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Production Agriculture Versus the Environment: The Role of Statistics

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ABSTRACT—Corn production in the United States provides an example of the agricultural changes that have occurred in recent times. Because all such agricultural activity potentially can affect the environment to some degree, the challenge is now to quantify and understand those effects. Although monitoring of the environment for such effects is not new, the procedures often fall short of providing reliable quantitative data. One example is the inconsistent, incomplete, and unreliable information currently available to assess US surface water quality and trends in that quality. The utilization of probability-based sampling designs could play a vital role in the improvement of information on the interface between agricultural activity and environmental quality.

Today only 2.5% of the United States workforce are in farm occupations. In contrast, in 1820, the US had an agrarian society with 71.8% of the workforce engaged in such jobs (World Almanac 1998). Although the proportion of people farming has declined in the US, food is inexpensive and plentiful, and massive amounts are exported to other nations. However, since the publication of Rachel Carson's *Silent Spring* in 1962, awareness of the potential negative effect of pesticides on the nation's natural resources has increased. Agriculture has a particularly large impact on the environment, especially water, through its manipulation of the land, pesticide use, irrigation, etc. (Frederick 1980; Soule and Piper 1992). Resulting environmental concerns have given rise to legislation, such as the 1972 Clean Water Drinking Act. Here I review the interrelationships of agriculture, the environment and policy, with an emphasis on the role of statistics in this arena.

To provide focus, I examine corn production as an example. It is now the most widely produced grain crop in the world, yielding approximately 604 million metric tons in 1998 (Food and Agriculture Organization of the United Nations 1999). On average, corn constitutes an estimated 143 of the estimated 2,745 calories consumed per capita daily. Its extensive use as an

animal feed leads to additional, secondary consumption. Further, the complex issues faced in corn production are common to most crops, certainly all of the primary crops of the Great Plains. After providing a short history of modern corn production, farm policies, and environmental impacts, I discuss the current status of these interrelationships and the role of statistics.

Corn: Production, Policy, and the Environment

Corn is a New World food. The modern history of corn began on 5 November 1492, when Christopher Columbus, then at Cuba, recorded in his journal: "There was a great deal of tilled land sowed with a sort of beans and a sort of grain they call 'Mahiz' which was well tasted baked or dried, and made into flour" (Giles 1940:9). Later explorers to the New World found corn being grown from Canada to Chile, wherever agriculture was practiced (Giles 1940; Walden 1966; Hardeman 1981). Corn from cultivated fields was used to augment the diet of fish and game of semi-nomadic hunting and fishing tribes in both North and South America. In contrast the Maya, Aztecs and Incas all looked to corn as the main staple in their diet (Walden 1966). Corn's abundant harvests, supplemented with beans, squash and pumpkins, permitted these groups to devote time to weaving fabrics, molding pottery, building highways and pyramids, inventing a system of arithmetic, and perfecting a calendar more accurate than the Old World one for the same period.

The European colonists adopted the corn plant. They also embraced the methods of culture, harvesting, and utilization that had been developed by the Native Americans (Giles 1940; Hardeman 1981). These practices included planting corn in hills, interplanting corn with beans and squashes, using husking pegs in harvesting, storing the ears in ventilated cribs, using green corn for roasting ears, and removing the hull with lye to make hominy.

In the early days of European exploration, land was abundant, inexpensive, and easy to acquire. Labor was expensive and capital was often lacking (Sanford 1961; Batie and Healy 1980; Cochrane 1993). These factors led to land being viewed as expendable. Practices were adopted that had long been abandoned in the Old World, such as absence of rotation and neglect of livestock and manures. The land was exploited without regard to its future use, mining the soil of its mineral and vegetative matter (Cochrane 1993).

The "collection of agricultural statistics and distribution of seeds" was initiated in 1839, when Congress appropriated $1,000 to the patent office for this job (Olsen et al. 1999). In 1862, this work was moved to the newly

formed US Department of Agriculture (USDA). A year later the Division of Statistics was formed within USDA. This unit was a forerunner to the Statistical Reporting Service and, subsequently, today's National Agricultural Statistical Service.

