Pesticide Use and Produce Quality

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WHO MAKES PESTICIDE USE DECISIONS: IMPLICATIONS FOR POLICYMAKERS

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Concern about the impacts of pesticide use on food safety, worker safety, water quality and the environment has motivated establishment of a complex set of pesticide-use regulations. However, these policies are far from perfect and research continues on how to improve control of pesticide use. Identifying efficient and effective policies requires understanding both who makes decisions regarding pesticide use and how these decisions are reached.

Most quantitative models of pest management choices assume, either implicitly or explicitly, that decisions are made by farmers. While there is some literature addressing the importance of pesticide advisors, not much attention has been given to the role of other elements in the agricultural production chain in decisions regarding how to manage pest problems. On the other hand, there is growing recognition that the production of food and fiber represents a process that involves many entities. Since decisions at each stage of the production chain are interrelated, pest management choices are likely to be affected not only by farmers and advisors but also by other agents.

This paper presents the findings of a recent survey investigating the contributions of various agents at different stages in the food production chain to decisions on pest management and pesticide use. It identifies those links that affect pest management practices and describes the types of impacts they have. It also investigates how the pattern of pesticide decision making varies across agricultural industries and regions. The analysis is mostly limited to Calfiornia fruits and vegetables. Since California is the largest agricultural state and the major producer of many of the fruits and vegetables sold nationally, pest management choices in California have significant impact outside the state. Furthermore, we postulate that some of the generalizations derived from California data apply to other regions.

The first section of the paper identifies different types of agents

that are likely to affect pesticide choices and describes their sequential relationships. This is followed by a more detailed discussion of the role of each of these entities in pesticide decisions. The paper closes with policy conclusions and implications.

Pesticide Decision Makers

We distinguish two types of agents affecting pesticide use: decision makers that determine pest management options and strategies and decision makers who affect actual application methods. Figure 1 presents schematically some of the relationships between these two groups. The decision makers who affect pesticide-use options in-

