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Agriculture and the environment: an economic perspective with implications for nutrition[1]

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Abstract

Agricultural production has harmed environmental quality primarily because of inadequately designed policies and natural resource projects. Hence, most of the harmful side effects of agriculture can be reduced or eliminated by replacing these ‘bad’ institutions with policies and projects that create financial (dis)incentives for (un)desirable behavior. Provided appropriate policies are followed, environmental constraints should not keep people from meeting nutritional standards that emphasize more fruits, vegetables, and fish. Nutritional well-being can be achieved with policies and projects that give people sufficient access to food that has been produced with methods that minimize adverse impacts on the environment. © 1999 Elsevier Science Ltd. All rights reserved.

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Adverse health effects of pesticides, contamination of groundwater by agricultural chemicals, soil erosion and siltation, diversion of water from aquatic organisms to crops, and loss of forests, ranges, or wetlands to crop land contribute to the perception that agricultural production intrinsically conflicts with environmental quality. However, diversion of water, land, and other biophysical resources would have been

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greater if not for yield-improving technologies and resource management institutions that accompanied economic and demographic growth. Moreover, while agricultural production can generate environmentally harmful byproducts, some of the negative impacts are the result of 'bad' policies and projects not technologies. Furthermore, some modern technologies that depend heavily on biological knowledge and information science can reduce harmful impacts or enhance both agricultural productivity and environmental quality. Hence, agricultural production does not necessarily have to harm environmental quality and can supply consumers with sufficient amounts of nutritionally adequate food. Food prices might increase, however, because environmental protection is often costly. To meet minimum nutritional standards, people need sufficient access to food through some combination of their own personal income, welfare payments, food stamps, and community food banks.

The purpose of this paper is to provide an economic perspective on the relationship between agriculture and the environment and some institutions—property rights, regulations, taxes, and subsidies—that can effectively manage conflicts between the two. The next section presents an economic framework to analyze this relationship. The role of policies and projects in US agricultural production and their impact on the environment are discussed in the third section. The fourth section pertains to controlling environmental damages of agricultural production. Subsections address specific requirements of this control: determining the 'right' level of environmental quality, innovations in technologies, innovations in regulations and property rights, and research, education, and product development. Challenges of six current trends in agriculture for managing associated environmental impacts are discussed in the fifth section. Implications of our analysis for the question of whether adequate nutrition and environmental protection are compatible policy goals and for modification of agricultural production to achieve both goals are discussed in the penultimate section. Our analysis and its policy implications are summarized in the conclusion.

A conceptual framework

Numerous biophysical and socioeconomic forces affect the relationship between agriculture and the environment (Fig. 1). The willingness and ability of consumers to pay for, or demand, food and fiber is one of the two major determinants of the pattern and magnitude of agricultural production. As population grows, the demand for agricultural products increases. As income grows, the demand for food and fiber also increases but the increase is less than proportional to income growth. Hence, agricultural products are considered 'necessities'. The demand for environmental amenities also increases with population growth. However, in contrast to food and fiber, environmental amenities are considered 'luxuries'. That is, the demand for these environmental amenities grows more than proportionally with the growth of income. At high-income levels, consumption per capita of these amenities continues to grow whereas consumption per capita of food and fiber becomes stable.

Producer willingness and capacity to supply food is the second major determinant

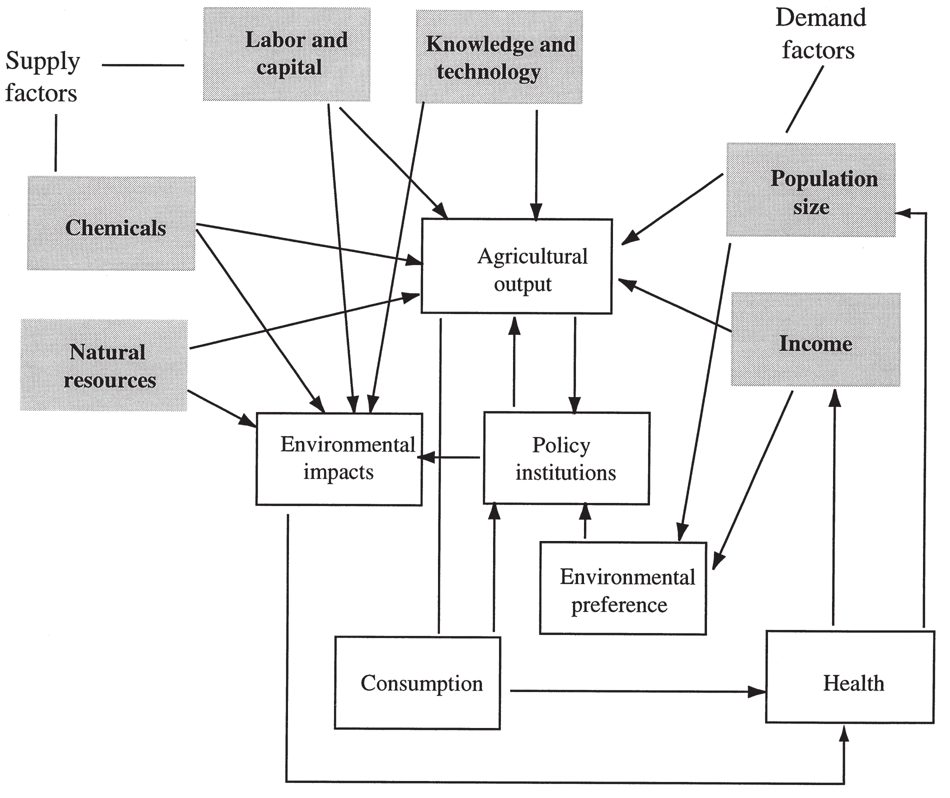

Fig. 1. Factors affecting agriculture and the environment.