The patent office completed the first agricultural census in 1840. It compiled the number of farms, their ownership, acreage, improvements, crop yields, livestock, and value. Unfortunately, the data were collected by federal marshals and temporary political appointees, and the work was poorly done (Olsen et al. 1999). For example, there is evidence that the data were carelessly transcribed, unscientifically tabulated, and inaccurately checked (or not checked at all). The result was numerous errors. To correct many of the errors, it was necessary to go back to the original manuscript schedules, many of which were lost. The American Statistical Association strongly criticized the methods used in this census. Although the criticism led to an improvement, problems continued. Thus, the results from the early censuses must always be used with caution. Later censuses brought changes in methods, making comparisons with earlier ones difficult or misleading. In the early 1960s, "objective yield" surveys which incorporated probability sampling were introduced. Today, the National Agricultural Statistical Service publishes nearly 400 national (Allen 1994) and 9000 state reports (Fecso et al. 1986) each year.

As the United States began to mature, agriculture became more commercialized, making it more subject to market fluctuations (Tweeten 1970, 1989). In times of good market prices, land was often purchased on credit, and marginally productive areas were planted. Drops in prices caused farmers to default on loans. During the years 1909-1914, known as the "parity years," farm prices peaked relative to other segments of the economy. However, as the country entered the depression of the 1930s, farmers began to suffer. In response to farmers' needs, Congress enacted the Agricultural Adjustment Act of 1933. This act became the cornerstone of US farm policy for more than 50 years (Tweeten 1989). An elaborate structure of farm income support programs, acreage incentive and control schemes, guaranteed low-interest loans, crop disaster payments, and government-pegged target prices for various crops was developed (Council for Agricultural Science and Technology 1992).

Congress has also shown a concern for the environment. For example, in 1935, Congress declared soil erosion was a national menace and directed the US Department of Agriculture to establish the Soil Conservation Service (Tweeten 1970; Cochrane 1993). The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947 provided the basis for regulatory

pesticide supervision. Note that this act was passed even though in 1952 only about 10% of the US cropland was treated with herbicides; today 90 to 95% of farmland receives herbicides (Council for Agricultural Science and Technology 1992). In 1969, Congress passed the National Environmental Policy Act (NEPA), the most comprehensive environmental legislation that has ever become law (Cochrane 1993). NEPA has had at least three important consequences. First, it requires each federal agency to complete an environmental impact statement before taking a major action that might negatively impact the environment. Second, NEPA authorized the establishment of the Council on Environmental Quality within the executive branch. Third, NEPA created the Environmental Protection Agency (EPA) and gave it responsibility for protecting and improving the natural and human environment within the United States.

The average corn yield per acre harvested from 1870 to present has increased dramatically (Fig. 1). The increased yields have allowed US farmers to meet consumer needs with fewer people. In 1950, there were 10.4 million people in farm occupations (US Department of Agriculture 1952). However, the number had dropped to 3.3 million in July, 1990 (US Department of Agriculture 1997). During this same period the number of US farms dropped from 27 million to 1.9 million (Council for Agricultural Science and Technology 1992). What are the technological and political forces behind such changes? What impact has there been on the environment, and what policy has resulted from these impacts?

Multiple technological changes have occurred, each of which has some potential environmental impact. Mechanization has increased and dramatically changed the manner in which farming is conducted (Cochrane 1993). No longer do farmers have to spend days walking behind an animal directing a plow. Farm machinery, including tractors, combines and corn pickers, has made husbandry of large fields possible. Consequently, instead of subsistence farms, modern farms tend to be relatively large acreages that specialize in only a few crops. This is especially true on the Great Plains, where the size of a farm is often given in terms of sections instead of acres (Cochrane 1993). Although the use of farm machinery pollutes the environment, it is not clear whether that pollution exceeds that which would develop from the number of animals that would be needed to perform the same tasks. Unlike machinery that can be turned on and off, animals must be maintained year around.