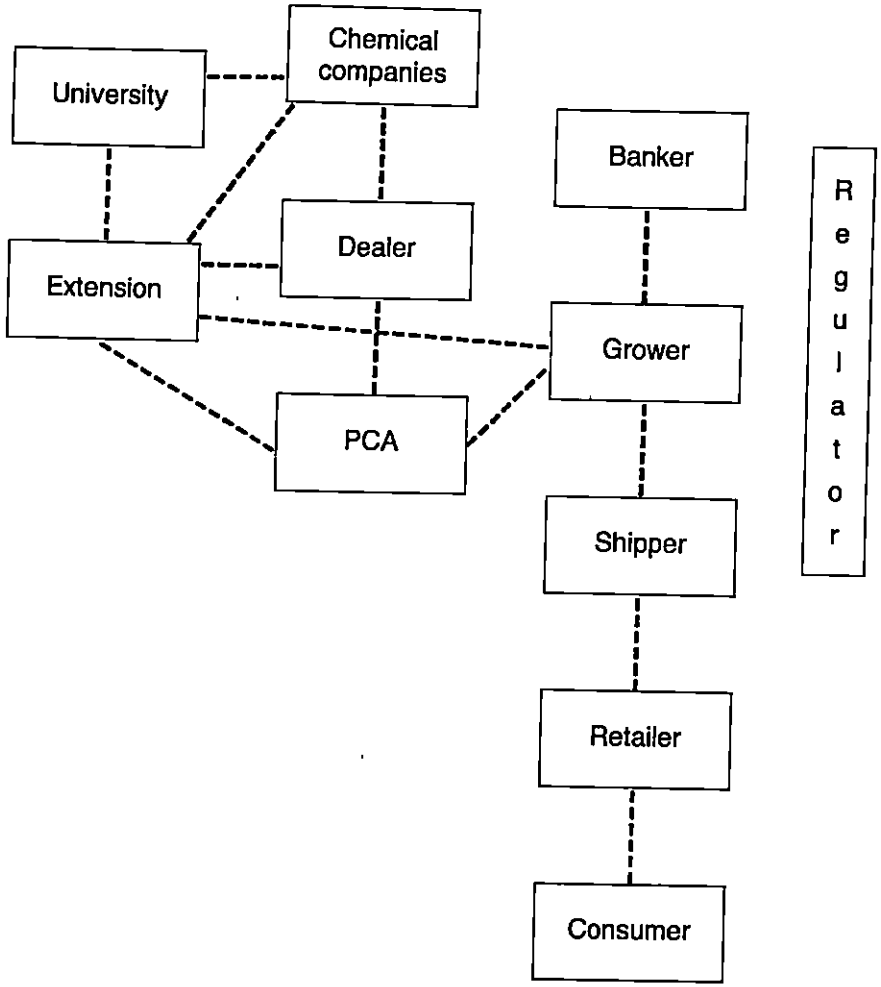

Figure 1. Decision Makers on Pesticides

clude chemical companies and university extension and research personnel. They provide information mostly to dealers and pesticide consulting agents/pest control advisiors (PCAs) and sometimes to growers. Though the grower is the ultimate decision maker about pesticide applications, his choices are constrained by bankers, PCAs, and dealers, as well as by shippers, wholesalers or processors. These latter middlemen translate the demands and preferences of retailers and consumers into information that affects the grower's use of pesticides. All of the decision makers are affected one way or another by regulations.

This paper primarily analyzes choices that determine measures of actual pesticide application. We start by outlining the relationships among decision makers who determine pesticide management options and strategies. Obviously chemical companies play a crucial role in decisions about pesticide options, but they are not alone in this regard. Decisions about pest management options result from interaction among pesticide companies and university scientists (at campus research labs and experimental research stations) and extension units located in agricultural production areas.

Pesticide companies are not homogeneous. Some are chemical and/or oil companies that produce pesticides as by-products of other production processes. For example, Chevron and Shell Oil produce pesticides to maximize their revenue from oil production. Similarly, Dow started as a chemical producer. Some companies are in the business of selling pest control agents rather than chemical pesticides. In some cases, as companies developed marketing networks and infrastructures for addressing pest problems, their relative commitment to sell chemicals (rather than biological agents) to address pest problems has been reduced.

Some companies, for example Monsanto, have invested heavily in developing non-chemical pest management treatments and plan to take advantage of their marketing networks to sell these products. Chemical companies seek to develop profitable products that can be sold through their marketing networks for pest control products. Though they may have a relative advantage in the use of chemicals to treat pest problems, at least some will expand into the development of pest control agents where they perceive a market for these products.

Because of the brevity of the literature on the supply of pesticides, more research is needed. However, the literature on the economics of research and development provides some insight regarding the behavior of pesticide manufacturers and the development of new products. Recognizing the incentives manufacturers face leads to hypotheses about factors that affect their behavior.

It is not necessarily true that manufacturers suffer from regulations banning certain chemicals for pest control. This is especially

true in the case of old chemicals that are unprotected by patent law and can be easily copied and produced by several manufacturers. Hence, the existing regulatory framework may not, in fact, conflict with the interests of existing chemical manufacturers. It can ensure a shorter economic life for materials and provide new opportunities for manufacturers to make monopolistic profits during the early stages of patent life. The cost of regulatory efforts also provides some relative advantages to existing manufacturers by preventing new entrants, thus leading to a less competitive chemical production structure.

Development of pest management options consists not only of introducing new materials, but also identification of materials appropriate for particular uses and determination of effective dosage levels. Chemical companies have large research facilities at which they test new chemicals for effectiveness and side effects. In some cases, they may even test the efficiency of new chemicals on experimental farms, but in most cases, they try to work with university scientists.

Companies send university scientists product samples and ask them to experiment for specific problems in different regions. In some cases, the universities may be paid by chemical companies to try products. Extension specialists receive many chemicals to try and then make their own assessments of the relative efficiency of certain of these products. This may affect their choices, the way they educate the PCAs and growers, and the way perceptions about the chemicals are developed.

Although chemical companies develop products and try to market them both nationally and internationally, often the development of new chemical solutions to pest problems is requested by growers. When there are pest problems, extension and university professionals may search widely to find appropriate products. For example, for several years scientists at the University of California have been looking for either chemical or non-chemical treatments to address the whitefly problem. There is a similar search underway for a solution to the phyloxera problem in grapes for the California wine industry. Every time a new plant disease is discovered, agronomists, producers and farmers look for a solution, including chemicals, and try to obtain new materials from chemical companies. On one hand, chemical companies are aware of the problems and try to develop appropriate materials. On the other hand, researchers look for solutions to new pest problems. So, in many cases, the introduction of new chemical solutions for pest problems represents a joint effort on the part of several parties.