of the pattern and magnitude of production. Agricultural producers seek higher and more stable profits. They tend to increase production in response to increases in crop prices, decreases in costs of labor, agricultural chemicals, and plant materials, or increases in the quality of these inputs. Prices of many agricultural commodities and inputs are determined by interregional and international transactions in markets. Commodity programs that support crop prices, taxes that increase costs of pesticides, and marketing cooperatives are examples of institutions other than markets that affect agricultural production. Biophysical endowments affect yields, cropping patterns, cropping frequency, land improvements, and technology adoption (Pingali et al., 1987; Caswell and Zilberman, 1985; Ruthenberg, 1980). These endowments include water, space, soil characteristics, climatic conditions, and the diversity of biological organisms and their underlying gene pools. Supply also increases with more human-made physical capital, such as farm machinery, water conveyances, and infrastructure for transporting, storing, or processing agricultural products. Finally, more technical information and expertise increase agricultural productivity (Schultz, 1975). Indeed, generation and dissemination of technical know-how through research and extension are critical means of increasing agricultural productivity and improving environmental management.

Suppliers and demanders interact through markets to determine the quantities and prices of agricultural outputs and inputs. Agricultural production and input use patterns can affect the environment through two mechanisms: (1) depletion or modification of on-site natural resources and (2) off-site movement of polluting materials, e.g. runoff of soil, nitrates, or pesticides. These impacts depend on local biophysical endowments (Fig. 1). Some impacts of agriculture on the environment take time to reach critical thresholds. In a given ecosystem, if cropping patterns and production techniques remain constant, increases in production, cropping frequency, and input use are likely to exacerbate any negative environmental impacts that had occurred previously. However, choices of crops and technologies do not remain constant as prices change. For example, increases in crop prices or land costs stimulate the development and adoption of improved crop varieties that increase yields and, thereby, enable more preservation of natural resources for nonagricultural uses. Similarly, increases in the prices of agricultural chemicals or runoff penalties induce farmers not only to use less and increase their efforts to prevent runoff but also to invent or adopt technologies that enable more precise application of these chemicals and, thereby, reductions in use and associated runoff. Payments by recreational organizations and farmers' desires to create goodwill have induced them to leave crop residues in their fields to support larger wildlife populations. Thus, agricultural production can have positive environmental impacts and technologies that improve productivity also have the potential to improve some indicators of environmental quality.

Past trends in the United States: policies and development projects

Agricultural production has affected and been affected by the environment since humans began crop cultivation. In the last 150 years, policies and projects of the US government, in addition to population growth, have been the chief determinants of the evolution of agriculture and, thus, its impact on the environment.

Natural resource and agricultural policies

In the 19th century, the US government aimed to speed settlement and economic development by granting private rights over natural resources. For example, the federal government passed the Homestead Act, which gave individuals ownership rights to public land in the West as long as they settled it. Similar arrangements created water rights. The prior appropriation doctrine established queues for rights to divert water from lakes, rivers, and other aquatic bodies. The queues operated according to the principles of 'use it or lose it' and 'first-come, first-served'. Private companies developed many canals and water conveyances. Railroad companies acquired lands adjoining their tracks under this doctrine. The General Mining Law enacted in 1872 permitted mining companies to extract hardrock minerals from Federal land and not pay the government any significant fees for the privilege (CEA, 1997, pp. 217–220).

Government sale of land rather than taxation was used as a major vehicle to finance land-grant universities and schools.

The same policies that created private rights of people to use certain natural resources for certain purposes ignored other beneficial uses and other resources entirely. The result was an incomplete specification of rights for some resources and unrestricted, or open, access to others. For example, water rights in the West were and, in many cases, still are incomplete. Under the prior appropriation system, rights to diverted water are maintained as long as the water is used for beneficial uses. However, environmental amenities are not necessarily considered beneficial uses. The American bison in the last century exemplify a resource to which access was unrestricted. Bison and other wildlife are renewable resources provided that habitat is sufficiently large and hunting is controlled. However, since there were no restrictions on hunting, individual hunters treated the bison as an open-access resource. If they did not shoot the animal, someone else would. This myopic thinking, motivated by the lack of hunting restrictions, led to almost complete decimation of the American bison in the 1870s.

