III. Steering Agriculture in a More Sustainable Direction—The Role of Green Technologies

Generations can share resources in numerous ways. This study distinguishes between two broad approaches. The first approach directly conserves natural resources for future generations. This approach has been, and will continue to be, widely used in government programs. Numerous programs have been instituted to limit environmental degradation and to conserve natural resources. For example, the Food Quality Protection Act (FQPA) of 1996, Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and the Federal Food, Drug, and Cosmetic Act (FFDCA) allow the EPA and the Food and Drug Administration (FDA) to restrict the use of certain pesticides based on their risks to human health, wildlife, ground-water quality, and other environmental effects. Similarly, the Endangered Species Act (ESA) was enacted as a way to preserve/conserve plant and animal species that are in danger of extinction (endangered species) or that may become so in the foreseeable future (threatened species).

With respect to agriculture, USDA offers landowners financial, technical, and educational assistance to implement conservation practices on privately owned land and thereby directly invests in natural resources. Using this help, farmers and ranchers apply practices that reduce soil erosion, improve water quality, and enhance forest land, wetlands, grazing lands, and wildlife habitat. For example, the CRP was established to reduce soil erosion on highly erodible land and to achieve other secondary objectives. Similarly, the Wetland Reserve Program (WRP) provides easement payments and restoration cost-shares to landowners who permanently return previously converted or farmed wetlands to wetland condition. Most recently, the 1996 Farm Bill also expanded the Department's conservation programs with the Wildlife Habitat Incentives Program (WHIP) and the Farmland Protection Program. WHIP allows for technical and cost-share assistance to landowners to develop improved wildlife habitat. Under the Farmland Protection Program, USDA leverages Federal funds with State and local funds to protect farmland.

A second approach, and the focus of this report, operates through a farmer's choice of technologies. This approach encourages research and development (R&D) and adoption and diffusion of more sustainable farming practices.[9] Investment in these "green technologies" is currently receiving a great deal of attention because they promise to augment farm profitability while reducing environmental degradation and conserving natural resources.

There is a wealth of information in the form of case studies suggesting that green technologies can be both economically profitable and environmentally sustainable (see Appendix 1). However, simply because a practice is available does not mean that farmers will adopt it. In the long run, the adoption and diffusion of alternative practices will depend on profitability. Other factors, such as differences in farm structure (e.g., crops grown, diversity of output, farm size), economic risk, and geographic location, will also affect adoption and diffusion rates of green technologies.

To assess what may be the most significant impediments to the adoption and diffusion of alternative production practices, we highlight four practices that are often considered more sustainable and have been researched. These practices are: integrated pest management (IPM), conservation tillage, enhanced nutrient management, and precision agriculture. These practices have either been broadly adopted or have the potential for wide-scale adoption in agricultural production. For example, farmers have used IPM in the United States for more than 20 years, and scouting is used on almost two-thirds of surveyed fruit and nut acreage and nearly 75 percent of vegetable acres (USDA, ERS, 1994). Wide-scale adoption of conservation tillage has a more recent history, with farmers employing mulch-till, ridge-till, or no-till systems on over 36 percent of planted acres in 1995; up from less than 18 percent in 1988 (USDA, ERS, 1997). Farmers also have considerable experience with enhanced nutrient management practices, although wide-scale adoption has not occurred. Among the most recent is an emerging suite of management practices known as precision agriculture.

Each of these practices is "information and management intensive," because a farmer is required to understand much more than in the past how the physical characteristics associated with farming, such as

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[9] Adoption refers to the use or intensity of use of a practice at the farm level. Diffusion refers to the intensity or rate of adoption at the sector level.

soil type, rainfall, and temperature, interact with managing inputs, such as pesticides, nutrients, and soil, to affect the production of commodities. Each practice uses inputs efficiently and may dramatically affect farm profits, the quality of the environment, and the pattern of natural resource use. These practices may improve our indicators of agricultural sustainability by both increasing food production and mitigating the impact of current agricultural production practices on the environment. For example, sediment and siltation are the primary pollutants of rivers in the United States (USEPA, 1998). Conservation tillage has significantly reduced soil erosion from farmland and therefore can potentially improve surface-water quality. Similarly, nutrients are the leading pollutant associated with lakes and estuaries and the second leading pollutant associated with rivers. Enhanced nutrient management can reduce the leaching of fertilizers and manures and can further improve surface- and groundwater quality. IPM can reduce the need for pesticides, which also improves surface and ground-water quality. Lastly, precision agriculture can improve all facets of the environmental performance of U.S. agriculture.