The Role of Regulatory Agencies

Regulatory agencies play a significant role in pesticide-use decisions. They establish parameters for the selection and application of

pesticides and for the certification and training of pest control specialists among other things. Regulatory agencies affecting pesticide choices include the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), the Occupational Safety and Health Administration (OSHA), and state agencies such as the California Department of Pesticide Regulation (DPR) in the California EPA, the California Department of Food and Agriculture, and the offices of the County Agricultural Commissioners.

The above regulatory agencies establish laws and procedures that explicitly address pest management problems. Under the provisions of the Federal Insecticide Fungicide Rodenticide Act (FIFRA), the EPA is authorized to grant pesticide registration and to regulate pesticide use and residues in food and feed. The FDA maintains responsibility for monitoring residues and enforcing tolerances set by the EPA. The Department of Transportation is authorized to regulate the shipment of hazardous material. OSHA has authority over worker safety regulations in the manufacture, formulation and distribution of pesticides.

California's DPR is responsible for registering all pesticides prior to sale in the state; for monitoring and regulating use of pesticides; for licensing pest control specialists, distributors, and dealers; and for testing produce for pesticide residue levels. The County Agricultural Commissioners administer local programs regulated by DPR. This includes enforcement of regulations pertaining to pesticide use, transportation, storage and sale; registration of pest control specialists; and monitoring the activities of growers, pest control businesses and pesticide dealers.

In addition to government agencies responsible for policies that explicitly address pesticides, other agencies have important impacts through regulations affecting agriculture and the food sector. For example, there is an ongoing debate over whether U.S. Department of Agriculture (USDA) revenue support programs encourage over-production and over-use of pesticides. Marketing orders and agreements established by USDA and various state departments of agriculture set product quality standards, including standards of appearance and cosmetics, that may induce substantial use of pesticides. Even the Bureau of Reclamation's water pricing scheme may affect pesticide use through its impact on water application techniques and water use patterns. When water is cheap, farmers may tend to adopt gravitational irrigation technologies, while, when water prices are high, farmers shift to sprinkler and drip irrigation and to irrigation scheduling. Modern irrigation technologies may also serve as more efficient vehicles for the application of pesticides in the field and thus reduce pesticide-use levels.

The remainder of this paper addresses the role of private parties in pesticide development and use choices.

Pesticide Choices, Application Methods: Role of Different Agents

Banks play an important role in pesticide-use choices. Bankers provide credit for short-term production activities as well as for long-term investments and they look at pesticide choices in terms of potential impacts on both repayment and viability.

In many interviews, we heard that bankers inspect farmers' planned pesticide use and even set lower bounds on amounts to be spent addressing pest problems. They do this in order to reduce yield risks. Because bankers suffer when farmers are unable to repay loans, they have in-house staff members who conduct inspection activities to assure minimum yield losses and profitability. This has become especially important in recent years.

In the past, banks relied heavily on using land as collateral for loans. In recent years, however, they tend to use ability to repay as the major criterion in loan decision making. The reduction in the importance of collateral as criteria for loaning is a result of decreases in land values that occurred in the mid-1980s. When farmers defaulted, banks acquired a great deal of land and they suffered steep financial losses trying to sell this property.

·Banks have increased the intensity of their efforts to ensure that they do not provide loans that result in bankruptcies and loss periods. They may have their own staff members who assess behavioral criteria to address pest and other production problems. Our interviews suggest that, in many cases, bank loan assessors use narrow criteria to assess production and pesticide use. They may not be updated about new developments in pest management, for example biological controls, and may be quite conservative. The net result is that they recommend pesticide application levels that exceed optimal amounts, and may even recommend using materials that are relatively more harmful to the environment. On the other hand, bankers may be concerned that the use of pesticides will result in groundwater contamination or other long-lasting effects that will prevent resale or reduce the value of the land in the long run.

The role of bankers in pesticide decisions has two implications for the reduction of pesticide use. First, bankers should be informed about pesticide management issues and choices. In their assessment of farmers' production plans and loan applications, they should be aware of problems of resistance and the viability of non-chemical pest treatments. Second, farmers concerned with liability and profitability should emphasize the effectiveness of monetary inducements for reducing pesticide applications. If financial incentives (taxes against particularly toxic chemicals, subsidies for biological control) were enacted, bankers would take them into consideration in assessing farmers' production plans and could act as an important

voice to induce pesticide-use reduction and more sensitive environmental behavior by farmers.

