Plant Pests and Diseases: Assessment of Crop Losses

A multidisciplinary scientific approach is required to solve an ancient agricultural problem.

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Crop losses caused by pests and diseases have plagued man and his society from the very beginning of history. The word "pest," commonly used today to include birds, insects, mites, molluscs, nematodes, rodents, plant pathogens, and weeds, is synonymous with "plague," and plagues have affected man's health for many centuries. In the history of the ancient Hebrews, as recorded in the King James version of the Bible, we find mention of locusts, blights, and mildews. "I have smitten you with blast and mildew: when your gardens and your vineyards and your fig trees and your olive trees increased, the palmerworm devoured them: yet have ye not returned unto me, saith the Lord" [Amos 4:9].

More descriptive accounts of losses caused by man's major food competitors are found in the writings of classic Greek and Roman authors, among whom Theophrastus, Virgil, Pliny the Elder, and Columella are probably the most representative. It is interesting to note that so great was the fear of crop losses, and so little understood were the factors that brought them about, that pests and diseases and their causal agents, as we know them now, became an integral part of popular superstitions and of religious dogmas in most of the early civilizations. For example, in the pagan liturgy of the Romans special rites called "Robigalia" were introduced in April of each year to propitiate the goddess Robigo. This divinity (today identified with cereal rust diseases) was in fact considered so important during the spring that she was recognized as the *maxima segetum pestis* (the worst crop pest), if not properly pacified.

But we need not go back so far in time to search for serious crop losses caused by pests and diseases or for assessing their destructiveness. Anyone who has witnessed in modern times a swarm of the desert locust *Schistocerca gregaria* at work can attest to the tremendous damage this insect can do. Each locust nymph is capable of eating its own weight of food every day, and swarms of 100 to 200 million insects per square mile, covering sometimes up to 400 square miles, are capable of destroying 80,000 tons of crop per day (*1*).

Crop losses caused by pests and diseases have been so great and so frequent that they have actually led to famine conditions, and more than once have contributed to great economic-sociological changes in many countries. But it is not our purpose to review the importance of crop losses. We intend to stress the fact that little reliable information on the magnitude of crop losses caused by pests and diseases is available, and that the deficiency of such knowledge is particularly acute at the farm level. Although some of this ignorance is based on the intrinsic difficulty of measuring crop losses and the lack of suitable methods for assessing them, much of it also results from lack of interest and past neglect on the part of plant protection scientists.

The Need for Crop Loss Information

All too often, plant protection scientists have thought and operated along philosophical lines resembling those of Aristaeos, who considered maladies as "necessary forms of life" and clearly admitted that he gained more pleasure from studying them than from combating them. Today's plant protection scientists, however, are faced with entirely new realities which make it impossible for them to think and perform in such ivory-tower isolation. In fact, the greater economic, political, and sociological awareness of the general public demands objective justification for our widely used pest-control methods and sound data on which policy decisions, often affecting many different interests, can be based.

Of these external forces, those of an economic nature are probably most immediate to the agricultural and agrochemical industries. It is well known that pesticide costs have increased considerably in recent years placing much of the financial burden on consumers of farm products, and on the farmers. It has been estimated (*2*) that, while in 1955 the cost of pesticides in the United States was about 1 percent of the total crop value, in 1968 this had risen to 4.6 percent. Many different causes have contributed to this sharp increase. For example, the immediate and often spectacular results obtained with pesticides, combined with consumer demand for pest-free, blemish-free products, have required increased pesticide usage and have broadened the spectrum of treated crops. At the same time, the development of pest resistance and accompanying pest resurgence problems have encouraged the use of either higher pesticide concentrations or more expensive substitute chemicals. Costly pesticides were also introduced in many pest-control programs to replace cheaper materials which, for varied reasons, had been banned from common use. For the control of weeds the farmer, faced with the increasing scarcity of labor or its increasing costs, had no other alternative but to use larger amounts of herbicides to raise his crops. Unfortunately, in most circumstances, these pest-control programs have developed without full knowledge of the actual crop losses to be prevented and of the relevant economic factors involved.