Integrated Pest Management

IPM includes various techniques that maintain pest infestation at an economically acceptable level rather than attempting to completely eradicate all pests. The USDA uses the following definition: "IPM is a management approach that encourages natural control of pest populations by anticipating pest problems and preventing pests from reaching economically damaging levels. All appropriate techniques are used such as enhancing natural enemies, planting pest-resistant crops, adapting cultural management, and using pesticides judiciously" (USDA, Agricultural Research Service, 1993). IPM monitoring methods include scouting by regular and systematic field sampling, soil testing for pests, such as nematodes, using pheromone odors and visual stimuli to attract target pests to traps, and recording environmental data, e.g., temperature and rainfall, associated with the development of some pests. Pest management practices used in IPM include biological controls such as natural enemies or "beneficial" semiochemicals (including pheromones and feeding attractants) and biopesticides; cultural controls such as hand hoeing, mulching, and crop rotation; strategic controls such as planting dates and location; and plants resistant to some pests.

While IPM does not exclude the use of synthetic pesticides, the pesticides used in IPM often differ from those used on a preventive or routine schedule. Where possible, IPM uses pesticides that target specific pests and decrease toxic exposure to beneficial organisms. To the extent that IPM decreases pesticide use, gains in environmental benefits can occur in terms of improved water quality, decreased probability of wildlife poisonings, and decreased probability of negative health effects for applicators.

The following provides an operational definition of IPM to manage insects (diseases). A farmer uses IPM to manage insects (diseases) if: scouting for insects (diseases) and economic thresholds are used in making insecticide (fungicide) treatment decisions, and one or more additional insect (disease) management practices among those commonly considered to be IPM techniques are employed (Vandeman and others, 1994).

While many of the techniques under the umbrella term “IPM” have been around for some time, and unifying these practices into a cohesive group occurred about 25 years ago, large-scale adoption of some IPM techniques on U.S. farms is a fairly recent phenomenon. If current conditions prevail, adopting IPM techniques will reach 75 percent of the vegetable acreage nationally between 2008-36, except for scouting, which attains the 75-percent level in the present decade (Fernandez-Cornejo and Kackmeister, 1996). For fruit acres, the 75-percent IPM adoption goal will likely be achieved between 1995 and 2005, except for scouting which has already achieved this goal (Fernandez-Cornejo and Castaldo, 1998).

Conservation Tillage

Conservation tillage involves maintaining adequate soil cover to decrease soil erosion by wind and water. The following definitions for a set of systems that manage crop residue may help one better understand the distinctions between various approaches to conventional and conservation tillage (USDA, ERS, 1994):

Conventional tillage with moldboard plow: Any tillage system that includes the use of a moldboard plow.

Conventional tillage without moldboard plow: Any tillage system that has less than 30 percent remaining residue and does not use a moldboard plow.

Conservation tillage: Any tillage and planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion by water; or maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface during the critical wind erosion period where soil erosion by wind is the primary concern.

Two key factors influence crop residue: the previous crop, which establishes the initial residue amount and determines its fragility, and the type of tillage operations prior to and including planting.

Conservation tillage practices include:

Mulch till. The soil is disturbed prior to planting. Operators use tillage tools such as chisels, field cultivators, disks, sweeps, or blades.

Ridge till. The soil is left undisturbed from harvest to planting except for nutrient injection. Farmers complete planting in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges.

No-till. The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, inrow chisels, or rototillers.

Farmers have adopted conservation tillage partly in response to incentive effects associated with Conservation Compliance and, in many cases, on a voluntary basis. As depicted in table 5, adoption rates have generally increased since 1988. For example, in 1995, only 11 percent or less of acres were tilled using conventional tillage with a moldboard plow in corn, northern soybean, southern soybean, or winter wheat production; compared with as much as 28 percent for northern soybeans in 1988.

