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Integration of Agricultural and Environmental Policies

HARMONIZING AGRICULTURAL AND ENVIRONMENTAL POLICIES

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ABSTRACT

I discuss three general lessons drawn from economic theory and historical experience for improving the performance of agriculture with respect to environmental protection and resource conservation. First, government development of environment-friendly, resource-conserving technologies and government investment in improvements in human capital are critical for making it feasible to reconcile agricultural productivity with environmental quality. Second, because new technologies evoke responses that are difficult to anticipate, it is essential to maintain proper incentives for environmental protection and resource conservation (e.g., taxes on the use of polluting inputs, setting prices of resources at their social opportunity costs, establishing clear property rights). Third, agriculture sector policies like price supports, input subsidies, limitations on imports, and settlement

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promotion policies are important causes of environmental and resource degradation in many countries; thus, agriculture sector policy reform is necessary to improve environmental protection and resource conservation in agriculture.

I. Introduction

Forty years ago, increasing agricultural output was the principal goal of agricultural policies worldwide. Today, protecting environmental quality and the natural resource base of agriculture is supplanting it as the primary concern throughout much of the world. In many respects, that shift in emphasis is an indicator as well as a product of success. The intensification of agriculture has enhanced productivity sufficiently that the growth of food production has outstripped population growth, at least in those parts of the world spared the devastation of war. But the means through which that intensification has been achieved mechanization, expansion of irrigation, crop breeding, and the use of synthetic chemicals have created new problems of environmental degradation. Pesticide and fertilizer runoff has polluted surface waters. Leaching of those chemicals has contaminated ground waters. Illness and injury from exposure to pesticides during application, in drinking water, and from misuse of containers have become significant health problems in many developing countries. Expanded irrigation has depleted ground water stocks and surface water flows, drying up rivers, lakes, and wetlands and wreaking havoc on fisheries, transportation, downstream farming, and other industries using those water bodies.

The emergence of these problems calls for a reorientation of policies aimed at the agricultural sector. Increases in productivity are still needed; food is still too expensive and malnutrition still too common in many parts of the world. But productivity gains are no longer enough by themselves. If humanity is to be able to maintain progress in agriculture, policies for the agricultural sector must promote conservation of agriculture's resource base and protection of environmental quality.

Economic theory and historical experience with different policy approaches in developed and developing countries suggest three general lessons for designing policies appropriate for reconciling agricultural productivity and environmental quality goals:

1. Human capital development is essential for making it feasible to improve environmental protection and resource conservation in agriculture. The public sector necessarily plays a central role in such human capital development.
2. New technologies evoke responses that are difficult to anticipate. It is thus essential to maintain proper incentives (e.g., taxes on the use of polluting inputs, setting prices of resources at their social opportunity costs, establishing clear property rights) in order to ensure that anticipated improvements in environmental protection and resource conservation from the introduction of new technologies are actually achieved.
3. Agriculture policies like price supports, input subsidies, and limitations on imports are important causes of environmental and resource degradation in many countries, implying that agriculture sector policy reform is necessary to improve environmental protection and resource conservation in agriculture. More broadly, it is imperative to integrate environmental protection and resource conservation into agriculture sector policies.

In what follows, I discuss how these general lessons arise from the characteristic features of agriculture and explore their implications for policy in more detail.

II. Complexity, Human Capital, and Agricultural R&D

It is well known that investment in human capital is central to economic development generally. This is especially true for agriculture, whose complexity, dependence on random factors like weather, and sensitivity to local environmental conditions place a premium on sophisticated management.

1. Agriculture as Ecosystem Management

To begin, it is important to understand that agriculture is, fundamentally, a form of ecosystem management. A field sown with crop plants is an ecological community made up of many types of living organisms subsisting on an environment that consists of a natural resource base plus artificially provided enhancements to that resource base. Farming is a set of activities that seeks to influence the composition of that community in order to increase output of beneficial ecosystem services (crop and livestock yields, fish and game) and decrease output of detrimental ecosystem services (weeds, insect pests, pathogens) by manipulating the environment to favor the beneficial services and create difficulties for the unfavorable ones.

Manipulation of the environment to promote crop and livestock production can yield other ecosystem services as joint products or byproducts. Fields and pastures can provide habitat for fish and game that farmers harvest for food. In many parts of the U.S., farmers rent out their fields after harvest to migratory waterfowl hunters, producing recreation jointly with crops. Maintenance of scenic amenities and wildlife habitat is often an ancillary product of farming. (See Lichtenberg (2002) for a formal economic treatment of these issues).