The increasing apprehension concerning the widespread use of chemicals in agriculture has focused the attention of the general public on the "pesticide problem." Pollution of the

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environment, with its hazards to wildlife and human health, has become a major issue indicating the need for collective responsibility in dealing with pest and disease problems in agriculture. In most countries of the industrialized world, farmers represent a small minority of the total population (varying from 3.0 percent in the United Kingdom to 5.2 percent in the United States). But this small core of farmers is the center of other large and important interests including manufacturers and distributors of pesticides, pesticide application contractors, farm equipment manufacturers and distributors, food processing industries, wholesalers and retailers, as well as state, federal, and private organizations engaged in agricultural research, extension, and regulatory activities. Each of these groups has an important share of responsibility in agricultural production and in the use or misuse of pesticides. Each of these groups requires reliable information on the nature and entity of losses caused by pests and diseases so that discussions at all levels can be based on sound knowledge.

At the research level, plant protection scientists have been called upon to reexamine many hitherto accepted control measures to give primary attention to safety as well as to ecological factors. The term "integrated control" (*3*), suggested to indicate the complementary use of natural enemies and of chemicals (mainly to reduce their indiscriminate use), has since been expanded to include the coordinated use of all possible control methods (biological, environmental, and cultural) within management techniques directed toward the fullest utilization of natural insect mortality and other suppressive factors in any given agro-ecosystem. Within an integrated control program it is essential to establish the "economic injury level," that is the critical threshold of pest populations above which control is necessary to avoid economic losses. Again the need for quantifying crop losses is evident.

At the official level, increased responsibility for pesticide use has been felt in many national and international quarters. In the United States, the Department of Health, Education, and Welfare, the Department of Agriculture, and the Department of the Interior have taken an active role. After a careful review of all available information on the benefits and risks of pesticides (*4*), practical guidelines have emerged for the use of these chemicals, including those of the more persistent nature (*5*). Among the corrective actions recommended (*4*), are that pesticides "should be applied only when there is evidence that pest densities will reach a significant damage threshold," and that pest control "should be directed toward optimal management of pest densities" (*4*). Although these recommendations can be interpreted in different ways, for example because they do not make reference to the stages of plant development at which crops are susceptible to yield losses in the presence of certain pest densities, it is clear that both recommendations underline the fundamental need for quantifying both pest populations and losses. At the international level, several organizations, especially the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), have been seriously concerned with this matter. Some of the FAO activities will be discussed later in this article.

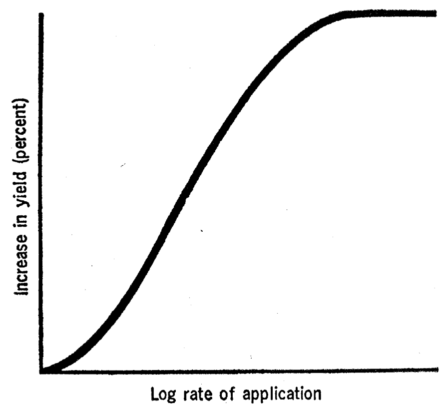

Fig. 1. Relationship between crop yield and application of increasing amounts of pesticide (tranformed to logarithmic scale).

The Value of Reliable Crop Loss Data

A thorough review of the value of reliable data on crop losses has been made on more than one occasion, either in scientific journals (*6*) or in organized symposia (*7*). However, it may be useful to reexamine this matter in the light of existing conditions.

Utilization of crop loss data by farmers. Several factors must be considered by the grower before he decides on a pest-control operation. These are essentially of an economic and managerial nature in view of the farmer's objective to produce maximum yield and improve production of his crop consistent with proper agronomic practices. The grower, contrary to common belief, is not as much interested in the total control of a disease, insect, or weed, as he is in the protection of that quantity and quality of his crop which will permit him to achieve and to maintain the highest economic return. To accomplish this, the farmer (or his pest control adviser) before reaching a decision should be able to analyze the cost/benefit ratio of various alternative methods which are available to control a certain pest or disease, and to select from these the one providing the lowest possible ratio.

This analysis, at first glance, may appear quite simple: on one side the elements of cost, or input, incurred under prevailing market conditions (such as expenses for equipment, materials, labor, replanting costs, extra harvesting, grading, and packing), and on the other side the benefit as measured by the increase in quantity and quality (or both) of produce per unit area (output). However, a closer and more careful consideration of the ratio of cost to benefit reveals instead the difficulties of determining, in strict economic terms, all of the input and output components. In fact, all estimated elements of cost must be matched against various degrees of control, and alternative ways of achieving a given degree of control should also be considered in the analysis, including in many instances the impact of side effects of the control procedure.