Clearly, some individual farmers perceive that the benefits of adopting conservation tillage outweigh the costs. Potential private benefits of conservation tillage include: increased profits, greater convenience, decreased economic risk, and the potential for reducing erosion. However, all farmers will not find conservation tillage equally attractive because, as was the case for IPM, the costs and benefits will vary by farm. For example, studies comparing profitability of conservation and conventional tillage systems provide mixed results. Several studies have found net returns do not significantly differ between reduced tillage and conventional tillage (Duffy and Hanthorn, 1984; Jolly and others, 1983). Other studies have found conventional tillage has higher returns (Klemme, 1985; Martin and others, 1991) and yet other studies have found conservation tillage has higher returns (Williams and others, 1989).

Enhanced Nutrient Management

Enhanced nutrient management involves efficiently using nutrients from commercial fertilizers and animal and municipal wastes. The primary goal of nutrient management is to sustain an increase in agricultural production and minimize the environmental damage from unused nutrients. Enhanced nutrient management practices include altering existing practices by assessing nutrient needs, timing applications, placing fertilizer closer to the seed, using alternative products, changing crop and irrigation management, and using manure and organic wastes.

Assessing Needs

Soil tests and plant analyses play an integral part in balancing the supply of nutrients and the need for nutrients by crops. Soil tests can reveal the level of a nutrient present in the soil profile available for plant uptake before the application of commercial fertilizer. With a soil test, the farmer, in matching the crop's need for nutrients, can determine whether and how much additional nutrient should be supplied.

Timing

Timing nitrogen applications to meet the crop's biological needs can reduce application rates. Effectively timed applications match the biological needs of a crop resulting in less nitrogen available for leaching, runoff, denitrification, and other losses.

Placement

Farmers can employ a variety of improved nitrogen application practices to place nitrogen fertilizer closer to the seed or plant for increased crop uptake (Achorn and Broder, 1991). These include the use of injection, knifed-in, and side dressing applications. These application practices can increase the efficiency of plant uptake of nitrogen fertilizer.

Table 5—Adoption of alternative tillage practices, percent of acres, 1988-95
Adoption rates of alternative tillage practices have increased since 1988

Crop	Year	Conventional tillage with moldboard plow	Conventional tillage without moldboard plow	Mulch till	Ridge till	No till
			Percent of acres			
Corn	1988	20	60	14	*	7
	1995	8	49	23	3	17
Northern soybeans	1988	28	55	14	*	3
	1995	8	37	24	1	30
Southern soybeans	1988	3	85	5	*	7
	1995	1	67	7	--	25
Winter wheat	1988	15	67	16	--	1
	1995	11	67	15	--	7
Spring durum wheat	1988	14	63	22	--	1
	1995	6	67	22	--	5
Total	1988	19	63	13	*	5
	1995	8	56	19	1	16

* = included with no till.
Source: USDA, ERS, *Agricultural Resources and Environmental Indicators* (1997).

Alternative Products

A farmer can choose a variety of products that differ in their potential to leach and denitrify. Several researchers have ranked the chemical stability, ranging from least stable to most stable, for nitrogen products: ammonium nitrate, nitrogen solutions, anhydrous ammonia, urea, and ammonia-based fertilizer with an added nitrification inhibitor (Aldrich, 1984). Ammonia-based fertilizer can minimize nitrogen loss for land vulnerable to leaching. A nitrate-based fertilizer can best address areas vulnerable to ammonia volatilization.

Crop Management

Crops in rotation with a nitrogen-fixing legume crop can reduce nitrogen application needs and use. In addition, crops in rotation reduce soil insects, improve plant health, and increase nitrogen uptake efficiency. Legume crops at an early stage of growth absorb residual nitrogen in the soil and minimize leaching. Planting "scavenging" crops between crop seasons can prevent residual nitrogen buildup during land dormant seasons. Some nitrogen-scavenging cover crops include hairy vetch and small grain crops.

Irrigation Management

The quantity of water in the soil affects the nutrient concentration in soils and the rate of nutrient movement to the root zone (Rhoades). Too much water can promote nitrogen leaching, reduce nutrient concentration in soils, and lower plant uptake. Too little water can result in water stress with respect to plant growth. Water stress stunts plant growth and reduces crop yields. Farmers can improve irrigation efficiency, for example, by switching from gravity irrigation to sprinkler irrigation, by scheduling and applying irrigation water according to plant need, and by using improved gravity irrigation practices.