Historically, human ability to alter the composition of crop ecosystems was limited, so farmers were more heavily dependent on natural factors like rain, soil fertility, soil texture, and beneficial organisms. Stewardship of these natural resources was essential to maintaining farm productivity. Preservation of wildlife habitat was essential for maintaining the ability to harvest fish and game, which were important components of human diets. Most people were farmers or members of rural communities whose income derived from farming. Overall, then, natural factors played a much greater role in determining human standards of living than they do today.

Technical progress has lowered the value of many of the traditional goods and services provided by natural environments.

New agricultural technologies have lessened farmers' dependence on soils and natural pest controls and thus farmers' incentives to conserve them. Improvements in livestock breeding and rearing techniques have lessened dependence on natural environments for meat and fish and therefore incentives to conserve wildlife habitat.

At the same time, technical progress has transformed the fundamental economic character of other environmental services. Environmental resources like nutrient absorption capacity and water that were once abundant enough to be considered free goods. Their abundance was reflected in the lack of institutions for limiting access to them (e.g., pricing, quotas, priority usage rules, property rights). Technical progress has made these services economic goods, that is, goods scarce enough to have opportunity costs. The development of institutions for limiting access has lagged behind, allowing problems of environmental degradation and overuse of resources to multiply unchecked.

2. Management versus Capital in Improving Productive Efficiency in Agriculture

One way to mitigate problems of environmental degradation and overexploitation of natural resources in agriculture is to improve productive efficiency. From a materials balance perspective, many environmental quality problems exist because of inefficiency in production: Raw materials that are not converted completely into finished products are disposed of into the environment, where they become pollutants. For example, nutrient runoff and leaching occurs because crops do not take up part of the fertilizers applied; improving the efficiency of crop uptake would reduce nutrient emissions into the environment, while harm to human health or wildlife from pesticides is due to applications that never reach target pests. Efficiency improve- ments can mitigate overexploitation of natural resources as well. Excessive water use or drainage problems may result from inefficient irrigation: Both kinds of problems could be lessened by increasing the share of applied water actually taken up by crops (Lichtenberg 2002).

From this perspective, there often exist potential win-win improvements in productive efficiency that would simultaneously increasing farm profitability and environmental quality. These opportunities typically require development of sophisticated farming practices and enhancements in human capital. Management is at a premium in agriculture (compared to, say, manufacturing) largely because largely because of the difficulty of embodying sophisticated technologies in capital equipment. Because agriculture is, at bottom, a form of ecosystem management, it tends to be far more complex than manufacturing. Production conditions can be controlled much less completely in agriculture than in manufacturing. For example, agriculture remains dependent on stochastic factors like weather; manufacturing, in contrast, takes place in climate-controlled conditions. Living organisms react to management efforts in complex ways; manufacturing processes, in contrast, can be simplified and controlled with much greater precision. Ecosystem processes vary significantly across existing natural environments; manufacturing environments, in contrast, can be replicated.

Advances in the design of farming equipment have made it possible to conduct farming operations with much greater precision, but the potential gains in efficiency offered by this equipment can only be realized under sophisticated management systems. For example, low volume (drip) irrigation systems increases the efficiency of water use by timing delivery to match crop uptake, but requires knowledge of crop uptake rates, which vary according to the stage of plant growth, weather conditions, and soil quality. Variable rate application equipment makes it possible to adjust fertilizer application rates in accordance with natural soil fertility but requires knowledge of existing soil fertility levels, which can vary substantially even within fields of a uniform soil type (National Research Council 1997.)

3. Centrality of the Public Sector

Both economic theory and historical experience suggest that the public sector will necessarily play the central role in development of farm management strategies, enhancement of human capital in agriculture and dissemination of new agricultural technologies. As Huffman and Evenson (1993) have pointed out, the private sector has little incentive to develop management-intensive technologies. Patents on new farming practices or management strategies are difficult to obtain and virtually impossible to enforce. The same can be said for investments in human capital: New knowledge is easily transmitted by word of mouth. As a result, the returns from the development of new farming practices and/or management strategies are generally too low to justify significant private R&D, making public sector R&D absolutely essential for improving agricultural productivity, environmental quality, and resource conservation.