To better understand some of these difficulties, we should consider for a moment a dosage response curve that is theoretically obtainable in a given situation by plotting increasing doses of pesticide against corresponding increases in crop yield. If one assumes that the cost of the pesticide application as well as the price of the crop are known (see below), the curve for dosage response, and the curve for total revenue derived from it, will determine in strict economic terms the optimum rate of pesticide application.

Although many factors determine the shape of the curve for dosage response (such as the effect of the pest on the crop, the effect of the pesticide and its application method on both the pest and the crop, as well as the effect of the interaction of the pest-control operation with other factors related to yield), it will have a well-defined form as indicated in Fig. 1. In the lower range of suboptimal rates of pesticide application, the increase in yield progresses from nil to slow for each increased dose of the chemical. Above this range, the rate of yield increase (or the rate of "return") rises rapidly as the doses are increased. Following this, there is a slow and subsequently rapid marginal decrease of yield. Because of the phytotoxicity of certain pesticides, such a curve may also sharply decrease after the point of maximum yield.

It should be noted that the dosage response curve may vary considerably according to the degree of infestation. In fact, if we make curves corresponding to three theoretical levels of pest infestation and we substitute the cost of the pesticide application for the rate of application [as shown in Fig. 2 (*8*)], we see that for the same amount of cost (where $ab = a'b' = a''b''$) the rate of "return" is much greater for heavy than for slight infestations. Although it may still be economically convenient to control pests between these two extremes, the profitability is greatly reduced for slight pest infestations, as graphically shown by the difference $d - d''$.

If the dosage response curve is to be of value in helping to decide the optimal rate of pesticide use, the relationship of pest infestation to crop damage and yield must be known. We will discuss this later in the article but must emphasize here that under actual field conditions there exist other biotic and abiotic factors (such as weather, number and concentration of natural enemies of the pests, and other crop pests) which also greatly affect an economic analysis based on dosage response curves.

Another difficulty is that of assigning a price value to the increased production. Recognition should be given to what economists call "elasticity of demand" for a given commodity. Under free market conditions, the law of supply and demand dictates that an increase in production (such as that resulting from elimination or decrease in crop losses) will be accompanied by a corresponding reduction in unit price. This reduction in unit price may have a different effect on "elastic" crops and "inelastic" ones. For example, if prices of table grapes or of pineapple (elastic crops) drop as a result of a larger supply, it is probable that the demand on these luxury items will expand, and that this expansion will result in economic benefits to the producer (but especially to those who have first adopted suitable new pest-control measures). On the other hand, if the demand for other crops is an inelastic one, as for example, for wheat or lemons, there is little increase in demand when prices of these two commodities decrease as a result of an increased supply. As a consequence, the oversupply of these inelastic commodities actually depresses the market price and this, in turn, reduces the grower's income. To overcome this problem in an economic analysis of the grower's cost/benefit ratio, it may be possible to use average market prices for recent periods.

In addition to decisions taken by the grower on *how* to intervene to control a certain pest or disease (for example, how to select control measures, chemicals, dosage, and mode of application —all elements which in one way or another influence the economic considerations already discussed), it is important to know *when* to intervene to prevent losses. Ideally, the grower (or his adviser participating in the decision) should know the extent of the area threatened, the probable course of the pest population and its total impact on yield if left unchecked at a given particular stage of crop development.

Lacking this information, but knowing from experience what an uncontrolled insect, disease, or weed can cause to his crop, the grower has the tendency to eliminate or at least to reduce the uncertainty and risk by applying control measures as an "insurance" against losses. The premium paid for this insurance is proportionately greater for corps of high commercial value and for those requiring a high preharvest investment. Insurance treatments are accordingly based on a calendar schedule rather than on proper timing of control (for example, when control is really needed). That certain control operations could be more economical by basing them on actual pest thresholds rather than on the calendar scheme is clearly demonstrated by numerous studies. For example, in a 6-year study in Imperial Valley, California (*9*), it has been shown that gains above the cost of pesticide treatment in the control of the corn leaf aphid (*Rhopalosiphum maidis*) or the oat bird–cherry aphid (*R. padi*) on barley, could be obtained when insects reached a threshold of 25 to 30 aphids per tiller prior to stem elongation.

