1. ADOPTION AND DIFFUSION OF SUSTAINABLE FOOD TECHNOLOGY AND POLICY

Darwin C. Hall and L. Joe Moffitt

I. BEGINNINGS OF SUSTAINABLE FOOD TECHNOLOGY AND POLICY – AN EARLY HISTORY

In the late 1800s, a philosophical battle raged between advocates of chemical controls for pest management and advocates of biological and cultural controls. "Charles W. Woodworth, Professor of Entomology at the University of California, advocated an ecologically based pest management approach throughout his long career. In 1896, he stated that everyone should have a clear idea of the controls available and how to apply them" (Smith, 1978).

A. Integrated Control and Integrated Pest Management

Then, following the Second World War, agricultural technology underwent a revolution with increasing applications of water, chemical fertilizers, pesticides and mechanization. Agronomic research focused on crop varieties best suited to exploit low-priced inputs, with dramatic increases in yield per acre. In the United States, the institutions propelling the technological revolution were financed by the national government, subsidizing research at land-grant universities in each state. Since the passage of the Hatch Act in the 1800s, every college of agriculture has faculty with joint appointments in agricultural experiment stations to carry out basic research, and agricultural extension

Economics of Pesticides, Sustainable Food Production and Organic Food Markets
Volume 4, pages 3–18.

ISBN: 0-7623-0850-8

positions to deliver the results to growers and assist with adoption of new technology. Major chemical companies and farm equipment manufacturers donated increasing amounts of funding, helping to shape the kinds of technological improvements borne of this institutional system. Headley (1968) found that increases in yields more than offset the costs of pesticides to growers. As he predicted, the production and sales of pesticides doubled in the next ten years just as it had done in the prior decade (USDA 1964, USDA 1971–1977).

In the 1950s, a group of entomologists in the United States changed the course of technological innovation. They had concerns about adverse impacts of agricultural chemicals on workers, consumers, fish and wildlife, and to the agricultural ecosystem itself. Knowing that economics drove growers' decisions, these entomologists focused on adverse effects to the agricultural ecosystem, and consequent economic loss, and they searched for pest controls that would be economic alternatives to pesticide applications (van den Bosch, Reynolds & Dietrick, 1953; van den Bosch & Dietrick, 1953, 1957; van den Bosch, Schlinger & Dietrick, 1957, 1959; van den Bosch, Schlinger, Dietrick & Hall, 1957; van den Bosch, Schlinger, Dietrick, Hagen & Holloway, 1959). By the mid-1950s, some graduate students left their Ph.D. programs in entomology and opened pest management consulting practices and insectaries (e.g. Dietrick), selling advice and biological pest controls to growers. As early as 1954, the entomologists revolutionizing agricultural research had coined a term to describe their philosophy, "integrated control" (Smith, 1978). Bottrell (1979) credits Bartlett (1956) as the first to publish the term, integrated control.

In their seminal paper, Stern, Smith, van den Bosch, and Hagen (1959) defined the concept of integrated control as "pest control which combines and integrates biological and chemical control" (p. 86), where pesticide application is "based on conclusions reached from periodically measured population densities of pests and beneficial species, . . . and based on a sound knowledge of the ecology of the organisms involved and projected future population trends of pests and natural enemies" (p. 87). The concept of integrated control was subsequently broadened to include all control methods (Smith, Apple & Bottrell, 1976) and formally renamed Integrated Pest Management (IPM) by the Council on Environmental Quality (1972) of the President. From an economist's perspective, "IPM substitutes knowledge and information for pesticides by optimally choosing from a wider set of available actions; considering interactions between pests, natural enemies, weather patterns and crop growth and utilizing more accurate knowledge of such interactions;

monitoring insect and mite populations in a timely and precise fashion; and utilizing more accurate monitoring methods and devices" (Hall, 1977a).

The role of IPM can be juxtaposed to the "pesticide treadmill", caused by resurgence, secondary out-breaks, and resistance. Pesticide applications kill and reduce populations of pests and natural enemies (parasites, predators), and then the pest populations resurge to much higher levels, because there is a time lag until food sources are available for predator and parasite populations to resume previous levels. Unable to wait for natural control to reestablish itself, the farmer is compelled to apply more pesticide. Some potential (secondary) pests are controlled by natural enemies to populations below levels that cause economic damage. Pesticide application kills the natural enemies of secondary pests, and their populations resurge to levels that cause economic damage, compelling even more pesticide applications. Arthropods are small, and the smaller the creature, the shorter the life span, and the more fecund, with greater "genetic plasticity". With pesticide application the survivors that reproduce have some inherent resistance, and they reproduce by the thousands within short time periods. Repeated exposure results in pest resistance to the pesticide, compelling higher dosage rates (Carlson, 1977). Ever more frequent applications at higher doses define the pesticide treadmill. The alternative, IPM, considers the economic costs of resurgence and secondary outbreaks when making the economic decision to use chemicals, and requires monitoring the agro-ecosystem to measure the level of pest infestations and to identify populations of beneficial insects – augmenting them with releases of biological controls and/or maintenance of habitat or crop rotation conducive to enhancing the populations of beneficial insects, timing pesticide applications to destroy pests when they are most vulnerable or avoiding applications when biological controls might be vulnerable, and applying pathogens to kill pests, for examples. The reduction in pesticide use slows the rate of pest resistance.