By the end of the 19th century, the United States had become the major agricultural producer in the world because of cropland expansion. Farm acreage reached its peak during the early 1920s. Yields per acre during the 19th century did not expand much (Cochrane, 1993). Consistent with the theory of induced innovation (e.g. Hayami and Ruttan, 1985; Hicks, 1932), people developed the steel plow, various types of harvesters, and other labor-saving farm machinery because labor was scarce relative to land.

As most of the arable land in the United States became utilized, policies aimed at increasing agricultural production became focused on increasing yields through use of improved crop varieties and synthetic chemicals, namely fertilizers and pesticides. The Hatch Experiment Station Act of 1887 created and provided annual funding for agricultural experiment stations in land-grant colleges in all of the states (Scheuring, 1988). The Smith-Lever Act of 1914 provided funds for cooperative administration of agricultural extension by the United States Department of Agriculture and land-grant colleges for the twin purposes of increasing farm productivity and improving rural life (Scheuring, 1988). Research and product development led to dramatic growth in yields, particularly after World War II (e.g. Antle and McGuckin, 1993, pp. 177–178).

Public support of research and extension to improve yields made economic sense because the information and techniques created were ‘public’ goods. People made use of the basic knowledge and could not exclude others from also using it. But the yield-improving technologies contributed to faster growth of agricultural supplies relative to demands. Agricultural prices fell. Low commodity prices created bankruptcies. Labor-saving mechanization led to a decrease in the demand for labor. Farmers and farm workers left rural areas for cities. The tremendous success in improving agricultural production also created the moral and political reasons for government support of farm income. Hence, agricultural policies in the United States, as well as other developed countries, have also aimed to increase incomes of agricultural producers. Some policies support agricultural prices by requiring farmers to remove land from production.

Although set-asides can enhance environmental quality, some of the older yield-improving technologies had negative environmental impacts, which were mostly ignored until catastrophes occurred, such as the dust bowls of the 1930s. However, the dust bowl experiences led policymakers to enact soil protection mechanisms as parts of the agricultural commodity programs. In general, adverse environmental impacts, greater knowledge and concern about ecosystems (e.g. Carson, 1962), and political action have led to greater regulation of agricultural production. US commodity programs, especially since 1985, have had major environmental components.

Natural resource projects

Government projects to build and maintain physical infrastructure that enabled more control and use of natural resources for agricultural production have been the other major reason why this production conflicted with environmental quality in the past. The introduction of income taxes and the drastic expansion of the tax base in the United States at the start of the 20th century enabled the government to take a more prominent role in financing resource infrastructure. Two agencies, the Army Corps of Engineers and the Bureau of Reclamation, were established. They were responsible for flood protection, dam building, increased conveyance facilities, and provision of water for agricultural irrigation. Although the projects expanded the productive capacity to meet growing demands for food and fiber, they substantially modified the environment. Forests or prairies were converted for crop cultivation or grazing, water was diverted from rivers and streams for irrigation, and rivers and other navigable waters were altered to reduce transportation costs.

The key economic principle in project assessment should be whether social benefits exceed social costs. Social benefits (costs) consist of market, environmental, and other non-market benefits (costs). Since benefits and costs occur over a long period of time, they have to be discounted. Choosing an appropriate discount rate can influence the assessed desirability of projects (e.g. Tietenberg, 1996, p. 82). Developing techniques to assess market and non-market costs and benefits is not only difficult but also the subject of on-going policy debate and research (e.g. Mitchell and Carson, 1987). Nonetheless, project assessment techniques have improved over time and have been used to give reasonable appraisals of ex ante and ex post project performance. Empirical evidence indicates that too many resource development projects adversely affected the environment (e.g. Reisner, 1986), and some did not even create an excess of discounted market benefits over costs (Tietenberg, 1996, p. 82). This excessive investment occurred for several reasons:

1. *Public investment decisions were political*. Development projects were determined for political reasons, even though the market benefits of the products were below the project costs. The number of new water projects in the United States has declined significantly because major resource agencies in the mid-1970s began requiring that proposed projects pass cost–benefit tests (USWRC, 1983).

2. *Environmental impacts of projects were not given sufficient weight in project design.* Until the 1950s, environmental benefits and costs of resource projects were not considered. By the mid-1970s, many government agencies had to account for environmental impacts of resource projects. The agencies now have to treat environmental amenities associated with resources as beneficial uses. For example, the Central Valley Improvement Act of 1991 recognizes environmentally beneficial uses of water.
3. *Structural solutions to resource problems have been emphasized*. Resource projects have often been initiated in response to perceived problems, such as water scarcity. The solutions are usually structural and engineering-based, which involve investment and modification of the landscape. But perceived scarcities sometimes occur because property rights to resources are inadequately specified or government policies actually discourage resource conservation. In general, non-structural solutions, such as financial incentives, institutions, and operational procedures, have received insufficient attention. For example, drainage taxes can lead to adoption of water conservation technologies and reduce the perceived need for drainage canals. Tradable water rights could also lead to a reduction in perceived scarcity. Finally, operational procedures that emphasize water temperature at biologically critical times can be as important as additional supply from conveyances.
4. *Evaluation procedures have been misused*. Public and private agencies that analyze benefits and costs of development projects might have recommended extra investment because they made one or both of two common methodological errors. First, agencies might have used support prices, which include subsidies, to measure marginal social value of commodities. But commodity prices that are artificially high because of price-support programs do not represent the value of incremental units of the commodities to society. Using the support price to value output can make a project seem economically worthwhile while correct analysis shows that an increase in supply due to the project has a negative social value (Lichtenberg and Zilberman, 1986). Second, agencies might have assumed that present technology and economic conditions would not change during the length of the project. Yet, technologies, prices, household income, and environmental attitudes have changed. If these changes had been considered, market benefits of projects could have decreased while environmental costs could have increased. For example, modern irrigation technologies have reduced the value of some of the water diverted for agricultural production and greater awareness and recreational use have increased the environmental benefits of water. If lower values of diverted water and higher values of water for environmental amenities had been considered, some of the investments would not have been justified and the need for some environmental restoration would not exist.