Relationship Between Farmers and Pest Control Advisors

When it comes to farmers' pesticide choices, one must first recognize there are many reasons for differences in farmers' choices. One obvious difference is farm size. Very large growers, with tens of thousands of acres of cotton or thousands of acres of fruit trees, conduct most of their pesticide choices and application activities in-house. Growers such as Boswell (the largest cotton grower in California) and others have their own entomologists and pest control advisors. They have all of the equipment necessary for ground spraying of pesticides and may even own planes for aerial spraying. In contrast, middle-sized and small farms rely on purchased services for many pesticide activities. These farmers may rely more heavily on professional pest control advisors and pest control application companies.

Pest control advisors may be paid employees of pesticide dealerships or act as independent consultants paid on a per acre basis. In our interviews with growers and dealers, several dealers confirm that, since pesticide advisors may be perceived to over-prescribe pesticides if they are paid in proportion to their sales, they are starting to pay their pesticide control advisors a flat fee. But even under such arrangements, compensation is still tied to sales since advisors receive bonuses based on the profitability of the dealership and their performance is reviewed for promotions or pay raises.

Still, many interviewees suggest that advisors' personal reputations are often much more important than the dealers' reputations, and farmers may retain a particular advisor when the advisor moves from one dealer to another. Some farmers also perceive very small differences in the prescriptions between independent and dealer-employed pesticide consultants. They suggest that, although there are some independent consultants who particularly emphasize non-chemical pest controls, both independent and dealer-employed advisors can encourage farmers to participate in integrated pest management schemes and the use of non-chemical controls.

Our interviews suggest pesticide dealers are aware their continuous employment as consultants depends on their ability to reduce pest damage, and both kinds of advisors prescribe heavy doses of chemical treatments when they see severe pest damage. Furthermore, decisions on the extent to employ non-chemical treatments depend heavily on the farmer and on his or her interaction with the pesticide control advisor.

Our interviews suggest several factors affect the choice of pest control agents. Farmers with small farms who rely on dealers for the

purchase and even the finance of pesticides are more likely to use the dealers' PCAs, while larger farms that may buy directly from wholesalers and receive volume discounts may use either their own or independent PCAs. PCAs working for dealers may not specialize in specific crops as independent PCAs often do. Rather, they may identify a market niche in terms of a commodity or a treatment and specialize in that. Therefore, growers of high value crops may rely on independent PCAs who specialize in their commodity. For example, the growers of processing tomatoes tend to use dealers' PCAs, while the growers of fresh market tomatoes, that are of much higher value, may approach independent specialists. Similarly, a small farmer who grows feed for his animals will use the local dealer's advisor, while the growers of vegetable crops may go to an independent PCA specializing in his crop even if the independent is further away.

Independent specialized PCAs may provide consultations and advice, not only about pesticide problems, but also about other aspects of production and irrigation, for example, irrigation management. In addition to monitoring the field for pest problems, these specialists may also conduct soil tests and other services.

Both independent and dealer-employed pesticide control advisors scout the fields for farmers. Farmers also conduct monitoring activities themselves and are involved jointly with PCAs in making pest application choices. The results of monitoring efforts, both by consultants and farmers, are crucial in the determination of pest control measures.

In many cases, farmers continue to use preventive pesticide measures. Government regulations may actually shift farmers from the use of responsive pesticide controls to preventive ones. For example, changing the time period during which reentry to the field is disallowed after spraying may lead farmers to adopt preventive spraying so they are assured entry at the planned harvest date.

A recent study by Wiebers (1993) surveys California tomato growers on their involvement in pesticide choices. It shows that the extent to which farmers themselves make pesticide choices depends heavily on their degree of involvement in scouting. Growers who invest greater effort in scouting the fields for pests, both in terms of their own time and in terms of the intensity of their efforts, are more likely to have a major say in pesticide-application strategies. It is also estimated that the more say growers have about pesticide applications, the less pesticides are actually applied. Thus, increased grower effort in monitoring and scouting the fields leads to savings in pesticide expenditures. The study also finds that growers who tend to be more involved in scouting and pesticide application choices are likely to be more educated and have greater familiarity with pest behavior and pesticide properties. Thus, education is a key element in

improving grower participation in pesticide choices and reducing pesticide use.