The development and dissemination of integrated pest management (IPM), which has increased pest control efficiency and reduced environmental damage simultaneously, illustrate this point. The manufacturing model of pest control, which posited sanitizing fields as a goal, rapidly proved a complete failure, with resurgence of insect pest populations leading to escalating spraying, the spread of resistance to the most heavily used insecticides, and widespread threats to wildlife and to human health and safety becoming apparent by the early 1960s (Bottrell 1979; National Research Council 1996).

Responding to these phenomena, researchers in land grant universities in the United States developed an alternative approach to insect pest control based on the ecosystem management concepts including economic thresholds, adjusting the timing of insecticide application and the areas to be treated to reduce damage to invertebrate predator populations, and other location-specific cultural controls (Mumford and Norton 1984; Pedigo, Hutchens, and Higley 1986; Brown 1997). IPM was essentially a craft product, a service that could be provided only by a highly trained, skilled practitioner. It could not be embodied in a turnkey product that could be used by farmers without a sophisticated understanding of crop ecosystem dynamics. As a result, the private sector had little or no incentive to develop and market IPM systems. In the U.S., the public sector (researchers in state agricultural experiment stations and the U.S. Department of Agriculture's Agricultural Research Service) was responsible for developing IPM strategies for different crops and for disseminating them among farmers. The public sector took on the tasks of training IPM consultants capable of making sophisticated pest management recommendations and familiarizing farmers with the use of their services as well (Wearing 1988).

IPM remains a management-intensive craft product even today even though advances in computer technology have made it feasible to develop computerized decision support systems that can use sophisticated algorithms to derive IPM recommendations. Limits on human knowledge about crop ecosystem dynamics and the need for location-specific information combine to keep IPM highly management-intensive. Lack of knowledge limits the reliability of models. The appropriate combination of actions varies so much from place to place that it is very difficult to calibrate those algorithms so that they yield reliable recommendations. As a result, it is still infeasible to embody IPM strategies in a turnkey product that can be mass-produced and mass-marketed.

The case of precision agriculture also illustrates the centrality of public sector R&D. New technologies like yield monitors, variable rate chemical application equipment, and geographic information system (GIS) technology promise to increase agricultural productivity while reducing nutrient runoff by adjusting fertilizer application rates in accordance with existing soil fertility to match crop needs more closely. But actual crop needs are not well understood. Most fertilizer recommendations are simple rules of thumb that do not take soil and topographic characteristics into account. A more sophisticated understanding of how soils affect crop growth is needed for these precision technologies to result in yield increases and fertilizer cost savings large enough to justify their expense. Improving understanding of soils and crop growth is a job for the public sector (National Research Council 1997).

Technologies that enhance environmental protection and resource conservation tend to be highly location-specific, as we have seen. One implication is that agricultural R&D and human capital enhancement efforts must be correspondingly location-specific; in other words, it is essential to develop and disseminate management strategies, farming practices, new knowledge, and farming skills adapted to localized conditions. That may present a problem for developing countries because it means that each country ought to maintain its own agricultural R&D establishment (or, in some cases, participate in regional R&D efforts together with neighboring countries having very similar environmental, resource, and agricultural production conditions). The general scientific literature and the experiences of other countries can provide valuable guidance in developing environmentally friendly, resource-conserving farm management strategies. But local research is needed to complete their development and local dissemination efforts are needed to ensure that they are widely adopted.

III. Unintended Consequences and the Importance of Proper Pricing

New technologies are essential for making improvements in environmental quality and resource conservation feasible. But simply introducing them will not automatically resolve environmental and resource degradation problems. The fundamental reason is that new technologies frequently have broader consequences that are difficult to anticipate. Often, they have uses their inventors failed to foresee, as the examples of personal computers and the Internet demonstrate strikingly. In other cases, they cause adjustments in unforeseen dimensions. Agriculture is not immune to such unintended consequences. Broadly speaking, the reverse is true: Agriculture is so complex and subject to such significant variability that one might well expect unintended consequences to be more prevalent in farming than other sectors of the economy. Problems can arise because these unforeseen adjustments can have some perverse effects.