Controlling damages from agricultural production

Reducing negative environmental impacts of agricultural production has been partially successful. Analyses of the economic reasons for pollution and other negative side effects (e.g. Zilberman and Marra, 1993) suggest that most of these problems usually reflect bad policies or projects and not inherently damaging modern technologies or anti-environmental attitudes of farmers. That is, agricultural pollution reflects 'market failure'. Polluting residues are byproducts that have no market value. Producers are not taxed for discharging the byproducts nor are they paid to reduce them. Use of production techniques depends on their contribution to profits and is affected by financial incentives. Some technologies are more environmentally friendly than others.

Balancing the incremental benefits and costs should be the key principle in designing policies controlling the environmental side effects of agricultural productivity. Benefit and cost estimates should consider cost of implementation and transaction imposed by the policies. The design of the policies should also recognize the need to have policies that are easy to monitor and enforce. Policies should encourage use of more benign technologies. Cost–benefit calculations associated with policy design should take a long-term perspective. The design of the policies should balance the tendency to change policy regulations as new knowledge is acquired with the high cost of adjustment that policy changes induce and the benefits that farmers and consumers obtain from a stable regulatory environment.

Determining the 'right' amount of environmental damage

In most cases, it does not make economic sense to eliminate pollutants completely. That is, the cost of eliminating a minuscule level of contaminants may well exceed the benefits. As a rule, the 'right' amount of damage occurs when the incremental social costs of eliminating damage from an additional unit of pollution equals the social benefits of doing so. Implementation of this decision rule, however, is an extremely difficult task for at least two reasons.

First, the environmental risk-generation process is not known with certainty. The transition from agricultural activity to environmental damage has several stages—transport and fate of applied agricultural inputs, exposure of vulnerable species, the dose response, and damage. Measuring and modeling this whole process is difficult because of randomness in weather or other biophysical aspects of local ecosystems, heterogeneity in the response of different organisms in different locations, and incomplete scientific knowledge. As a result, estimation of physical damage is also difficult and subject to high degree of statistical variability.

Second, comparing the benefits of reducing environmental damages to the costs of associated policies is difficult. Monetizing these benefits and costs provides a consistent basis of comparison. Environmental amenities are not market goods. Hence, there are no prices for these amenities that could be used to directly estimate their value to society. However, there are techniques that indirectly infer values of environmental amenities by related behavior. The value of clean water at a beach can be inferred by the number of people who will travel to this beach instead of other beaches. Values of marketed properties that are similar in all aspects except an environmental attribute (e.g. air or water quality) may be an indicator of the values of this specific amenity. This type of inference is limited in its application.

Contingent valuation is a stated, as opposed to revealed, preference technique to assess environmental amenities. Researchers interview people to elicit their willingness to pay for preserving environmental amenities or for increased safety. Reliability of this and other techniques to value non-marketed goods is the subject of an ongoing debate (Diamond and Hausman, 1994; Hanemann, 1994).

The difficulty in assessing benefits of reductions in environmental damages has led the Environmental Protection Agency to establish maximum levels of acceptable pollution or environmental damage and to seek mechanisms to reach these levels at least cost.

Technological innovations

Conservation technologies significantly improve accuracy of input application relative to traditional methods (e.g. Khanna and Zilberman, 1997). Conservation technologies include drip and sprinkler irrigation, high precision pesticide applicators, integrated pest management, and 'precision technologies', which rely on modern communication and sensing equipment to modify input application according to spatial variability. Since the crop utilizes a higher percentage of the input applied with a conservation technology, a lower percentage of the input ends up as environmentally damaging residue. For example, irrigation efficiency of 60% is quite common for gravitational technologies. Thus, 40% of the water ends up as runoff or deep percolating water and may carry chemicals and cause water logging and environmental contamination. In contrast, irrigation efficiency may reach 95% for drip irrigation. Similarly, aerial spraying of pesticides has an accuracy level between 25 and 50%. Thus, 50–75% of the sprayed chemical does not reach its target level and is a source of environmental damage. Ground-level application has an efficiency of 75% or more. Adoption of these technologies will increase yields and, under some conditions, also reduce input use and pollution per unit area (Khanna and Zilberman, 1997, p. 33). But these new technologies require investment in capital or labor. Penalizing pollution or use of polluting inputs provides additional incentives for adopting these conservation technologies.