Our interviews also reach similar conclusions. PCAs prescribe application levels that are on the product labels. These dosages assure reliability of pest control that may be above what makes sense economically when the cost of the materials is taken into account. The more informed and experienced farmers are, the more likely they are to reduce applications below these recommended levels. In many cases, farmers argue that the cost of pesticides may make them ignore the advisors' recommendations and not apply chemicals. Furthermore, the management of pesticide activities tends to be dependent on the timing and extent of other activities, such as irrigation and harvesting, and farmers may not follow the advisors' recommendations if there are negative effects on irrigation scheduling or harvesting decisions.

Farmers may adopt a preventive approach to pest management and sometimes predetermine pesticide applications without knowing actual pest situations if their production structure is very rigid and if their flexibility in pesticide application is limited. Therefore, production systems that allow flexibility and do not preclude access to the field because of the requirements of other practices, such as irrigation, are more likely to reduce pesticide use and encourage responsive pesticide-use choices.

These findings suggest that requiring pesticide application levels to be prescribed by experts may not necessarily reduce spraying. Studies from other countries suggest that farmers may actually apply pesticides at below the recommended levels in order to reduce costs. When they have more control of pesticide choices and are informed about the risk-benefit ratios, they may apply less chemicals and even take extra risks relative to the recommendations of manufacturers or PCAs. Therefore, it appears that increased education and extension efforts may have important results in reducing pesticide applications in the long run. Educated growers who face the right incentives are likely to be most effective in reducing their level of pesticide use.

The Role of Extension

Extension plays a major role in pest management choices. Although in California, extension specialists' direct contact with farmers is declining, and most farmers do not receive much direct advice on their daily operations from farm advisors, many farmers do participate in workshops sponsored or developed by extension agents and here they receive a great deal of recent information and advice. Farmers regard extension agents as objective sources of information and rely on their advice and recommendations in choosing among different brands and different strategies.

On the other hand, extension agents are more directly involved in educating and informing pesticide control advisors and dealers about the efficacy and risk of different pest control agents. And we have seen that direct contact with, and education of, farmers is now done by these paid advisors.

Farm advisors and extension agents are actively involved in developing new integrated pest control management schemes. They work with university researchers in developing and testing such strategies. Their experiments are conducted on some farmers' plots and, therefore, they may work more intensively with a small group of selected farmers. Successes of some of these experiments are disseminated among farmers by imitation. Furthermore, as new strategies prove to be effective, PCAs prescribe them.

Extension specialists are also very important in recruiting university and chemical company assistance in identifying solutions and management strategies for new pesticide problems. Since pest problems and viable solutions tend to be locally specific, advisors are able to provide information about the history and problems of specific locations and provide immediate access in implementing new solutions. Farm advisors and extension specialists may also provide training and education for farmers who want to become their own pest control advisors with the legal right to prescribe pesticide treatments as well as provide the training for pesticide applications.

The university, experiment stations and extension are especially important in developing and diffusing non-chemical pesticide treatments. The research undertaken by chemical companies is, by and large, directed at developing new products to control pesticide problems and these may earn income for the developers through product sales. Even new companies developing non-chemical solutions seek to create products (bacteria and nematodes) that will provide income from sales.

University researchers and, in particular, extension specialists do not have strong incentives to sell new products. Therefore, they may consider and encourage the adoption of alternative practices, such as biological controls and protective practices, to reduce pest problems. Thus, it can be argued that reduction in support for extension activities increases the dependency of agriculture on purchased inputs to address pesticide problems.

Extension specialists also play an important role in addressing the environmental side effects associated with agricultural production activities, including pesticide use. A recent study on extension activities in California (Goldman, Shah and Zilberman) suggests that many extension activities are aimed at control of the environmental side effects of agriculture.

Shipper and Grower Participation in Pesticide Choices

There is much evidence that quality is a crucial element in determining produce prices. In certain commodities, quality premium may raise prices four times over the base price. Parker and Zilberman study the behavior of peach prices as a function of time and quality. They find a very strong seasonal pattern in which prices may be three times higher in the early season than in the middle of the season, and quality premiums (in the case of peaches, premiums are for size and sugar content) are very high, especially early in the season. Given the importance of product quality, it is not surprising that farmers make great efforts to improve their products and we see increased focus on sweetening fruits and vegetables. Increased sugar content attracts certain types of pests and, thus, may lead to increased pest control activities.