Irrigation has also had a major impact on agriculture. The government policies begun in the 1930s resulted in a "go-grow" philosophy (Council for Agricultural Science and Technology 1992). Fences were removed. Grass
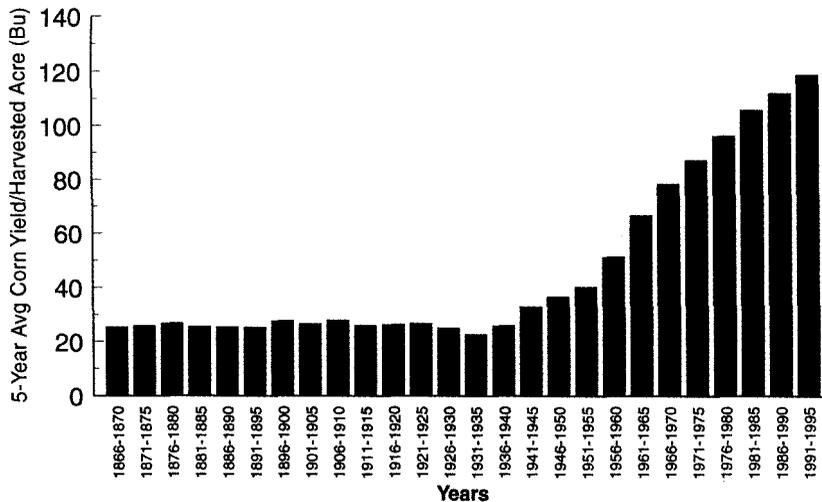
Figure 1. Five year average corn yield per harvested acre (in bushels) from 1866 to 1995 (US Department of Agriculture 1952, 1962, 1973, 1987, 1996).

waterways, vegetative buffer strips and shelter belts were plowed. Wetlands and swamps were drained. Ground water irrigation systems permitted more extensive farming. Lands with poor moisture-holding capacity and lands with no natural or engineered drainage systems were put under irrigation. The result was increased soil erosion, water pollution, loss of genetic diversity, and loss of fish and wildlife habitat (Soule and Piper 1992). In addition, irrigation water is one of the major sources of increased soil salinity; and, soil salinity can result in crop yield reductions and water quality degradation (Frederick 1980).

   Although mechanization and irrigation have increased the acreage that one person can farm and the extent to which new areas can be farmed, they are not primarily responsible for the increase in the average yield per acre (Aldrich et al. 1986; Jugenheimer 1985). The main factors that have increased corn yield are (1) hybrid corn, (2) the ready availability of nitrogen fertilizer, and (3) chemical herbicides.

   Numerous opportunities for hybridization were created through trade and migration of Native Americans (Giles 1940; Walden 1966; Hardeman 1981). Colonialists continued the process, often unconsciously. Although research to develop improved strains had been conducted, a major breakthrough occurred about 1920 when a new method of improving corn through hybridization, and controlling the utilization of hybrid vigor, was widely adopted (Fitzgerald 1990). The method is based on advances in corn

genetics, led by G. H. Shull of the Carnegie Institution, E. M. East of Harvard University, and D. F. Jones of the Connecticut Agricultural Experiment Station. Although hybrid seed is expensive to develop, it provides jobs for thousands in the corn belt each summer. Its immense productivity has resulted in about 90% of the US corn acreage being planted annually to hybrid corn. Of all of the advances, the increased use of hybrid, is the one with the least direct impact on the environment.

About 23% of the US acreage is planted to corn, and corn accounts for approximately 43% of nitrogen fertilizer use (Carey 1991). Initially, fertilizers were produced organically from tankage (meat or garbage waste products), sewage sludge, castor pomace, bones, cottonseed meal, fish scraps, and dried animal manures, including guano (Nelson 1990). Also, natural deposits of nitrate of soda, the first source of chemical nitrogen fertilizers were mined. The first deposits were discovered in central Chile in 1809 by Thaddeus Haenke. Spaniards began mining the deposits about 1813. Another advance was made when techniques were developed to fix nitrogen from the air. Before 1850, nearly all nitrogen fertilizers were organic; however, by 1950, the natural organics had declined to a minor place in supplying nitrogen fertilizers to the world.