Innovations in regulations and property rights

Effective policies need to be 'incentive compatible', or take account of the decision-making process that guides farmer behavior. The Endangered Species Act exemplifies a policy that ignores farmer decision-making and sometimes creates perverse outcomes as a result. If farmers are penalized whenever an endangered species is discovered on their land, they have an incentive to destroy the species. Thus, the policy may increase rather than reduce the endangerment of important species.

Because farmers seek higher or more stable profit, financial incentives represent an important approach for modifying farmer behavior to achieve environmental goals. Financial incentives for pollution reduction are either carrots or sticks. They often provide farmers more flexibility than direct controls do and, thereby, enable compliance at lower total costs. Consistent with the principle, 'the polluter pays,' pollution taxes are behavioral sticks. Farmers resist government's use of pollution taxes, however, because they pay the taxes and the revenues are not necessarily used within the agricultural sector. Farmers favor subsidies for pollution reduction because they receive government revenues for each unit of pollution that they reduce below an initial level. In the short run the impact of the same level of tax or subsidy is likely to be the same. In the long run, however, taxes may lead to reduction in industry size and subsidies may result in more production, expansion of the industry, and new pollution problems.

Of course, existing policies might also create financial incentives for depletion or pollution of natural resources. For example, subsidization of water or energy for irrigation leads to over-irrigation and under-adoption of conservation practices. Policies that reduce subsidization and raise prices to be commensurate with their full cost will reduce the need for new water projects.

The use of tradable pollution permits has recently become more popular. The government establishes a regional target level of pollution. Each producer receives a quota of the permits, often in proportion to its existing level of pollution, and has the right to trade these permits. In theory, the price of a permit is equal to the pollution tax or subsidy rate required to achieve that regional target level of pollution. Unlike the case of taxes, the revenues generated by the pollution permits are distributed among farmers. In general, tradable permits allow producers with lower costs of pollution abatement to reduce their pollution proportionally more than others and sell their permits to higher cost abaters. Producers with higher costs of pollution abatement buy permits and do not reduce their pollution more than the average amount of reduction.

Lack of trading of water rights has helped create a perception of water scarcity in many US regions. Individuals who cannot trade water and lose their rights to it if they do not use their entire allotment do not have an incentive to invest in water conservation. Theoretical analyses indicate that farmers who can trade water will adopt modern irrigation technologies—sprinkler, drip, and a shorter, more efficient use of gravitational technologies—that will save water and increase yields (Shah et al., 1993). Introduction of water trading may also require some investment in infrastructure, but this investment will allow for more efficient use of existing resources and may prevent the need for further expansion of water diversion projects (Chakravorty et al., 1995, p. 38).

Implementation of policies such as taxes or tradable pollution permits requires monitoring of pollution residues generated by individual producers. But the monitoring task is a technological challenge. Most agricultural pollution problems are 'non-point source' problems in which aggregate pollution is observed but attribution to individual sources is very difficult. Proposed solutions to nonpoint source problems include the following:

Assign collective responsibility for attaining regional environmental target levels

Producers who are responsible for generating non-point source pollution typically share the same basin, are in close proximity, and can monitor each others' activities (Segerson, 1988). In many situations there are regional ambient quality targets, for example, water quality targets for a lake that is polluted by waste materials from farming activities. Under Segerson's proposal, each producer is penalized in the amount equal to the damage whenever the ambient quality target is violated. As a result, individual producers have the 'right' incentive to control their own emissions and to develop a system of regional self-governance that monitors and enforces pollution protection activities by other producers so that aggregate compliance cost will be reduced. Although the assumptions of Segerson's analysis might not hold in some situations and impose Draconian costs when regional target levels are violated, the principle of assigning responsibility for a shared pollution problem is sound and has been applied in several instances.

Randomly punish violation of regional target levels of environmental quality

This variant of Segerson's approach is that whenever violation of aggregate target levels occurs, a certain percentage of the producers will be randomly selected and heavily penalized. This approach is politically infeasible and, some would argue, morally unacceptable. This approach can be modified. Instead of automatically imposing severe punishments on individuals who are randomly drawn from the population, regulators scrutinize the activity of randomly selected producers. Thus, heavy penalties will be imposed only when evidence indicates generation of excessive pollution.

Use financial incentives based on observed activities in specific locations

When the relationships between pollution generation and observed activities—production, input use, technology choice—are known, pollution problems can be corrected by providing financial incentives based on those observed activities. For example, when pollution is the result of input residues, regional environmental quality target levels can be achieved at least cost by taxing input use rather than pollution (Khanna and Zilberman, 1997). But in order to be equivalent to the least cost pollution tax policy, input taxes must vary according to technological choice and environmental conditions. The amount of a tax on applied water that can cause waterlogging problems should vary with the irrigation technology used and soil quality. If water is applied with drip on heavy soil, taxation may be minimal. However, on water that is applied with gravitational technology on sandy soil, the taxation might need to be quite high.