The case of boll weevil eradication in the southern United States illustrates this point. This technology was a characteristic win-win technology promising to improve agricultural profitability and environmental quality simultaneously. The program, which substituted regional eradication for individual farm-level control, worked quite well: Insecticide use fell markedly on existing cotton fields and the profitability of cotton farming increased substantially (Carlson, Hammig, and Sappie 1989; National Research Council 1996, 30). But the eradication program also made cotton once again more profitable than competing crops. Total cotton acreage in the region rose and total insecticide use rose along with it, because cotton is more pesticide-intensive than the alternative crops these farmers had been planting. As a result, the program's overall effect on environmental quality is not clear.

The introduction of low-volume irrigation methods in the United States led to similar kinds of unintended consequence with respect to resource conservation. Low-volume irrigation methods are water conserving, at least at the field level: By reducing the volume of water delivered at any point in time, they permit water application to be matched more closely with crop uptake, resulting in substantially increased efficiency of water application. Drip and similar low-volume irrigation methods also allow irrigation on hillsides (Caswell and Zilberman, 1986; Green et al. 1996) and sandy soils (Lichtenberg 1989) where gravity-based application methods works too poorly to permit irrigation. In California, drip irrigation was used mainly to plant fruit and nut orchards on hillsides (Caswell and Zilberman 1985). In the High Plains, the introduction of center-pivot irrigation systems resulted primarily in expansion of irrigated corn production using exhaustible groundwater from a fossil aquifer (Lichtenberg 1989. In both cases, the introduction of low-volume irrigation methods exacerbated water scarcity problems.

Improper pricing was a major reason why these technologies failed to perform as expected. In the United States, pesticide prices are based on costs of production but do not include adjustments for any environmental damage they create.

As a result, too many farmers find cotton more profitable than less pesticide-intensive crops. Similarly, the cost of irrigation water in California is kept artificially low by government subsidies and restrictions on water transfers while the cost of groundwater in the High Plains remains lower than socially optimal because of a lack of clearly defined property rights. As a result, too many farmers in California find gravity-based irrigation more profitable than drip, while too many farmers in the High Plains find irrigated corn more profitable than dryland wheat or grazing.

Taxes on inputs that damage the environment can help ensure that new, more environmentally protective technologies fulfill their promise. Taxes on pesticides differentiated according to toxicity, persistence, formulation, and other indicators of environmental and human health risk can help induce farmers to choose more socially efficient pest control methods (Lichtenberg 2002). Taxes on fertilizers can help reduce excess application as well.

For resources like water, establishment of clearly delineated, exclusive, transferable water rights and the creation of competitive water markets can be the most important steps needed for ensuring pricing at scarcity value, although it may also be necessary for government to limit water withdrawals to protect water quality or wildlife. Taxes on energy used in pumping or differential taxes on more water-intensive crops may also be means of influencing water use.

Formally, measures that raise the prices of environmentally damaging inputs or overdepleted resources eliminate unintended consequences of the types created in the boll weevil eradication and low-volume irrigation cases because they work the same way on both the intensive and extensive margins (Lichtenberg 2002). In other words, they induce farmers to both lower the use of environmentally damaging inputs on existing fields and shift away from crops and cultivation methods that use environmentally damaging inputs intensively. Simply introducing more efficient new technologies, in contrast, created opposing incentives on the intensive and extensive margins, e.g., less pesticide use per hectare of cotton but more land allocated to cotton, respectively. Thus, requiring the use environmentally protective or resource-conserving technologies that appear attractive at the individual farm level can turn out to worsen environmental or resource depletion problems in the aggregate.

Not all new agricultural technologies that enhance environmental protection and resource conservation are win-win in the sense that they increase agricultural productivity as well. Moreover, some technologies that are win-win in a long-term sense (i.e., result in increases in profitability with a positive present value over their lifetime) may require investments or have up-front adjustment costs that make them unattractive to farmers in the short run. Thus, public sector R&D can make it feasible to enhance environmental quality and resource conservation but may not be sufficient to ensure that those enhancements are actually realized. Appropriate pricing of environmentally damaging inputs and scarce natural resources is usually essential to achieving socially efficient adoption of these agricultural technologies.

The proposition that getting prices right, i.e., devising ways of making farmers pay for the pollution damage (or excessive resource depletion) they cause, is the standard economist's prescription for inducing compliance with environmental quality standards (or conserve natural resources appropriately) efficiently. The heterogeneity of agricultural production conditions also speaks to the desirability of price mechanisms as a means of addressing environmental and resource degradation: As is well known, the advantages of prices over direct controls increases with the heterogeneity of the regulated industry.