Contaminants, such as excessive amounts of nitrogen and phosphorus from commercial fertilizers and manure or pathogenic microorganisms from manure, may cause water quality problems (Soule and Piper 1992). These could arise from run-off or leaching into the groundwater from agricultural areas. Although nitrate nitrogen levels at or below 10 mg/l would not be expected to cause nitrate/nitrite-related health problems for adults, the nitrite standard for drinking water is 1 mg/l, the legally-enforceable Maximum Contaminant Level (MCL) for municipal water supplies (US Environmental Protection Agency 1989, 1990). However, eutrophication can occur in surface water at nitrate levels as low as 1 mg/l, and phosphorus can cause fresh water eutrophication at even lower levels.

Weeds can have a major impact on yield (e.g., Aldrich 1986). In 1944, experiments showed that 2,4-D, a growth-regulating chemical, would selectively kill many broadleaf weeds without serious injury to corn (Craig 1948). This compound was the forerunner of the many synthetic organic chemicals now used to selectively kill certain weeds or families of weeds, while minimizing damage to the crop. These herbicides differed in principle from earlier chemicals in that they upset the internal growth mechanism of plants, instead of killing on contact. The amount of chemical needed to upset the growth mechanism is much less than the amount needed to kill by

salt concentration or solubilization by petroleum compounds, two ap-
proaches commonly used earlier. Thus, small dosages could be used to
cover large areas. Usually herbicides are used prophylactically in corn.

Chemical insecticides are another aid to modern agriculture. Before
the 1870s, methods to control pest damage in crops were largely cultural
and physical (Council for Agricultural Science and Technology 1992).
Approaches included crop rotation, destruction of crop refuse, timing plant-
ing date to avoid high pest population periods, use of trap crops, pruning and
defoliation, and isolation from other crops. "Paris green" was developed in
1890 to combat the potato beetle, initiating chemical pest control in US
agriculture (Metcalf 1986; Young and Young 1994). Because of the wide use
of pesticides, including fungicides, nematicides and rodenticides, in addi-
tion to herbicides and insecticides, resistance has occurred. Although more
widely reported in insects than in weeds, resistance is a concern for both
types of pesticides.

Numerous factors affect the penetrability of pesticides through soils,
including formulation, frequency of application, soil condition, and rate of
rainfall or irrigation (Council for Agricultural Science and Technology,
1992). These factors can be grouped into two broad categories: intrinsic
vulnerability factors and anthropogenic vulnerability factors (Kellogg et al.
1992). The intrinsic vulnerability factors are the environmental factors,
such as climate and soil properties, that are present irrespective of human
activities. Anthropogenic vulnerability factors are producer activities, such
as chemical use and irrigation, that have potential impacts on ground and
surface waters. Both intrinsic and anthropogenic vulnerability factors are
geographically diverse.

Statistical Analysis Tools in Environmental Assessment

Some of the major agricultural developments have potentially negative
environmental impacts. Has the environment been significantly impacted
negatively? In a 1986 report to Congress, the nation's remaining water
quality problems were attributed to pollution from nonpoint sources (US
Environmental Protection Agency 1986). At that time, about 50 to 70% of
the assessed surface waters were adversely affected by agricultural nonpoint
source pollution from soil erosion of cropland and overgrazed ranges, and
from pesticide and fertilizer application. Identified agricultural pollutants
included pesticides, sediment, nutrients, and bacteria from agriculture crop-
land; livestock production and waste management facilities; and grazing

areas. Both pollutant losses in surface runoff and pollutant leaching to ground water contribute to agricultural nonpoint source pollution. Yet, how accurate are these numbers?

The sampling procedures used by the National Agricultural Statistical Service provide accurate agricultural statistics for production (Olsen et al. 1999). Unfortunately, the statistics used to evaluate the degradation of the environment, particularly water, are not of the same quality. For example, under Section 305(b) of the 1972 Clean Water Act, each state is required to submit a surface water quality assessment, a 305(b) report, to the Environmental Protection Agency every two years (Olsen et al. 1999). Each state is to assess how well their water bodies support: (1) aquatic life, (2) fish consumption, (3) shellfish harvesting, (4) drinking water supply, (5) primary contact recreation-swimming, (6) secondary contact recreation (e.g., boating), and (7) agriculture. The objective is to evaluate progress on the "fishable and swimmable" goals of the 1972 Clean Water Act. Each water body is assigned to one of five categories: (1) fully supporting, (2) threatened, (3) partially supporting, (4) not supporting, and (5) not attainable.