Utilization of crop loss data by national and international communities. During a 20-year period, spanning approximately the mid-1940's to the mid-1960's, basic research in the United States began to be encouraged as an individual enterprise and given support

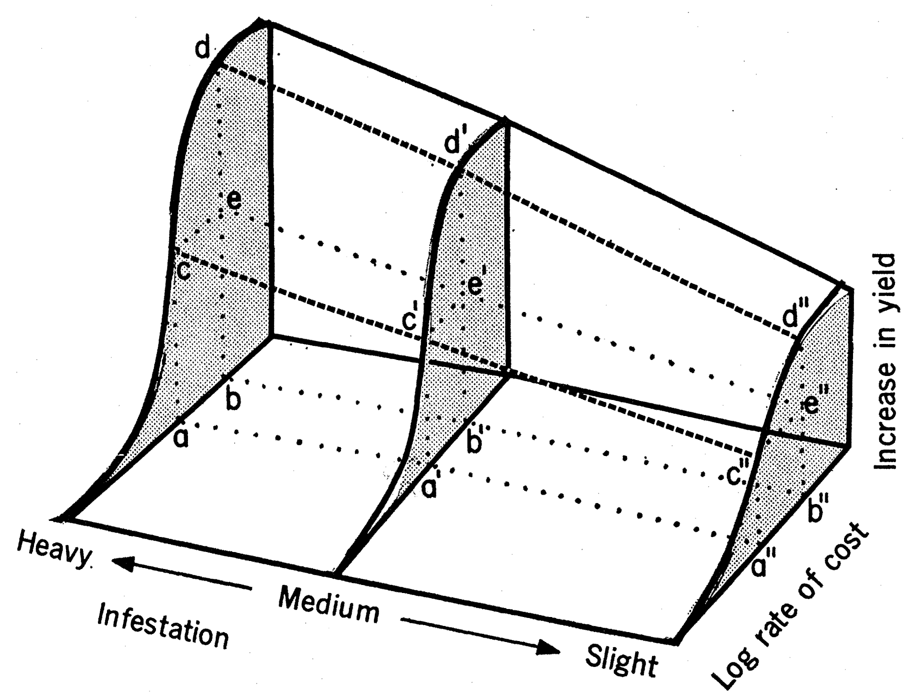

Fig. 2. Relationship between crop yield and pesticide dosage (logarithmic scale) with increasing infestation. a, a', and a'' represent the lower rates of cost for heavy, medium, and slight infestations, respectively; b, b' and b'' represent the higher rates of cost for the different degrees of infestation; c, c', and c'' represent increases in yield for the lower rates of cost with the heavy, medium, and slight infestations; d, d' and d'' represent increases in yield for the higher rates of cost with the different degrees of infestation; e, e', and e'' are half of the b's and d's. [Adapted from Edwards and Heath (*8*)]

by the establishment of the National Science Foundation and the granting of sizable funds by the National Institutes of Health and the Atomic Energy Commission. As a result of this period, great changes of emphasis have become evident. Administrators in more than one university, institute, or agency have become increasingly aware of the need for more research aimed directly at the solution of pressing local problems and of the need to shift from the individual the responsibilities for the selection and financing of research projects. This has called for improved methods of collecting data from local sources on the economic importance of various problems requiring classification according to cogent priorities. In the area of plant protection, the lack of reliable data on crop losses has created considerable embarrassment and at the same time has stimulated much new interest in this field. For example, in 1963 the administrators of the University of California found that no such data were available and therefore requested a statewide study of crop losses from plant diseases, including an evaluation of the cost of controlling diseases (*10*). A comprehensive study along these lines for the entire United States was also conducted by the U.S. Department of Agriculture (*11*) mainly to satisfy the need for crop loss information by producers, processors, and marketers of agricultural products, and by manufacturers and distributors of agricultural chemicals. The weakness of these surveys, however, is that they rely too heavily on the subjective estimates of individual observers with their bias and inevitable variability.