Using Manure and Organic Wastes

Manure is a source of nutrients and an important source of organic matter. Organic matter in soil provides nutrients to crops and acts as a soil conditioner enabling crops to achieve high yields. Managing nutrients in animal manure for better use requires testing the manure to ascertain its nutrient content.

Precision Agriculture

Precision agriculture encompasses a range of management practices that attempt to achieve optimal crop, livestock, or forestry output by using information to adjust inputs to expected soil, weather, and environmental conditions (National Research Council, 1997). Precision agriculture is simply a more disaggregated version of the kinds of best management practices already recommended at the field scale (Ogg, 1995). Furthermore, precisely matching fertilizer and pesticide inputs to the capabilities and needs of the crop for small areas and exactly when the crop needs the inputs limits the amounts of these materials that can escape to the environment. Some evidence suggests precision agriculture can reduce the amount of chemicals applied and can reduce the level of residual nitrogen (Kitchen and others, 1995). Information technologies used in precision agriculture cover the three aspects of production: data collection or information input, analysis or processing of the precision information, and recommendations or application of the information.

Data Collection

Data collection consists of two major components: data collected in advance of crop production, and data collected in "real time" as production activities occur.

To collect data at precise locations, a farmer can use the global positioning system (GPS) satellite data alone, or use differentially corrected for positional error with supplemental data (DGPS). GPS/DGPS location information enhances the spatial accuracy of the data (National Research Council, 1995).

Data collection technologies operating in advance of crop production include grid soil sampling (Goering, 1993), yield monitoring, remote sensing (Jackson, 1984; Moran and others, 1997), and crop scouting (Johnson and others, 1997). These provide basic information on the conditions under which production occurs or will occur. A farmer can apply each to crop, forage, or tree production, although the frequency, timing, and density of sampling will likely vary between production systems.

Other data collection, known as "local" sensing, takes place nearly simultaneously with management (Morgan and Ess, 1996; Sudduth and others, 1994). For example, probes thrust into the soil on the front of fertilizer spreaders continuously monitor electrical conductivity, soil moisture, and other variables and predict soil nutrient concentrations to instantaneously adjust fertilizer application at the rear of the spreader (Birrell, 1995; Colburn, 1991). Other examples include optical scanners that detect soil organic matter, or "recognize" weeds to instantaneously alter the amount of herbicides applied (Gaultney and Shonk, 1988; McGrath and others, 1990). These "local" sensors do not need GPS location capability, but a farmer may use them in association with a GPS for entry into a field geographic information system (GIS). In livestock production, electronic ear tags can trigger automated feeding bins that provide (or withhold) a precise ration for specific animals (*AgWeek*, 1996).

Analysis or Processing

The precise data can improve productivity only if a farmer can analyze or process the information to adjust management. The principal technology used to integrate spatial data coming from various sources is the GIS. This is primarily an intermediate step, because data collected at different times on the basis of different sampling regimes and different scales must be combined in space (and time) for use with subsequent decision technologies (Usery and others, 1995). Decision technologies take three forms: process models, artificial intelligence systems, and expert systems (National Research Council, 1989, 1996). Process models use frequent time-steps to simulate the processes of crop, livestock, or forest growth, or generation and movement of potential pollutants through the environment. Artificial intelligence systems use more heuristic or empirical decision rules (rather than the theoretically based relationships in most process models) to reach conclusions about appropriate management techniques. Expert systems incorporate the "rules of thumb" used by human experts that match the conditions reflected in the input data to reach recommendations (McGrath and others, 1995).

Application

Ideally, a farmer can adjust production inputs for each corn plant, animal, or tree to optimize production according to physical, economic, and environmental goals. In practice, technology limits how small an area can be addressed and how finely calibrated input applications can be controlled (Chaplin and others, 1995). Variable rate application is used to describe precise control of inputs, which can include fertilizer and micronutrient application, liming, seed variety and rate, pesticides, irrigation water and drainage, and livestock feed. Also, a farmer may use selective harvest, expressed in the timing of crop harvest to optimize quality aspects, as rotational grazing in livestock systems, or by selective thinning in forestry.