Methods of monitoring and assessment of surface water quality vary from state to state, and they may vary within a state from year to year as well (Olsen et al. 1999). Most states do not assess or monitor all water bodies every two years. At present, probability sampling and long-term trend assessment are uncommon. The Environmental Protection Agency published standards for the 305(b) reports in 1992. However, state participation is voluntary. And, the reliability of the statistics vary greatly among the states. Further, national coverage is incomplete. For example, the last three biennial assessments for the United States covered an average of 28% of total stream length, 44% of lake surface area, and 75% of estuarine shoreline length in coastal waters. Yet, these incomplete reports form the basis for the Environmental Protection Agency's determination of the nation's surface water quality that then provides a foundation for policy decisions.

The Environmental Protection Agency, the US Congress, and private organizations with environmental and natural resource interests have long recognized the nation's inability to determine whether the frequency and extent of environmental problems are increasing (or decreasing) on a regional scale (Messer et al. 1991). Congressional hearings on the National Environmental Monitoring and Improvement Act in 1983 and 1984 concluded that federal agencies could assess neither the current status of ecological resources nor the progress toward legally-mandated goals, in spite of the millions of dollars spent on monitoring each year (US House of Repre-

sentatives 1984). The Environmental Protection Agency's Office of Research and Development initiated work on the Environmental Monitoring and Assessment Program in response to this assessment need. The design of this program is based on a systematic grid of sampling points across the United States, including the continental shelf waters. The points were established in a hierarchical design to permit changes in the intensity of sampling related to programmatic needs (Stevens 1994). Probability samples from each resource category are selected. The strong statistical foundation of the Environmental Monitoring and Assessment Program permits assessment of the status and the trends in the nation's natural resources. Although some of the demonstration projects in the Environmental Monitoring and Assessment Program were conducted in the early 1990s at regional scales with the goal of an eventual nationwide implementation, funding cuts in the mid-1990s have made national implementation unlikely. Recent progress has been made in incorporating the probability design of the Environmental Monitoring and Assessment Program at the state level. This is an exciting development that may eventually lead to higher quality reports.

In summary, the 305(b) reports suggest that the status of surface waters is less than desired. However, the flaws in data collection, analysis, and reporting prevent an accurate assessment of the current status or changes in that status. The Environmental Monitoring and Assessment Program, which does have a strong statistical foundation, has had only limited implementation. Therefore, our ability to quantify the status of surface waters on a state, regional, or national level is severely limited.

Studies of ground water quality have a stronger statistical foundation. In the National Survey of Pesticides in Drinking Water Wells (US Environmental Protection Agency 1990b), random sampling was used to select 564 community and 783 rural domestic drinking wells for study. The selected wells represented different patterns of pesticide use and ground water vulnerability. Based on these samples collected in 1988 and 1989, an estimated 10% of the nation's community drinking water wells and about 4% of the rural domestic wells had detectable residues of a least one pesticide. However, less than 1% of the wells had pesticide residues above the levels considered protective of human health. About half of the nation's wells contained nitrate, with about 1.2% of the community wells and 2.5% of the rural wells above 10 mg/l nitrate, the maximum contaminant level established to protect human health. Although much of this nitrate undoubtedly originated from nutrients applied in agriculture, state surveys in the early and mid-1900s showed ambient levels of nitrate from 40 to more than 1,000

mg/l, suggesting that at least in some instances high nitrate levels have resulted from natural causes (Council for Agricultural Science and Technology 1992).