In most cases, farmers do not sell products directly, but rather go through several middlemen. Parker and Zilberman find that the premiums for quality paid to farmers by wholesalers and packers are not necessarily consistent with the premiums paid by consumers in retail markets. At the farm level, farmers are paid higher premiums mostly depending on the time of season and size and not so much for sugar content, but at the retail level sugar content is an important contributor to price.

The marketing network changes constantly, mostly due to improvements in computer and communication technology. The food processors and distributors we interviewed express a strong desire to improve the quality of the product sold to consumers and they recognize the need to provide farmers with incentives to grow products consumers really want. Growers and packers believe there is strong demand for fresh and ripe fruit (ripeness reflects higher sugar content) and, therefore, they are developing new modes of packing and transportation to provide more tree-ripened fruits.

Growers report that shipping tree-ripened fruit, both within California and to the eastern United States and Canada, has been highly profitable and in the future they intend to increase both the sugar content of the product and the amount shipped. This suggests that some fruit may have to stay on the tree longer and may require increased pesticide applications. Thus, the pursuit of quality may lead to increased pesticide use. Alternatively, this may lead to more local production because if the fruit does not have to be shipped great distances, it can stay on the tree longer. Much pesticide use is undertaken to ensure that the fruit is of sufficient quality for transport and storage. With local production, the demands of transport are lower.

A study by Babcock, et al. (1992) shows that at least one-third of the benefits associated with pesticide use reflects quality improvements rather than increased yields. In some cases, quality improve-

ments are cosmetic, but in many cases they mean improved flavor. Thus, increased consumer income, which leads to increases in demand for quality, may lead to increased pesticide applications.

On the other hand, consumers are aware of the negative side effects associated with pesticides and they prefer low chemical content in the fruits and vegetables they consume as well as reduced chemical applications in production. There is much evidence that consumers are willing to pay at least 15 percent more for reduced pesticides or pesticide-free products. Some of the population is especially averse to pesticides and the amount they are willing to pay for untreated produce may be much higher. Therefore, it seems that the use of pesticide content as a product attribute should be encouraged and policies should facilitate establishment of markets for green (reduced-pesticide or pesticide-free-organic) products.

In recent years there has been an increase in the acreage of organically-grown fruits and vegetables and our interviews suggest farmers perceive the organic market to be growing. There has been some attempt to grow and market pesticide-free food with mixed results. Interviews suggest some growers suspect the demand for these products may not be as great as willingness-to-pay studies suggest. Other interviewees argue that, while efforts to improve current processes of labeling, certification and promotion may increase consumer awareness about pesticide-free food, these are expensive processes that may hamper the development of such markets. It may also be that loss of quality characteristics (in terms of appearance) associated with reduced-pesticide use may make these products less attractive overall. In this case, the challenge is to develop production practices that yield high quality products with little or no chemical use.

The extent to which shippers and retailers affect pesticide use varies between crops and regions and according to the final destination and use of the crop. Fruits and vegetables exported to countries with strict pesticide-tolerance regulations, such as Japan and Canada, may be treated differently than fruits and vegetables grown for the domestic market. The shippers and producers of processed foods (wine, tomatoes) are more explicit in their specifications regarding pesticide use in the production of the inputs for their processing activities. Producers of baby food are very strict regarding the specifications of the products they use. Furthermore, increased concern about the vulnerability of small children to pesticides may toughen some manufacturers' pesticide specifications. Wine producers (Gallo and others) anticipate that pesticide control regulations are likely to become tougher in the future and, therefore, they have started instructing many growers not to use any pesticides (except sulfur) in wine production. Their policies are particularly rational given that wine is durable and may be stored for many years; they want to ensure that the future value of the wine is not reduced because of the present use of pesticides. Even tomato processors provide farmers with specification of pesticides they cannot use. Again, this is in order to protect the value of stored inventory.

In most cases, producers of products for the fresh market do not specify chemical use. They specify quality standards and they expect farmers to use all legal means to attain this quality. One important phenomenon is increased vertical integration of fruit and vegetable production, either through contracting or the establishment of vertically integrated firms. Some of the larger packers and shippers of fruits, such as Sun World or Di Mare Brothers in California, are establishing their own brands and they provide their growers with detailed instructions regarding production practices and product specifications. These agribusiness organizations have also started to develop private extension services to further control the products their farmers produce. These vertical relationships may be used to enhance more environmentally sound practices in the future.