More recently there have been good examples of countrywide surveys based on a more objective approach. For example, in England and Wales (*12*) it has been possible to assess national crop losses caused by foliar diseases of barley with the help of a computerized system of data collection and processing. The field methodology used in this survey was in turn based on years of research through which it had been possible to establish a firm relationship between disease incidence and losses. It is only through factual information supplied by this type of approach that we can acquire sufficient confidence for short- and long-term programing of resources (whether these are to be directed toward the development of a single research project or to the building of a new pesticide plant). Of course, objectivity in conducting a survey will depend greatly on availability of methods of observation and measurement. These methods must at the same time be consistent, reproducible, and acceptable to the surveyors and to the scientific and farming communities. These same methods for quantifying damaging thresholds of certain pests are also needed by regulatory and public health agencies before they can justify and permit the use of pesticides in agriculture.

International aid agencies, also, are concerned by the lack of realistic worldwide information on crop losses. Such information is essential for mobilizing and concentrating limited resources on problems of significant economic importance. Often, in fact, pests and diseases are the main factors that limit agricultural development.

The Procurement of Reliable Crop Loss Data

It is evident, from what has been said, that there should be a general awareness of the necessity to appraise crop losses before more effective and safer measures for pest and disease control can be developed. Only by uncovering "real" losses can we focus on absolute opportunities for gain through plant protection measures (including opportunities for avoiding expensive research on unimportant pests and disease problems). The procurement of such data would place decisions for pest and disease control programs at all levels on firmer ground.

One of the major steps in the right direction has been the establishment of the FAO international collaborative program for the development of reproducible methods for the assessment of crop losses (*13*). A major objective of this program is the production of a manual on *Crop Loss Assessment Methods* (*14*). The manual outlines principles and provides examples of methods for establishing relationships between incidence of harmful organisms (or the extent of the resulting damage) and effects on crop yield or crop quality, or both. It is foreseeable that the adaptation of these methods to local conditions and the development of new methods will place future pest control activities on firmer ground and at the same time automatically increase the reliability of estimations of crop losses over large areas.

To reach this goal it will be necessary to secure a continuous, multidisciplinary interest and participation at the national level on the part of plant protection scientists, economists, biomathematicians, and ecologists. It will be necessary to mold these interests into interdisciplinary activity in universities, research institutions, and agencies. Special study groups might also be formed for the purpose of developing and applying new methods for assessing crop losses. Agricultural extension or similar advisory services could benefit greatly from working closely with such groups.

The most immediate advantages from these activities would be to the growers themselves and to the agrochemical industries. For this reason, it is our opinion that the initial financial support for the functioning of a research program on crop losses might be provided by agricultural commodity groups and manufacturers and distributors of pesticides. In addition, because society as a whole has vested interest in this, agencies that grant funds, especially those concerned with public health, might direct a portion of their funds toward the support of these activities.

The success of all these initiatives will depend on the personal interest and the technical knowledge of the participants. Much can be done by teaching institutions or experiment stations in the training of specialists in crop loss appraisal and by directing research in the development of new methods. At the same time special efforts should be made by all entomologists, plant pathologists, weed scientists, and pest control specialists, to introduce the element of loss assessment as an integral part of their experimental techniques. Scientific societies in various fields of plant protection, which for years have had special committees on crop losses, must continue to play a very important role in crop loss appraisal and prevention.

In conclusion, it can be said that the time has arrived for public health officials, economists, regulatory personnel, biometricians, theoretical ecologists, sociologists, administrators, as well as crop protection specialists to become more closely concerned with the problem of evaluating and preventing crop losses by considering together all economic, safety, and ecological aspects. Because of the complexity of this approach, only activities that are multidisciplinary in scope can solve these problems and benefit society. This is the time when plant protection specialists and scientists in allied fields are called upon to take a lead on actions that have been suggested. The benefits to be gained in this collaborative effort are immeasurable.

Summary

The need, value, and procurement of reliable crop loss data are examined in the light of current economic, sociological, and ecological requirements for a modern agriculture. Initiatives already under way to secure more useful information are examined and the need for further work in crop loss methodology and surveys is emphasized.