Some states have also conducted studies of ground water quality. For example in 1990 Iowa, in the heart of the corn belt, conducted a study of 686 nonrandomly sampled wells (Iowa Department of Natural Resources 1990). The mean nitrate measured as nitrogen concentration, was 6.2 mg/l, and 18.3% of the wells exceeded 10 mg/l nitrate. For wells of less than 50 feet depth, 35.1% exceeded the 10mg/l level. For wells deeper than 50 feet, 12.8 % exceeded that concentration. Pesticides were found in 13.6% of the wells overall, 17.9% of the wells less than 50 feet deep, and 11.9% of the wells deeper than 50 feet.

The 1933 Agricultural Adjustment Act, mentioned earlier, set agricultural policy until the 1980s, even though Congress continually refined the details (Tweeten 1989). In the 1930s, Congress debated the degree to which government should be involved in supporting farm income. In the 1940s, the discussion centered on whether flexible or fixed levels of supports were better. In the 1950s, choices between continued control supports or a transition to a market orientation were debated. In the 1970s, Congress weighed whether to phase out the commodity programs or to focus on farm structure. In 1980, farmers relied on the government for only 5% of their net cash income. The 1981 Agricultural and Food Act supported farm prices above normal market levels. This policy created excess stocks and led to loss of world markets. By 1986, farmers obtained half their income from Washington. Government expenditures on farm income support programs grew from $3.8 billion in 1981, to $18.6 billion in 1983, and to $33.4 billion in 1987 (Council for Agricultural Science and Technology 1992).

Concern about growing expenditures and negative environmental reports prompted Congress to enact the 1985 Food Security Act. The new law began incremental decreases in loan rates and target prices for various commodities (Tweeten 1989). Farmers were encouraged to plant non-program crops and to reduce the acreage planted. The law established the Conservation Reserve Program to compensate farmers for removing highly erodible and other fragile lands from production for 10 years. In addition, export promotion measures were used to alleviate the oversupply of grain storehouses.

In 1996, the Federal Agriculture and Improvement Reform Act, also called the "Freedom to Farm" Act, was enacted (Stuart and Runge 1996). This Act provides for declining, market- transition payments to ease the

shift of production agriculture to a more market-oriented basis. The govern-
ment set-aside program was eliminated. The Conservation Reserve Program
was altered, specifically to target only the most environmentally fragile
lands. Some funding was provided to encourage new conservation efforts by
crop and livestock producers.

The concept of market-driven agriculture was severely tested in 1998
and 1999. Large yields and poor export demand caused market prices to
drop, dramatically reducing or eliminating grower profits for most farm
commodities. Some financial relief was provided by Congress; however,
there is concern that many farmers, especially the newer and smaller ones,
will not be able to survive. It remains to be seen whether these pressures will
lead to further changes in farm policy.

As with the population as a whole, today's farmers are more environ-
mentally conscious than those of the past. After all, it is the farmer's drink-
ing water that is most likely to become polluted first, if fertilizers or pesti-
cides either leach through the soil or run off the fields. Further, economic
pressures and the possibility of increased regulations are resulting in evalu-
ations of reduced chemical inputs (Stafford and Miller 1996).

At one extreme, the use of fertilizers and herbicides, and perhaps even
irrigation could be discontinued. Estimates of the impact of such action
depend upon models that cannot be fully validated, because fertilizers,
herbicides, and irrigation have not been removed. Thus, the estimates vary
widely. One estimate is that corn yield would be reduced by 41% if fertil-
izer and herbicide use was stopped (Smith et al. 1990). Although other
estimates differ, most agree that shortages could occur and that prices would
increase.

Another alternative is adopting practices that maintain good yields
while protecting the environment. "Precision agriculture" is attracting great
interest from farmers (see, e.g., Robert et al. 1996). In this approach, a field
is intensively sampled, usually on a spatial grid. Based on the resulting soil
analysis at each sample point, a management program is developed, one that
involves applying the appropriate type and amount of fertilizer in variable
amounts throughout the field. An area in a field that is rich in nitrogen would
not receive any fertilizer, but another region with less nitrogen would.
Because grid sampling for soil nitrates annually may not be economically
feasible, alternatives such as yield maps and remote sensing images are also
being evaluated (e.g., Blackmer and White 1996; Blackmore and Marshall
1996; Schepers et al. 1996; Sudduth et al. 1996). In addition, prophylactic
herbicide usage is being reevaluated (Gerhards et al. 1996; Stafford and

Miller 1996). One alternative would be to treat only a portion of the field, based on the weed population the preceding year. In precision agriculture, statisticians play a major role in establishing the sampling design and the estimation methods.