Governments and environmental advocacy groups, in contrast, have tended to favor direct controls, that is, requiring firms to install pollution control (resource conservation) equipment, largely in the belief that compliance is more easily and cheaply verified. In agriculture the direct control approach takes the form of requiring that farmers use best management practices such as IPM, nutrient management, conservation tillage, and similar measures. The complexity and variability characteristic of agriculture, however, suggest that government enforcement costs, too, are likely to be lower under price-based policies than under direct controls. Agricultural production is typically carried out by large numbers of producers spread out over a wide geographic area, making inspection for compliance costly. Moreover, the use of most environmentally protective, resource-conserving technologies is not readily observable from casual or periodic inspection because, as discussed in the preceding section, most involve changes in management rather than installation of permanent equipment or changes in landscape. For example, one can't tell from casual inspection whether a farmer is using IPM or calibrating fertilizer applications to match crop uptake needs. Requiring farmers to use IPM or to reduce fertilizer applications is thus virtually unenforceable without expensive, continuous monitoring of every farm. Taxing pesticides, in contrast, makes them more expensive relative to labor and management and thus makes IPM, which substitutes labor and management for chemicals, more attractive.

The case of nutrient management regulations illustrates this point. Attempting to reduce nutrient emissions from livestock by direct regulation, Denmark requires livestock producers to install manure storage facilities with capacities that make it feasible to store manure for use as fertilizer. However, chemical fertilizers are so much cheaper and more reliable as sources of nutrients that livestock producers continue to dispose of manure than apply it as fertilizer. Compliance with the storage facility construction requirement is easy to enforce, but compliance with the provision that manure be used in place of chemical fertilizers is not. As a result, the regulation accomplishes little in the way of reducing nutrient emissions (Dubgaard 1993).

An alternative to either the Danish nutrient management policy would be to impose a tax on chemical fertilizers high enough to make it profitable for farmers to use manure instead of chemical fertilizers, reducing the total amounts of nutrients applied in the region and thus nutrient pollution of ground and surface waters. Enforcement would be cheaper because much less monitoring of farmers' production activities would be needed.

Incentive-based policies are also likely to impose lower costs on farmers than direct controls that achieve the same improvements in environmental quality or resource conservation because they give farmers the freedom to choose least costly means of compliance. Variations in agricultural production conditions from farm to farm mean that the least costly means of compliance typically varies markedly from farm to farm. Incentive-based policies like taxes on polluting inputs give farmers the freedom to select the most profitable input usage levels and management strategies for their own specific circumstances. To be at all meaningful, in contrast, direct control based regulations have to restrict farmers' choices. For that reason, they necessarily limit farmers' ability to meet environmental and resource conservation targets at least cost.

IV. Harmonizing Agricultural, Environmental, and Resource Conservation Policies

Agriculture is central to human civilization. Without agriculture, stable human settlements, let alone nation states, are impossible to maintain. Ensuring adequate and reliable food supplies is thus a central concern of virtually every country. In many countries, agriculture remains the core form of economic activity, making farming central to general economic policy goals. In those countries, farming remains the principal type of employment; for this reason, labor force and employment-related policy aims are closely linked to agriculture. Agriculture is also the principal form of land use in many countries, creating close interrelationships between agricultural and land use policy aims. In a number of countries, promoting settlement has been a major political and economic goal. Agriculture-related policies have played a central role in settlement efforts because of farming's centrality to economic activity and its impacts on land use and employment. Unfortunately, these agricultural policies have proven to have important adverse impacts on environmental protection and resource conservation. Additionally, they often interfere with policies aimed specifically at promoting environmental protection and resource conservation. Thus, in most countries, reorienting overall policy towards enhancing environmental protection and resource conservation requires fundamental restructuring of agriculture sector policies.

1. Support and Stabilization Policies

In high- and middle-income countries, the main agricultural policy goal is maintaining the farm sector by keeping farm income and agricultural commodity prices above free market levels and by stabilizing prices and income. The most damaging of these policies occur in countries at a comparative disadvantage in important agricultural products, that is, natural importers. Japan, Korea, and Taiwan, for example, keep agricultural commodity prices high largely by restricting imports. Supporting commodity prices in this way creates incentives to farm more intensively, that is, apply larger amounts of agricultural chemicals per unit of area cultivated, which is likely to worsen chemical runoff and leaching problems. Japan's farm sector uses almost 3 times as much fertilizer per hectare as the United States while Korea's uses over 4 times as much fertilizer and over 9 times as much pesticides (United Nations Development Program et al. 2000). Price support policies also tend to induce farmers to irrigate more intensively, thereby exacerbating surface water scarcity and/or ground water depletion in addition to water quality problems.