References and Notes

1. *The Locust Handbook* (The Anti-Locust Research Centre, London, 1966), (38056) 37.
2. J. Neumeyer, D. G. Gibbons, H. Trask, *Chem. Week*, **104**, 38–68 (1969).
3. V. M. Stern, R. F. Smith, R. van den Bosch, K. S. Hagen, *Hilgardia* **29**, 81 (1959).
4. *Report of the Secretary's Commission on Pesticides and their Relationship to Environmental Health* (U.S. Government Printing Office, Washington, D.C., 1969), parts I and II, pp. 59, 231–233, 179.
5. G. W. Irving, Jr., *Science* **160**, 1419 (1970); *FAO (Food Agr. Organ. U.N.) Agr. Stud.* No. 84 (World Health Tech. Rep. Ser. No. 458).
6. K. S. Chester, *Plant Dis. Rep. Suppl.* **193**, 196 (1950).
7. Papers presented at Symposium on Crop Losses (FAO, U.N., Rome, 1967).
8. C. A. Edwards and G. W. Heath, *The Principles of Agricultural Entomology* (Chapman & Hall, London, 1964).
9. V. M. Stern, *J. Econ. Entomol.* **60**, 485 (1967).
10. *Estimates of Crop Losses and Disease Control Costs in California, 1963* (Univ. of California Agr. Exp. Sta. and Agr. Ext. Serv., 1965).
11. *U.S. Dep. Agr. Handb.* No. 291 (1965).
12. W. C. James, *Ann. Appl. Biol.* **63**, 253 (1969).
13. L. Chiarappa, *FAO Food Agr. Organ. U.N. Plant Protect. Bull.* **18**, 29 (1970).
14. *Crop Loss Assessment Methods* (FAO, AGP: CP/22, Rome 1970).

Population Trends of the 1960's

Some early results from the 1970 census are given.

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The nineteenth decennial census of the United States was taken as of 1 April 1970, and, like its predecessors, it provides a great deal of information about all areas of the country. The Founding Fathers established a decennial count of the population in order to solve the vexing question of how to allocate seats in the House of Representatives. They recognized that there would be changes in the rate of growth of the existing states and that new states would be added as the territory to the West was settled. Periodic reallocation of the seats in the House was established as the best way of providing for equitable representation. It was recognized at the outset that a count of the entire population could provide much useful information. Over the years, the census has become the source of much of the information needed by the citizens and their government—it reveals progress and lack of progress, growth and decline, and increased opportunity and lack of opportunity. From it we learn what progress has been made in dealing with some major problems and the magnitude of the problems that remain. It is not all flattering, for it reaches into the inner-city ghettos as well as the suburban gold coasts; into almost forgotten backwoods, as well as the most modern, rapidly growing suburbs.

A major contribution of the census is the information it provides for every state, county, village, town, and city, as well as the smaller areas within them. It confirms or corrects the national indications provided by sample surveys during the decade, and it provides adequate data for detailed cross-tabulations. In this way, it adds depth to such analyses of broad national trends as those provided annually by the *Current Population Survey* (*1*).

Overall National Trends

There are now about 209 million residents of the United States—almost twice as many as there were in 1921. About 24 million were added to the current total between 1960 and 1970, a larger absolute gain than in any other decade in our history except during the 1950's. However, the rate of growth was slower in the last decade than it was in the 1950's; in fact, it was about the same as the rate in the 1920's and 1940's and double that in the 1930's, the Depression years. Overall rates of growth have varied sharply in this century. They were declining during the 1920's and dropped to all-time lows in the 1930's. They recovered somewhat in the 1940's, but the war years were not favorable to population growth. After the end of World War II, there was a period of relatively rapid growth, with annual increases that averaged about 1.7 percent per year. During the 1960's the rate of growth slowed down, and in the last years growth has been at about 1 percent per year. The total growth during the decade of about 24 million resulted from 39 million births, 18 million deaths, and a net immigration of nearly 4 million (see Table 1).

Changes by Age

The age composition of the population in 1970 clearly reflects the variations in the number of births in previous years. Birthrates in the late 1960's had declined from earlier levels, and there were fewer children under age 5 in 1970 than in 1960. However, the number of children between ages 5 and 14 years was up approximately 15 percent over the number in 1960. The relatively high birthrates of 1947 through 1955 are reflected by an increase in the number of 15- to 24-year-olds—an increase of nearly 50 percent during the decade (see Table 2). These persons are in the prime ages for family formation, entrance into the labor force, and college

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