Statistics has long been an important component in developing new agricultural practices. The statistician R.A. Fisher was instrumental in developing specific statistical methods for the analysis of agricultural data (Fisher 1926; Folks 1981). In 1919, Fisher was charged by Sir E. John Russell, Director of the British Rothamsted Experiment Station at the time, to study the station's records. His task was to assess their suitability for statistical analysis and to determine whether more information could be extracted from them. Fisher's work at Rothamsted eventually led to his development of the principles of experimental design (Fisher 1926; Fisher 1935) and the analysis of variance (Fisher and Mackenzie 1923), techniques that are widely used in many areas of science today. These statistical methods provide researchers tools for determining key results, such as which variety of corn has the highest average yield, whether a till or a no-till approach is better, how much nitrogen and other nutrients result in optimal yield, and when and how much water can be used most effectively by the plants.

Increasingly, research advances require a better understanding of the subtle interactions among plants, animals, and the environment. To address these issues, more sophisticated statistical approaches are often needed. When insecticides were first produced, the general philosophy was to treat a field if any insect, such as a European corn borer (*Ostrinia nublialis* (Hübner)) or a corn rootworm (*Diabrotica spp.*), was observed. Costs and expressions of resistance have led to a reevaluation of this approach. Integrated Pest Management was introduced as a more ecologically sound approach to rectify the overuse and misuse of pesticides (see, e.g., Burn et al. 1987; Dent, 1995). Pesticide use may be an important part of integrated pest management, but pesticide applications are integrated where possible with other biotic and abiotic factors to help regulate the population dynamics of the pest species below the economic threshold. Doing this requires a thorough understanding of the underlying biological processes. Both deterministic and stochastic models have been used to help analyze and explain these processes (see, e.g., Curry and Chen 1971; Duncan 1975; Baker and Horrocks 1976; Childs et al. 1977; Stupper and Arkin 1980; Williams et al. 1984; Jones and Kiniry 1986). In developing such models, knowledge gaps are often identified. Further studies are then conducted so that the models can be made more realistic. Statistics is a fundamental component in the

development of stochastic models as well as a major tool in gathering the data in these auxiliary studies.

One outcome of integrated pest management is the identification of economic thresholds (Higley and Pedigo 1996). An economic threshold is the level above which the yield loss due to a pest species exceeds the cost of control for that pest. This threshold may fluctuate with crop stage as the crop matures. Statistical tools play a critical role in the accurate determination of economic thresholds. During the season, a field manager must be able to determine whether a pest species, such as the European corn borer, exceeds the economic threshold, indicating a need for pesticides. It is easy to determine that a field with few insects has a low pest population, one that is below the economic threshold; and, it is clear when a field has a lot of insects that it has a high pest population, one that is above the economic threshold and requires control. In both cases, the decision to treat the field or not is easy to make. However, decisions for intermediate levels of infestation are not always so obvious. Sampling programs can be used to provide a sound decision-making foundation in these cases. Those sampling programs based on statistics permit decisions to be made with a minimal amount of error.

Thus, statistics has a primary role at the interface between agriculture and the environment in both research and farm practice. The previous examples have focused on the scale of the individual farm. However, statistics are also needed at the interface between agriculture and the environment on the larger state, regional, and national scales. Surveys based on probability sampling permit unbiased estimates of the status of both farm production and environmental conditions. The surveys designed by the National Agricultural Statistical Service have demonstrated their value to agriculture and the American public. As noted, the quality of these surveys is due, in part, to early calls for improved methods by the American Statistical Association. For surface waters, the quality of environmental reports is still questionable. Better sampling designs and analyses are currently available. Should we, as scientists, attempt to impact the quality of today's environmental studies? Each of us should, at the very least, consider this question.

Acknowledgments

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