Even income support policies that do not create significant incentives for greater input intensity can contribute significantly to environmental and resource degradation simply by maintaining farm output above socially desirable levels in cases where environmental quality is a substitute in production to agricultural output (Lichtenberg, 2002). For example, farm income support programs can promote conversion of land to agricultural uses, leading to deforestation, drainage of wetlands, and greater erosion from cultivation of virgin prairie. They may also lead to the application of chemical fertilizers and pesticides to a greater expanse of crop area, possibly exacerbating chemical runoff and leaching problems. They may also distort cropping patterns in favor of more pesticide-, fertilizer-, and, in some cases, water-intensive crops (Lichtenberg 1989; Wu and Segerson 1995).

Policies that stabilize (rather than support) agricultural commodity prices can also be important contributors to environmental quality and resource degradation problems. The U.S. crop loan program sets a floor under agricultural commodity low enough to exceed market prices only in exceptional circumstances. The U.S. also offers heavily subsidized crop insurance and ad hoc disaster assistance that amounts to free insurance, programs that may encourage farmers to intensify their use of risk increasing chemicals like fertilizers and pesticides (Horowitz and Lichtenberg 1993), to expand production of more environmentally damaging crops (Wu 1999), and to convert environmentally sensitive land in risky production areas to crop production.

In fairness, it should be noted that price and income support programs can have positive effects on environmental quality, as occurs when agricultural output and environmental goods and services are clearly complements, e.g., scenic amenities provided by cropland. Price and income support policies in developed countries promote preservation of farmland and thus provision of highly prized scenic amenities and open space (for a French example, see Bonnieux, Rainelli, and Vermersch 1998). Similarly, in cases where farmers bear significant costs of resource depletion (e.g, soil erosion in developed countries), higher commodity prices may create incentives to increase resource conservation while income supports may make financing feasible (Lichtenberg 2002; LaFrance 1992; Clarke 1992; Barrett 1991).

Lower-income countries frequently adopt two distinct kinds of agricultural policies. One set of policies aims to promote production of export crops while another attempts to keep urban food supplies cheap at the expense of farm income. Export crops are usually more fertilizer-, pesticide-, and water-intensive than domestic food staples. Moreover, many of these countries subsidize chemical fertilizers and pesticides and irrigation water. Such policies can substantially worsen chemical runoff and leaching problems.

The case of the Aral Sea is an extreme example of the potential negative consequences of such policies (see for example Micklin 1988). Policies that strongly encouraged irrigated production of cotton and rice led to diversion of water away from the rivers feeding the Sea and increased use of chemical fertilizers and pesticides was increased. As a result, flows into the Aral Sea have continued to decline, and the water that does reach the Sea has high concentrations of fertilizers and pesticides and of heavy metals leached from cotton producing areas. The result has been one of worst environmental disasters known.

2. Settlement Promotion Policies

Some of the most severe environmental degradation and resource depletion problems in the world today have been largely caused by policies aimed at promoting settlement of national territories. In many parts of the world, governments have provided cheap land, water, and, in some cases, variable inputs, in order to encourage expansion of farming in areas where environmental sensitivity and/or resource scarcity limited settlement and economic activity generally. The degree of inefficiency involved remains lows as long as economic activity is low because the social value of the resources involved is low. But the scarcity of these resources rises as economic activity does. Thus, the economic distortions created by those policies increase in direct proportion to their success in promoting settlement. Unfortunately, policy rarely changes accordingly, creating environmental and resource problems escalating over time.

During the late 19th and early 20th centuries, for example, the U.S. offered cheap land to lure settlers into the West. Exclusive property rights systems for water and limitations on water transfers were designed to promote settlement as well.

Federal irrigation projects and irrigation subsidies were later used to ensure complete settlement of the West. Limits on water transfers and irrigation subsidies have remained entrenched even though settlement of the West has long been complete. Both have fueled political pressure for new water projects and have thus led to excessive diversion of surface waters and depletion of ground waters, with severe adverse effects on instream water quality, recreational and commercial fishing, and other activities. Both have also given farmers little incentive to switch to water conserving irrigation technologies, increasing pressure on scarce water resources to support growing urban populations.