Policies that discriminate by locations—for instance, product taxation rather than bans that leads to pesticide use in areas where it is most advantageous or introduction of markets for the right to apply a small volume of chemicals—can reduce environmental damages at relatively low cost. The reason is that situations exist in which a small percentage of an applied input can generate most of the economic benefits (e.g. Sunding et al., 1997). Implementation of a location-specific tax on input use might be difficult, however. A uniform tax on input use would be easier and more practical. Sales taxes on output produced or input taxes on applied water, pesticides, or fertilizers are uniform taxes because the tax rate does not vary across farmers. Alternatively, one can introduce tradable permits for rights to use inputs such as fertilizers and pesticides. A uniform input tax policy is appealing when its extra cost relative to the non-uniform input tax is small. In cases where monitoring input use is difficult, the pollution can be regulated by taxing or subsidizing farmers according to technology choice. Application of inputs with conservation technologies should be subsidized while application with technologies that are pollution-intensive should be taxed.

Restrict the right to prescribe and apply environmentally sensitive materials

When environmental impacts of inputs such as pesticides depend on when, where, and how they are applied, their optimal regulation with financial incentives for producers is difficult. An alternative solution is to restrict the right to prescribe and apply chemicals to appropriately trained individuals who will be held liable for mismanagement. This approach has gradually spread in the United States with the proliferation of pesticide and agronomic consultants (Wolf, 1998). Its expansion should be done with caution, since it may be very expensive and involve high transaction costs. However, it will help overcome some of the problems of heterogeneity and variability that make uniform policies ineffective. This approach will also introduce more experimental treatments and methods and establish automated documentation of when and where chemicals and other sensitive environmental treatments are being applied. Thus, increased professionalism and accountability and application of input may lead to increased learning capacity of the pest management system.

Purchase habitat, pay for set asides, and create conservation easements

In some areas, agricultural production adversely affects important habitats or ecosystems. Examples include riparian zones, certain forests, places of great scenic value, and natural prairies that sustain wildlife. Purchases of habitat and payments to remove cropland from production, such as the publicly funded Conservation Reserve Program or the privately funded Nature Conservancy, can be very useful for preserving environmental quality. Babcock et al. (1996) show how developing a rational purchasing strategy, which targets purchasing areas that have the highest rate of environmental benefit gain to agricultural productivity cost, may yield significant increase in environmental quality at relatively modest expense to the public. Private purchasing funds can augment public purchasing funds and signal the willingness to pay for environmental preservation.

Zone certain sensitive areas

When environmental impacts vary across locations and when monitoring of exact activities of farmers is difficult, it may be useful to consider zoning as a way of preventing environmental damages in sensitive locations. Zoning may be very useful in controlling the type of activities that are conducted in riparian zones as well as in the urban fringe. It may be very effective in restricting applications of certain pesticide applications, in banning certain pesticide application practices or certain pesticides near population centers, or restricting the intensity of application of inputs or the choice of crops in riparian areas with erosion problems.

Continuously monitor environmental quality

Many problems of non-point source pollution, such as contamination of lakes or ground water aquifers, are the result of an accumulative process. Continuous monitoring of environmental quality enables early detection of deterioration and problem-solving intervention. Such monitoring also allows time for further research and development of technologies to control and reduce problems. In contrast, failure to regularly monitor can cause late discovery of contamination and may result in immediate and more drastic measures.

Remediate damages from previous projects

Since many environmental problems of today are the result of resource projects of yesterday, one key method of solving these problems is remediation. In some cases, certain aspects of environmental quality can be restored by paying farmers or resource owners to stop production or to divert water from agricultural activities in support of fish and wildlife. In other cases, remediation requires structural measures, such as demolition of certain water diversion facilities, dams, or canals. In all cases, the goal of remediation is improvement of environmental quality but not necessarily complete restoration of the ecosystem(s) that existed prior to any agricultural production. Furthermore, discounted benefits of remediation projects should exceed discounted costs and, given the environmental objectives, these costs should be as low as possible.

Research, education, and product development

Research, education, and product development are necessary for better understanding and control of the environmental side effects of agriculture. For example, research and product development leads to better methods of monitoring, detecting, and measuring environmental damage caused by agriculture. As a result, government officials can develop more effective policies that are based on principles of ‘polluter pays’ and individual accountability. Research and extension on organic agriculture, integrated pest management, and other technologies that are more environmentally benign leads to lower costs and, thus, increases the extent to which farmers use these methods.

Environmental education creates more awareness about the impacts of agricultural production on ecosystems. As a result, consumers are more likely to increase purchases of food that is produced with more environmentally benign methods, e.g. organic produce. Also, farmers might change their agricultural practices, especially if modification significantly improves environmental quality and is not very costly. Education about rural life, agricultural practices, environmental risk-generating processes, and risk assessment can improve the quality of the debate between citizens and policymakers, both of whom are often uninformed on these issues.

Current trends and implications for managing environmental impacts

Higher incomes and greater appreciation of ecosystems imply that people's environmental concerns are likely to play a major role in shaping the future of agriculture and other production activities that involve natural resource husbandry. Six different changes in our economies create new challenges for reducing conflicts between agriculture and the environment in the future.

