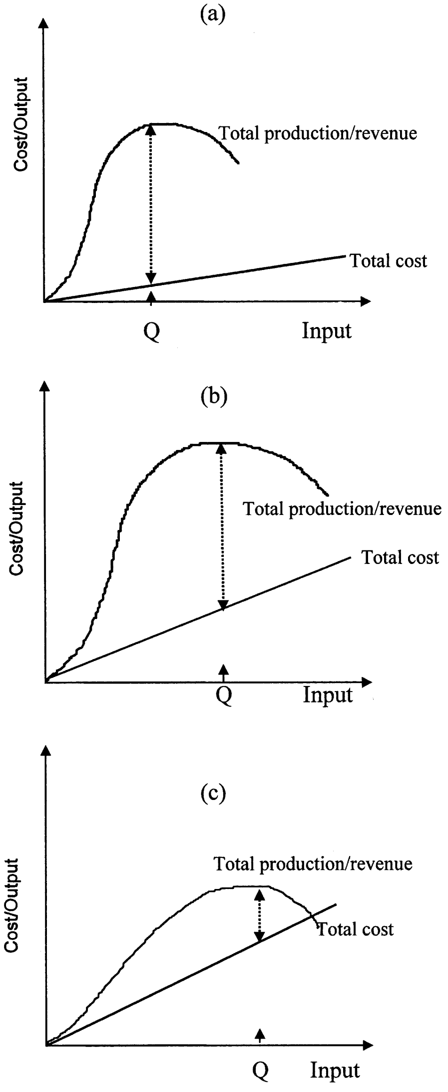
[4] The exchange rate prevalent during the study period (June–September, 1996) was \$AUD 1 = Rs 37 (approximately).



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 total revenue and total cost is smaller than in (a) & (b).

Q = quantity of inputs

Fig. 2. Output/cost relationships before and after pesticide pollution.

cides? 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 the discounted net present value of stream of returns from doing so is positive. This can support the use of unsustainable pest control strategies and is more likely to do so, the higher 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 is 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 boost yields in the short-run, but eventually lower yields and raise costs of production in the longer term as shown in Fig. 2c. 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. 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 the sustainability of pesticide use. Its use may be believed to be more sustainable than is in fact the case. Pesticides are an integral part of commercially grown high yielding varieties (for example, 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 their use by advertising and promotion and this may create a bias in favour of their 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 (Tisdell, 1999). This is especially so if there is no countervailing argument from consumers or activists against their use. Loans obtained by farmers for the purchase of inputs (for example, pesticides and fertilizers) may also be a barrier to switching to other strategies. Damage to agricultural land from the use of pesticides occurs 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 and 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 reasons.[5] As the WRI (1994) points out, IPM in developing countries is more the exception than the rule. Farmer knowledge and management of crop disease is also an important factor in the use of pesticides (Bentley and Thiele, 1999).

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 (for example, 1 year) and include time costs as well. Lack of medical facilities in developing countries make the problem more complicated. As pointed out by an anonymous referee, lack of medical facilities is also a problem in developed countries. 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 is complicated and because of the time involved is less easy to prove (Pimentel and Greiner, 1997). 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, 1998). Enforcement of laws in LDCs is also often weak for institutional reasons.

As a result of one or more reasons mentioned, farmers become locked into 'unsustainable' agri-

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

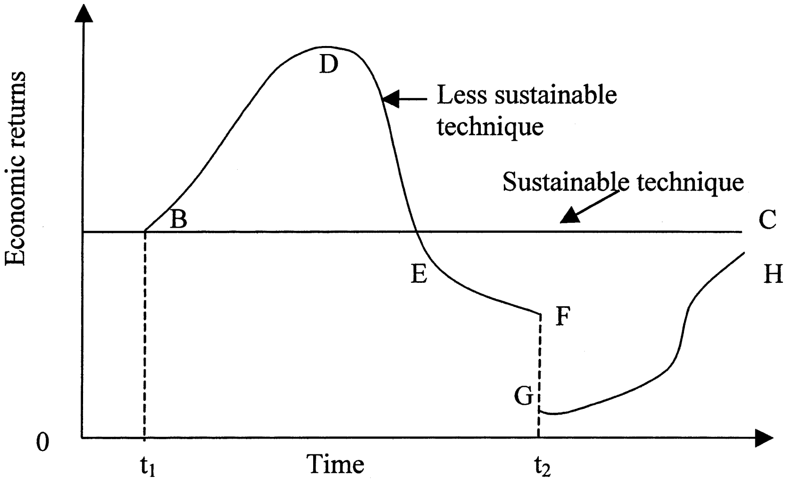

Fig. 3. Producers may become locked into the use of a relatively unsustainable technique such as the less sustainable one indicated here.

cultural 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 Fig. 3.

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 of the traditional technique, but may 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) points out, reversion 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) demonstrates, when chemical agricultural systems are adopted, agricultural yields or returns become 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 ‘inclined towards’ such systems once they are adopted despite being unsustainable (Tisdell, 1991, 1993). Cowan and Gunby (1996), too, point out that once a pest control strategy is adopted, then it becomes the dominant strategy as 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, and 58% were devoted to testing pesticides. By 1947 these proportions were 17 and 76%, respectively' (Cowan and Gunby, 1996, 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 (Cowan and Gunby, 1996, 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), 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) 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). According to Food and Agricultural Organization of the United Nations (1999) data, in many countries (for example, Sri Lanka, India, China, Austria, Italy) the use of pesticides per hectare has increased during the last decade. However, some countries have made the commitment to disentangle from the 'pesticide trap', but this, has involved a large economic cost and a political commitment. Some of the countries that have reduced pesticide use are Indonesia, Sweden, Norway, Denmark, Netherlands and Guatemala.[6] These countries have recently decreased their annual pesticide use by 33–75% without diminishing crop yields (Edland, 1997; Pettersson, 1997; Pimentel, 1997). The province of Ontario and New York State, too, have reduced pesticide use (Pimentel, 1997). The economic costs, however, have been large. For instance, Indonesia in the late 1980s invested as much as $1 million US dollars a year in ecological/biological research, followed by extension programmes to train farmers to conserve natural predators of pests. Sweden and other countries mentioned above reduced pesticide use due to socio-political reasons (Pettersson, 1997). One of the countries that has shown remarkable success with biological pest control and low pesticide use is Indonesia where yields have increased by 12% in recent times (Pimentel, 1997). Another factor that is partly responsible for the decline in pesticide use is the introduction of pyrethroids which uses only a fraction of the organochlorines and organophosphate compounds (Szmedra, 1991). For example, the substitution of pyrethroid group pesticides for older insecticides has resulted in cotton insecticides in the USA falling from about 5–6 lbs per acre prior to 1997 to around 1.6 lbs after 1977 (Szmedra, 1991). It should be mentioned here that the official reductions of pesticide use in developing countries should be interpreted with caution. This is because as the WRI (1998) notes, that there is an illegal trade and use of banned pesticides in these countries where such data are rarely accurately recorded.

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 to pesticides. The manner in which pesticides reduce pest infestations and how chemical control creates a disequilibrum 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

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[6] An anonymous referee points out that in the case of Guatemala most of the reduction in pesticides has been brought about by externally imposed structural adjustment

also high. The private costs to farmers from exposure to pesticides in Sri Lanka, for instance, were shown to be high using three valuation approaches. It was then demonstrated why farmers continue to use pesticides and in most countries 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.

Acknowledgements

We wish to thank the editor of Ecological Economics and the anonymous referees for their useful comments.

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