Research entomologists claimed that advances in IPM strategies could increase yield and reduce pesticide applications and costs (see above references to Van den Bosch et al.). From 1972 to 1978, the National Science Foundation, the Environmental Protection Agency, and the U.S. Department of Agriculture funded a $5.5 million, 18 university research project lead by Carl B. Huffaker (Huffaker, 1978). In the late 1970s and early 1980s, Perry L. Adkisson lead the continuation of the research in IPM; the Adkisson project became known subsequently as the Consortium for Integrated Pest Management, reporting successful IPM programs for cotton, alfalfa, soybeans, grapes, and apples (Frisbie & Adkisson, 1985). In Europe, research on IPM and low input alternatives has helped growers substitute alternatives for pesticides (OECD, 1993, 1994a).

Fungicide use remained relatively stable during the 1980s, and insecticide use actually dropped as a result of the development and adoption of integrated pest management (Carlson, 1988; Zilberman, Schmitz, Casterline, Lichtenberg & Siebert, 1991).

Concern about the widespread use of pesticides persists for at least two reasons. Pesticides are unique among intentionally introduced environmental contaminants in that they are specifically designed to be injurious to living organisms. Agricultural uses of pesticides can involve direct risks of residues in food and water potentially ingested by humans. As an example, the safety of apples that contain chemical residues for consumption by children has produced a vigorous debate in the United States and has raised further concerns about the appropriate management of pesticides in the environment (Natural Resources Defense Council, 1989). There is also concern about potential adverse impacts on wildlife and environmental resources due to pesticides. Moreover, water quality has been a continuing pesticide-related concern among environmentalists. The environmental and human health concerns have contributed to interest in economically efficient pesticide use among farmers, researchers, environmentalists, the general public, and economists as well.

Because of the concerns about pesticides in the environment, it is perhaps not surprising that concurrent with the definition of integrated pest management was the development of interest in agricultural pest management among economists. The first economic analysis of pest control in agriculture (Hillebrandt, 1960a, b) appeared one year after the pathbreaking definition of integrated control by the entomologists, Stern et al. (1959). Patricia Hillebrandt's work is not only noteworthy for being the first economic analysis of its kind but also for foreshadowing the important role that female economists would come to play in pest management economics research. In the decades that followed Hillebrandt's seminal piece, important contributions by economists such as Christine Shoemaker (1973a, b), Katherine Reichelderfer-Smith (1979), and Carolyn Harper (1989, 1992) would prove to be influential in the field.

IPM challenged the eradication philosophy inherent in chemical control with the concept of pest control. Instead of eradication, the idea was to find the "economic threshold", originally defined by economists (Headley, 1971) as the level to which the pest population is reduced by controls, although the common meaning of "threshold" used by entomologists is the population level at which pesticide applications are initiated (Hall & Norgaard, 1973, 1974). The first econometric application, Carlson (1970) found that adjusting applications to a forecast of the pest population, rather than calendar spraying, reduced pesticide use and increase expected profits. Casey, Lacewell and Sterling (1975) found that profits increase for farmers who reduced pesticide use when beneficial insects are present.

IPM as a strategy means to control pests with a combination of controls: biological, mechanical, cultural, chemical, genetic and legal. However, the early work on the economics of pesticides tended to focus on basic functional relationships involved in crop protection from pests and rarely ventured into the realm of deployment of an arsenal of controls deployed by pest management consultants, as envisioned by integrated control's entomological founders, with some exceptions (e.g. Willey, 1974; Hall, Norgaard & True, 1975; Hall, 1977a, b, 1978; Hall & Duncan, 1984; Carlson, 1980). Moreover, IPM became more generally accepted by conventional agriculture, and by the end of the 1980s, Zilberman et al. (1991) estimate that "more than 50% of California growers practice IPM in one form or another." The practice of IPM, however, did not easily integrate biological and chemical controls; to the contrary, Carlson (1988a) found substantial obstacles to the adoption by growers of biological controls. IPM decision strategies can be defined solely in terms of pest decision making that maximizes profit to growers, or more broadly by taking into account negative external costs to consumers (food safety), worker poisoning, contamination of drinking water, contamination of fish, and more general environmental damage via transport by air, surface and ground water. As Moffitt (1993) states, "One can apply IPM threshold decision making principles to define a rational pest control strategy that growers might accept but that environmentalists might not." Interest turned toward organic farming (Carlson, 1988b).