The establishment of brands of fruits and vegetables may help to improve the environmental quality of agricultural production in several ways. Some brands may differentiate themselves with a "green" label. (We know of one failed attempt to establish such an identity, but producers may be more successful in the future, especially if better mechanisms for certification of environmentally sound practices are established).

Furthermore, processors who buy from growers concentrated in certain regions may serve as an effective channel to implement environmental legislation. For example, if a large number of dairies generate waste that contaminates a bay, there is a non-point pollution problem. The establishment of pollution control legislation is complicated in such cases because it is difficult to assign responsibility to specific individuals. However, if all the dairies in a particular area sell their product to one processor, it may be effective to make the producer responsible for enforcement of some regional environmental regulations and standards. The processor is likely to be more familiar with the activities of individual producers than a government agency and, therefore, will likely be more efficient in assigning responsibility.

By assigning some responsibility for the environmental side effects of production to the buyers and processors of agricultural output, it may be possible to develop a more effective mechanism for improved environmental quality. Some marketing organizations have already started developing their own extension services in order to educate farmers about production practices. It may be that in the long run they can also assume some responsibility for introducing environmentally sound practices and reducing the environmental side effects of agricultural production.

Many growers market their products through cooperatives such as

Sunkist, Blue Diamond, etc. These cooperatives may play a major role in pesticide decisions and in establishing environmental quality performance standards for the agricultural sector. Some of these organizations serve as channels for input purchases. In some cases they also sell chemicals and even disburse information regarding pest management.

Two factors may contribute to cooperatives and processors playing a major role in the purchase of pesticides. One is volume discounting and the other is credit. When a packer has a large number of farmers working for him, he may purchase a large volume of chemicals to sell so both packer and growers share in the volume discount. The cost of the chemicals are deducted from the farmers' sales proceeds. So, in essence, the buyer finances the purchase of the chemicals. Cooperatives play a similar role. But large volume sales of chemicals by produce buyers may strongly affect pesticide choices. Low prices and credit availability may steer farmers' pesticide strategies away from biological control towards pesticides provided by the middlemen.

Agricultural producers may compete in production but collaborate in other areas such as marketing, purchasing inputs, lobbying, or R&D. Marketing order arrangements may have substantial impacts on both pesticide use and the environmental side effects of agricultural activities through product quality standards and the research and development activities they finance. It is clear that product quality standards established by marketing orders facilitate more effective sorting and marketing of products. It is also clear that grading affects pesticide use. To the extent that grades encourage the standardization, farmers may be discouraged from growing varieties that are more environmentally suited and require less pesticide use. Cosmetic appearance standards may increase the application of pesticides on crops such as apples and citrus. The impact of federal, state and industry grading on pesticide use must be investigated further. In particular, it will be useful to identify procedures that may lead to excessive use of pesticides from the perspective of welfare economics.

Similarly, growers' associations provide a substantial amount of money for research on specialty crops. Some of this money is allocated to identify solutions to pest problems and to find substitutes for pesticides that are banned or found to be ineffective. Furthermore, growers' associations play an important role in negotiating the implementation of pesticide policies with regulators. Recently a growers' association representing relatively minor commodities started negotiating with pesticide producers regarding possible cost sharing and other collaborative efforts to assure that chemicals are registered for use on specific products. Thus, organizations established for collective efforts by growers can have substantial impact on pesticide use and the set of feasible pest control practices.

Regional Size and Crop Differences

Agricultural producers are heterogeneous in terms of size, location and crop production. Pesticide-use practices and institutions that affect pesticide use vary across crops and across regions. The use of aggregate relationships to estimate the impacts of pesticide regulations may be misleading or even errant because, as many studies show, the distributional effects of pest control policies may be more substantial than the aggregate effects. Thus, one has to recognize regional differences in establishing policies and regulating pesticides.

Our studies suggest that growers of high value annual crops (such as vegetables and strawberries) are likely to be more intensive users of pesticides and chemicals and less likely to experiment with alternatives than growers of fruits and nuts. It seems that the production of perennials offers more leeway for experimentation and the consequences of mistakes may be less devastating than with the production of annuals. Even within the same crop, awareness of pesticide programs and the relative importance of chemical control vary substantially. This is in part the consequence of the growing of varieties (because of grade standards) that are not environmentally suited. For example, East Coast growers of apples are much more intensive users of fungicides than West Coast growers. Growers in California's San Joaquin Valley tend on average to use less chemicals than growers on the East Coast. Even within California there are differences within particular industries. For example, interviews with consultants to the wine industry suggest that growers in Napa and Sonoma Counties are much more quality conscious and tend to be more selective in pesticide choices even if it means some weeds are left between the vines. On the other hand, San Joaquin Valley growers are more production oriented, eliminating all weeds between the vines for fields that are meticulous in appearance.