The rapid deforestation of rainforests in Central and South America is similarly due to settlement promotion policies. Governments of these countries offer potential settlers cheap land by guaranteeing title to those willing to clear and work unclaimed forested land, much as the U.S. did to promote settlement of the West. Such policies can make land clearing valuable even in cases where the value of timber harvested does not justify the direct costs of harvesting and the opportunity costs of forest products foregone. As a result, deforestation can be excessive even in terms of each country's national economy, that is, even without taking into account global environmental damage in terms of climate change and biodiversity losses.

3. The Need for Harmonizing Agricultural, Environmental, and Resource Policies

Efforts to protect the environment and promote resource conservation have little chance of working in the face of longstanding agriculture-sector policies that create strong countervailing incentives. Thus, it is absolutely necessary for governments to restructure farm-sector policies in light of emerging environmental protection and resource conservation needs. Agriculture sector policies like price supports, input subsidies, and the like should be adjusted in light of environmental quality and resource conservation goals. At the very least, these policies must be stripped of features that actively encourage environmental degradation and overexploitation of natural resources. More generally, they should be restructured to integrate environmental quality and resource conservation policy goals. Settlement-oriented policies, too, should be redesigned so that they no longer encourage excessive resource depletion, be it overuse of water or excessive deforestation.

In high- and middle-income countries, price supports and import restrictions create significant incentives to farm both too extensively and too intensively. In these countries, one would expect trade liberalization to reduce environmental degradation and resource depletion by allowing production to be shift to regions with greater natural fertility, better climate, and low pest pressure, and greater availability of natural resources. Replacement of price supports with income supports independent of yields (e.g., the U.S. deficiency payment program from 1985 through 1995) would help reduce intensive margin effects like overuse of chemicals (albeit not extensive margin effects like overexpansion of agriculture).

In developing countries, the farm credit system may be one of the most important places to start reconciling agricultural production, environmental protection, and resource conservation goals. Agriculture is often too risky to be attractive to private sector lenders. Thus, many countries have established separate, government-run (or backed) farm credit systems to provide both short-term production loans and long-term investment credit. Lending criteria for those systems could be amended to give greater priority to investments resulting in greater environmental protection and/or resource conservation. In some cases, credit availability may be the key constraint preventing farmers from making such investments on their own, as has been shown in the case of soil conservation even when property rights are not complete (Feder and Onchan 1987; Migot-Adholla et al. 1991; Place and Hazell 1993; Gavian and Fafchamps 1996).

V. Conclusion

Resource and environmental degradation have emerged as major problems facing agriculture. In many parts of the world, they are becoming severe enough to threaten the long-term viability of farming and food production. While new, environment-friendly, resource-conserving technologies are sorely needed, well designed and thoroughly implemented public policies are absolutely essential for tackling these problems effectively. Research and development of new farming equipment and methods will make it feasible to improve environmental protection and halt resource degradation. The public sector will necessarily play an essential role in developing environment-friendly farming practices and in helping farmers acquire the enhanced management skills they will need to use those practices. Private sector efforts will generally be lacking because privately appropriable returns to R&D in these areas tend to be too low to justify private investment. New technologies are necessary, but not sufficient. Governments must also ensure that farmers face the proper economic incentives to shift to those new practices and to invest in resource-conserving equipment and structures. Economic theory and actual experience suggest that taxes on inputs that create environmental degradation problems will be more effective than either voluntary measures or direct controls like requiring the use of more environment-friendly farming practices. Thoroughgoing reform of agriculture sector policies will also be necessary. Price supports and import restrictions may promote unacceptably high levels of environmental degradation. Trade liberalization and shifts to income supports that are independent of yields should help improve environmental quality and resource conservation. More generally, agriculture sector policies should be restructured so that environmental protection and resource conservation are made central to their design.

REFERENCES

Barrett, S. 1991. "Optimal Soil Conservation and the Reform of Agricultural Pricing Policies." *Journal of Development Economics* 36: 167-187.

Bonnieux, F., P. Rainelli, and D. Vermersch. 1998. "Estimating the Supply of Environmental Benefits by Agriculture: A French Case Study." *Environmental and Resource Economics* 11: 135-153.

Bottrell, D. 1979. *Integrated Pest Management.* Council on Environmental Quality: Washington, DC.