1. *Globalization of markets and environmental problems*. Less restricted trade will lead to a change in the pattern and an increase in the magnitude of agricultural production in the United States because the country has relative advantage in production of many agricultural commodities, especially grains. Freer trade also provides greater opportunities for the introduction of exotic pests that could lead to higher costs of pest management and even undermine certain comparative advantages in the United States or other countries. Moreover, producers who are unable to compete in international markets could create political instability. In absence of well-informed consumers and effective environmental standards that 'level the playing field', producers and their public representatives in some countries will have strong incentives to lower or ignore environmental regulations for competitive advantage. In other countries, however, producers with sizable market shares have strong incentives to use their adherence to stricter environmental standards as a means to block imports of agricultural commodities produced with less regulation. Harmonization of environmental regulation between nations is likely to become a major theme of research and policy in the coming years.

   In addition to promotion of 'fair' trade, another reason why environmental regulations should apply and be enforced on an international basis is that some of the most important environmental problems—climate change and biodiversity preservation—are global in nature. Both of these problems are affected by deforestation and mismanagement of natural resources in developing countries. Developed nations should help to establish and pay for institutions that create incentives to reduce negative environmental effects of agricultural activities in developing nations because they express more concerns about these problems and have greater incomes. These institutions include policies that subsidize conservation activities and finance preservation of areas with high ecological value in developing countries. Policies should also provide incentives for production intensification of previously deforested land and disincentives for expansion of production onto forests or natural grass lands. Financial and intellectual support in developed countries for technological development and extension that enhance productivity in developing countries will also relieve land pressure and slow deforestation. The technologies to be developed and extended need to be appropriate for local, often tropical, environments.
2. *Consumerism*. Consumer concern for the environment and higher incomes is providing new opportunities for production of goods that are more environmentally benign (e.g. Batie and Ervin, 1998). As their income increases, consumers are able and willing to pay more for higher quality products. Although some of these products entail greater packaging or energy consumption (e.g. pre-cooked food

in packages or at restaurants), some are produced with stronger environmental safeguards (e.g. organic produce). Growth in consumer concern for environmental issues also leads to larger demands for these 'green' products, which also include range-fed chicken or wood from trees that are sustainably managed.

3. *Industrialization*. A growing share of the value added to food production is generated beyond the farm gate by agribusiness firms. These firms exert control over production through vertical integration and contracting, which have become particularly important in the poultry, swine, fruit, and vegetable sectors. Environmental regulation of agriculture will have to adjust. For example, in many contracting situations, farmers are not necessarily the most responsible parties for negative production externalities nor the most able to afford regulatory costs. Research is needed for the design of policies that effectively and fairly assign liabilities for management of livestock waste or other negative externalities in the presence of contracts and vertically integrated firms.
4. *Privatization*. Governments in the United States and other developed countries are reducing their subsidies to agricultural producers and changing patent laws to increase the capacity of private firms to develop genetically altered materials and production technologies for agriculture. Public sector research in agriculture will become more focused on generation of basic knowledge and understanding links between agriculture and the environment. With the process of industrialization and the increase of monopolization in some agricultural industries, the government's role as a regulator of trade practice in agriculture is likely to increase.
5. *Global growth and local decline of population*. Existing and emerging production technologies can supply sufficient food for larger populations in the United States and elsewhere during the next twenty years provided that policies do not exacerbate scarcities and pollution of water and expenditures for agricultural research do not decline (Rosegrant and Ringler, 1997). Population growth itself creates incentives for farmers to intensify production (Templeton and Scherr, 1999). Institutions that create financial incentives and rights for local people to restrict access to encroachers or poachers are needed, however, to keep a growing number of agricultural producers from converting critical habitats into new agricultural land. Policies are also needed in numerous local areas where population or allocated labor time is declining—e.g. forests in Switzerland, middle hills in Nepal, and some mountainous areas in Africa—to create incentives for people to disintensify production in ways that also do not create negative environmental impacts.
6. *Expanded farming activities*. Intensive cultivation of fish and trees, aquaculture and silviculture, are newer activities than agriculture. As natural fisheries and forests become more depleted or regulated, aquaculture and silviculture become economically more important. Policy-motivated expansion of these activities can help to 'solve' the problems of overfishing and deforestation (e.g. Jeffreys, 1995, pp. 325–328; Sedjo, 1995, pp. 177–209). As with most agricultural technologies, commercial silvicultural and aquacultural technologies have been focused on monocultures and can also create environmental problems. Research is needed to increase the productivity of these technologies and reduce their environmental

side effects. Although greater market integration leads to greater specialization of productive activities, greater understanding of production ecosystems and, in particular, the complementarities between crops and other organisms creates the informational basis for commercial farmers to manage more complex, multi-crop production systems.