B. Organic Farming

With the exceptions of some religious groups and the 1960–1970 counter-culture, few believed that organic farming was economically viable. Organic farming pioneers began the search for farming methods that do not rely on synthetic chemicals. In 1970, Rodale Press in Pennsylvania began a program to certify organic food, and in 1971 published a list of 34 organic farms in California. Some of these growers established the California Organic Growers, and in 1973, 50 growers reorganized this organization into the California Certified Organic Growers (CCOF). By 1988, CCOF had 380 growers and continued to expand rapidly. Cook (1988) estimates that in 1987 there were approximately 900 growers of organic products in California, equal to about 1% of the industry total of 82,463 (1982 Census of Agriculture), with revenue to growers of $50 million from 30,000 acres in California (relative to 7,831,307 total acres farmed). This represents very significant growth relative to 1982 when Altieri et al. (1983) estimated that there were 273 growers of organic products. "CCOF currently has about 736 growers that are CERTIFIED currently, and about 849 members certified if you include our processors. These numbers do not include pending or transitional members of CCOF" (Brian Sharpe, CCOF, September 2001).

With little support beyond their own organizations, growers have succeeded in devising complex strategies to grow and market organic food, and survived for more than a decade. Their survival is noteworthy given the comparable institutional superstructure that supports the research, development, registration, certification and application of synthetic chemicals. Partially in response to the needs of organic growers, the University of California established the Sustainable Agriculture Research and Education Program (SAREP) in 1986. Other states have developed similar programs, and in fiscal year 1988 a national program began, called Low-Input Sustainable Agriculture (LISA) and now referred to as Sustainable Agriculture Research and Education (SARE).

II. POLICY TO REDUCE NEGATIVE EXTERNALITIES FROM AGRICULTURAL CHEMICALS

The economics literature on policy relevant to integrated pest management is slim. The literature prior to 1981 is described in Osteen, Bradley, and Moffitt (1981) while a description of some key research/policy studies prior to 1993 is contained in Moffitt (1993). More policy-related material can be found in the early literature on policy related to organic farming (see Hall, Baker, Franco & Jolly, 1989, and the references therein).

Baker (1987, 1988, 1989) emphasized that price support policies based on acreage or yields encourage pesticide use, an issue picked up by Shortle and Abler (1999). Shortle and Abler (1999) mention non-point source run-off of pesticides to ground and surface water, contaminating groundwater in North America and Europe (OECD, 1991), and causing increased costs for water treatment and adverse impacts on human health. They also note damage to fisheries and ecosystems. Opschoor and Pearce (1991) point out that pesticides are persistent in the environment, with long half-lives; absorbed by microscopic animals and plants at the base of the food chain, they biomagnify as they pass through the food chain, stored in fatty tissue; and they are ubiquitous, found everywhere in the environment from close to the point of application to the polar regions of the earth. Thought to travel through water and the food chain, more recent work shows that pesticides travel on air currents across and between continents (AMAP, 1998; Raloff, 1996).

Shortle and Abler (1999) list the standard policy options: emission standards or taxes, and tradable discharge permits, but the costs of monitoring are prohibitive. They also suggest voluntary adoption of environmentally favorable technology, "combining public persuasion with technical assistance," but this approach is not economic, limiting success. They also mention pesticide registration, cancellation, and labeling so as to restrict use to safe practices or to avoid applications that risk human health or environmentally sensitive areas. Finally, they mention the option of taxes on pesticides, but note taxes on agricultural inputs have been so low as to have almost no impact, except in Sweden (OECD, 1994b) and Iowa in the United States.

Zilberman et al. (1991) argue that the risk to food safety is best addressed by labeling laws that distinguish among foods grown by low input methods and those that are organic. They list these policies to mitigate risk to workers, water contamination, and the environment: "chemical bans, use restrictions, pesticide fees or taxes, subsidies for non-chemical pest management practices, protective clothing, and application standards." They argue that uniform standards (bans, or uniform standards across crops and regions, such as use restrictions, protective clothing, application standards) are inferior to pesticide fees when trading off between policy costs and risks to human health and the environment.