In addition to (and maybe because of) physical differences among regions, there may be differences in production philosophies. Regional differences are also manifested in terms of the structure of industries. For example, the eastern side of the San Joaquin Valley consists of many older and smaller farmers who purchase pesticide advice, and even applications, from local suppliers. The western side of the Valley, which was settled more recently, has larger agribusiness conglomerates that often have their own in-house pesticide advisors and application capacities. These differences in structure may affect pesticide practices and the way new policies can be enacted and enforced.

Regional differences in terms of climate and resource availability can also affect pesticide use. Pesticide-use strategies are part of general farm management strategies and depend on the availability and cost of other inputs. When labor is scarce, farmers are more likely to

rely on herbicides rather than labor-intensive cultural practices to address pest problems. Where water is scarce and highly priced, farmers may adopt irrigation technologies that can both save water and reduce pesticide-use levels. In regions in which farmers use a diverse set of production practices to produce a variety of crops, such as the northeastern part of the San Joaquin Valley, there are many strategies for pest management and varied patterns of pesticide decision making and application. In regions that are dominated by one crop, such as Kings County where cotton is dominant, strategies for pest management in cotton are used for pest management in other crops.

While regional differences are crucial in explaining pesticide-use choices, there is a growing tendency toward the establishment of integrated marketing organizations which operate across regions. Some of the larger food marketers own production facilities in different regions so they can market products throughout the year. For example, the lettuce producer, Bruce Church, has operations in Salinas and Imperial counties and in Arizona. These organizations may be able to enforce some uniformity standards in terms of quality, but obviously operations and chemical use in each region are adjusted to local conditions.

Conclusions

This paper shows that pesticide choices are determined by the interaction of many agents. Pesticide-use decisions vary substantially across regions and crops and are dependent on environmental conditions and the structure of agriculture. The relationship of private and public sector research activities and the structure of university extension services affect identification of pest management solutions. Farmers' pesticide choices are affected by vertical integration and relationships with input suppliers, food handlers and packers. Farmers who are better educated tend to be more involved in their pesticide choices and use less chemicals. Less educated farmers tend to rely more on experts.

Alternative remedies to ameliorate the environmental side effects of pesticide use must take into account the properties of the decision-making process. Some of the policy conclusions this analysis suggests include:

- Policies that fail to take into account heterogeneity among pesticide users are inefficient. This implies that complete bans of pesticides are undesirable, particularly since pesticides with equal or greater environmental consequences may be substituted. Complete bans should be replaced with policies that allow more choice and flexibility for users. Taxation of pesticides (perhaps using the proceeds to subsidize research and adoption of biological controls and other environmentally sound practices, or to remedy the negative side effects of pesticides) seems to be a much more efficient policy. It allows users who derive great benefits from pesticide use to continue their use, while reducing pesticide use in situations in which the benefits are relatively low.

- Assigning responsibility for pesticide-use mishaps is not easy. It is incorrect and misleading to concentrate on only farmers and pesticide producers as the agents responsible for pesticide choices. Understanding the entire decision-making structure is important for assigning responsibility and liability rules for mishaps associated with pesticide use.

- Vertical integration in agriculture and the structure of food production and processing can be used in the design and implementation of pest control policies. Food processors and buyers as well as some input suppliers may provide a focal point for education of pesticide users and for provision of incentives. Similarly, regional and professional organizations in agriculture can play a role in shaping and implementing policies to improve environmental quality in agriculture.

- Consumers view pesticide content and food production practices as product characteristics. The food marketing chain may be utilized as a mechanism to demonstrate consumers' willingness-to-pay for environmentally sound practices. The government may assist and provide incentives to enable establishing markets for green products. Obviously, in the long run the effectiveness of such policies will be tested by the market.

- Prescriptive policies and direct control may lead to inefficient outcomes. Incentives and education provide a better avenue to improve environmental quality and pest management in agriculture.

- The design of efficient policies must recognize the decision-making patterns associated with pesticide-use choices. Failing to recognize these decision-making patterns or to affect the actual decision makers may lead to inefficient outcomes.

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