Brown, G.C. 1997. "Simple Models of Natural Enemy Action and Economic Thresholds." *American Entomologist*: 117-124.

Carlson, G.A., G. Sappie and M. Hammig. 1989. *Economic Returns to Boll Weevil Eradication.* Agricultural Economic Report No. 621. Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Caswell, M.F. and D. Zilberman. 1985. "The Choice of Irrigation Technologies in California." *American Journal of Agricultural Economics* 67(2): 224-234.

Caswell, M.F. and D. Zilberman. 1986. "The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology." *American Journal of Agricultural Economics* 68: 798-811.

Clarke H.R. 1992. "The Supply of Non-Degraded Agricultural Land." *Australian Journal of Agricultural Economics* 36(1): 31-56.

Dubgaard A. 1990. "Programs to Abate Nitrate and Pesticide Pollution in Danish Agriculture." Braden J.B., Lovejoy S.B. (eds.). *Agriculture and Water Quality: International Perspectives.* Boulder, CO: Lynne Rienner, 117-30.

Feder, G. and T. Onchan. 1987. "Land Ownership Security and Farm Investment in Thailand." *American Journal of Agricultural Economics* 69: 311-320.

Gavian, S. and M. Fafchamps. 1996. "Land Tenure and Allocative Efficiency in Ghana." *American Journal of Agricultural Economics* 78: 460-471.

Green G., D. Sunding, D. Zilberman and D. Parker. 1996. "Explaining Irrigation Technology Choices: A Microparameter

Approach." *American Journal of Agricultural Economics* 78(4): 1064-72.

Horowitz J.K. and E. Lichtenberg. 1993. "Insurance, Moral Hazard, and Chemical Use in Agriculture." *American Journal of Agricultural Economics* 75(4): 926-35.

Huffman, W.E. and R.E. Evenson. 1993. *Science for Agriculture: A Long-Term Perspective*. Ames, IA: Iowa State University Press.

LaFrance, J.T. 1992. "Do Commodity Prices Lead to More or Less Soil Degradation?" *Australian Journal of Agricultural Economics* 36(1): 57-82.

Lichtenberg E. 1989. "Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains." *American Journal of Agricultural Economics* 71(1): 187-94.

______. 2002. "Agriculture and Environment." B. Gardner and G.C. Rausser (eds.). *Handbook of Agricultural Economics*. Amsterdam: Elsevier.

Lopez R.E. and M. Nikklitschek. 1991. Dual Economic Growth in Poor Tropical Areas. *Journal of Development Economics* 36(2): 189-211.

Micklin, P.P. 1988. "Dessication of the Aral Sea: A Water Management Disaster in the Soviet Union." *Science* 241: 1170-76.

Migot-Adholla, S., P. Hazell, B. Blarel and F. Place. 1991. "Indigenous Land Rights Systems in Sub-Saharan Africa: A Constraint on Productivity?" *World Bank Economic Review* 5: 155-175.

Mumford, J.D. and G.A. Norton. 1984. "Economics of Decision Making in Pest Management." *Annual Review of Entomology* 29: 157-174.

National Research Council. 1996. *Biologically Based Pest Management: New Solutions for a New Century*. Washington, DC: National Academy Press.

National Research Council. 1997. *Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management*. Washington: National Academy Press.

Pedigo, L.P., S.H. Hutchins and L.G. Higley. 1986. Economic Injury Levels in Theory and Practice. *Annual Review of Entomology*

31: 341-368

Place, F. and P. Hazell. 1993. "Productivity Effects of Indigenous Land Tenure Systems in Sub-Saharan Africa." *American Journal of Agricultural Economics* 75: 10-19.

United Nations Development Programme, United Nations Environment Programme, World Bank, World Resources Institute. 2000. *World Resources 2000-2001: People and Ecosystems, the Fraying Web of Life*. Washington, DC: World Resources Institute.

Wearing, C.H. 1988. "Evaluation of the IPM Implementation Process." *Annual Review of Entomology* 33: 17-38

Wu, J-J. 1999. Crop Insurance, Acreage Decisions, and Nonpoint-Source Pollution. *American Journal of Agricultural Economics* 81(2): 301-320.

Wu J-J and K. Segerson. 1995. "The Impacts of Policies and Land Characteristics on Potential Groundwater Pollution in Wisconsin." *American Journal of Agricultural Economics* 77(4): 1033-47.