Implications for nutritional well-being

Although producers can supply enough food for people in the present or near future, some agricultural activities, e.g. indiscriminate pesticide use or elimination of genetic diversity of crops, can reduce food safety. Hence policies that address some of the environmentally harmful activities of agriculture are also likely to improve food safety. However, other policies to reduce pesticide use and, more generally, to improve environmental quality, e.g. tighter regulation of fertilizer use, can reduce nutritional well-being. These policies can lead to reductions in supplies and, consequently, increases in prices of food because environmental protection is costly. For example, Zilberman et al. (1991) estimated that a ban on food-use pesticides in California could have increased prices of five fruits and vegetables by 28% on average. Unless they receive income supplements, food stamps, or other secure means of access to food, poor people might reduce their consumption below recommended levels because of higher food prices. Both environmental quality and food safety are likely to improve, however, with the further development of agricultural production technologies that are environmental benign.

Environmental regulations and biophysical conditions of agroecosystems are not likely to constrain a transition of agricultural production to patterns that are more consistent with the dietary guidelines of McNamara et al. (1999). They recommend a shift in consumption from meats to grains and an increase in consumption of fruits, vegetables, and fish. Total area used for agricultural production is likely to decline because livestock are relatively inefficient converters of grain into protein. This reduction in agricultural area could free up natural resources for environmental recreation and preservation. Area used specifically for production of fruit and vegetables will increase, however, particularly in regions well suited for their cultivation. Supplies of irrigated land are not likely to constrain this potential shift, however. For example, less than 40% of irrigated land in California is used for production of fruits and vegetables. Similarly, water of the Central Arizona Project that has been used to grow low-value crops could be used for the production of fruits and vegetables. Consumer demand for these products will determine the extent of change in the allocation of irrigated land.

Production of fruits and vegetables is more pesticide intensive than grain production. Hence, if McNamara et al.'s recommendations become reality, total application of pesticidal active ingredients might increase in certain regions given current pesticide products and application technologies. Regional economic models and monitoring are needed to determine the conditions under which more active ingredients applied become more pollution. However, stricter pesticide regulations, growing use of precision technologies, and development of pesticides with less-toxic active ingredients reduce any potential impacts of pesticide use associated with increases in area devoted to production of fruits and vegetables in certain regions.

The recommended dietary increase in fish consumption could have substantial environmental impacts unless complementary environmental policies are also used. Many fisheries around the world are declining, and the sustainability of some is threatened (e.g. McGinn, 1998). Overfishing occurs in part because access to most fisheries is relatively unrestricted. Restricting and, in some cases, closing access are major policy challenges. If successful, these innovations in property rights will lead to at least a temporary reduction in catch. Thus, aquacultural production of some fish species, e.g. Pacific salmon or catfish (e.g. Tietenberg, 1996, pp. 282–284) may be necessary to supply the extra fish that are recommended for better diets. Expected gains in productivity are higher on fish than traditional crop farms since aquaculture is in a earlier stage of development than agriculture. As with fruits and vegetables, the major constraint for its expansion is consumer demand. Aquaculture is not a panacea, however, because without proper regulation, it too can adversely impact aquatic ecosystems.

Conclusion

Agricultural production has harmed environmental quality primarily because of inadequately designed policies and natural resource projects. Although agricultural producers appreciate environmental quality, they primarily pursue profit. Policies that recognize this fundamental pursuit can induce farmers to modify their behavior in ways that will improve environmental quality. Taxes of pollution or polluting activities, subsidies for environmentally-enhancing activities, and marketable pollution permits, should be emphasized over command-and-control regulation. Subsidies for input use, e.g. water, or production of specific crops should be reduced if the inputs or crops are environmentally harmful. In general, financial incentives can enable society to have the 'right' amount of pollution and, at least, to achieve environmental objectives at minimum cost. Since physical and economic damages of pollution are not known with certainty and change over time, officials should periodically reassess environmental policies.

Institutional innovations that better specify and restrict rights to natural resources are another important way to improve agricultural productivity while simultaneously sustaining or even improving environmental quality. These innovations include establishment of well-specified and restricted property rights in water, zoning laws or private ownership with conservation easements on certain critical habitats, government ownership of critical habitats, and creation of regional agencies for management of resources for which individual rights are difficult to assign, such as ground water, aquifers, and pest resistance.

Innovations in the procedures that public officials use to assess natural resource projects is a third important way to reduce conflicts between environmental quality and agricultural production. Assessments of new resource development projects should account for environmental costs and benefits in addition to market costs and benefits, use correct prices to assess benefits and costs, and incorporate expectations about changes in technology and preferences.

Public sector support for agricultural research and extension is critical if institutional and technological innovations that reduce environmental impacts of agriculture are to continue. Research should emphasize better understanding of the environmental impacts of agriculture and improved technologies to monitor these impacts. Education should aim to increase scientifically based environmental awareness, economic literacy, and an understanding of the tradeoffs between agricultural productivity and environmental quality among policymakers and the general public.

Environmental protection can be compatible with nutritional well-being. But the policy experience of reducing environmental damages of agriculture highlights the challenge of using policies to modify behavior for achieving nutritional goals. Understanding the economic reasons for patterns of food consumption and production, designing financial incentives, and developing educational programs are major tools for achieving these laudable goals.

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