Hall et al. (1989) consider the widest array of policy options: effluent charges, tradable permits, input taxes, subsidies, torts, food labels, application safety restrictions, and selectively banning or restricting use of pesticides. They review the options of effluent charges or selectively banning pesticides or restricting use, but dispersed use makes measurement and tax collection or compliance difficult to enforce, and the optimal charges or restrictions require information too costly for government to obtain. They note that food labels fail to include complete and accurate information of pesticide and byproduct residues, and experts disagree over risks. For farm workers, safety restrictions require literacy of workers and active participation by the growers, a principle-agent problem; torts will not solve the problem for illegal workers, direct and indirect exposure and cause and effect makes the burden of proof a separate problem (Tietenberg, 1988). More generally, Menell (1991) states that torts result in "highly unsystematic levels of compensation, distorted incentives, and high transactions costs." While Hall et al. argue that pesticide taxes or subsidies for low input or organic farming are the best options, they note that pesticide taxes redistribute wealth from chemical companies and growers, and make growers less competitive relative to other countries, reducing the political feasibility of this option.

Hall et al. (1989) also consider three policy options to increase the efficiency of organic food markets. One option is to subsidize research on marketing opportunities for supermarkets to sell organic food. A second option is to expand the existing Federal State Market News Information Service to provide data on prices, available distributors, wholesalers, and producers of organic food, not just conventionally grown food. A third option is to legally define several alternative labels, not just organic, but also CCOF (California Certified Organic Farmer) certified, chemical free, and IPM food.

One final area that the literature simply ignores is policy proposals to encourage the adoption of IPM.

III. IPM RELATED POLICY – AN EARLY HISTORY AND SOME MODEST PROPOSALS

One of the entomologists who invented the concept of integrated control, Robert van den Bosch argued in favor of prohibiting licensed pest control advisers from having a financial interest in the sale of pesticides. His position was that the conflict of interest inherent in a medical doctor not acting as a pharmacist is an apt analogy to the case of pesticides (van den Bosch, 1978). Hall (1977a, b), Burrows (1983), and Hall and Duncan (1984) estimate that growers who rely on advice from independent pest management consultants use about 50% less pesticide, have a slight reduction in yield, and are as profitable as growers who rely on pesticide salesmen for advice.

Hall (1977a) refined van den Bosch's idea. Instead of prohibiting pest control advisers from selling pesticides, create two classes of licensed advisers, those who are chemical salesmen and those who have no financial interest in pesticide sales. Hall pointed out that, in California, recommendations from licensed advisers must be in writing, and the data are tabulated. The data could, therefore, be summarized by crop and licensed adviser and then provided to growers to aid in their choice of an advisor. In 1980–1981, the Director of the California Department of Food and Agriculture worked with the California Legislature to craft a bill to implement this policy, but the bill was defeated. Had this bill passed, it would have been possible to alter restrictions on the uses of pesticides, allowing in certain cases the use of pesticides with a prescription from an independent pest control adviser.

In another refinement to van den Bosch's idea, Hall (1977a) suggested that EPA could allow the use of severely restricted pesticides in special cases where the pesticide is part of an IPM program and its use demonstrably and substantially reduces the total amount of pesticide applied. The EPA Administrator permitted, for a time, the use of a chlorinated hydrocarbon to control ants in citrus. Not a pest, ants eat a predacious mite, interrupting the biological control of a mite pest, and triggering the pesticide treadmill. Moffitt (1993) recounts another application of this idea in Massachusetts. There, 24 active ingredients are restricted from being applied in areas that contribute water to a well under severe recharge and pumping conditions or within a one-half mile radius of public drinking water wells that supply more than 100,000 gallons of water per day. A variance permits use of banned pesticides under certain conditions, including IPM pest monitoring and selective pesticide use.

Economic assessment of sustainable agricultural practices has continued to mature and to add to our understanding of how we might design policies to ensure an adequate and diverse food supply. This volume presents some of the recent developments and applications in this field.

IV. CONTRIBUTIONS IN THIS VOLUME

This volume is divided into four sections focusing respectively on pesticide use, sustainable food supply, demand for sustainable food production, and related policy. These four sections encompass the range of advances in theoretical and applied economic analyses concerned with pesticides and sustainable food markets. Chapter contributions include different methodological, ideological, and geographical perspectives.

A. Pesticide Use

The section on pesticide use contains four chapters that reflect recent trends in economic modeling related to pesticide use. Preceding even the appearance of Rachel Carson's (1962) influential Silent Spring, this area of economic research has its roots in the very beginnings of what is referred to currently as the economics of environmental resources. In the first chapter in this section, Hall and Moffitt reconsider a traditional topic in the economics of pest control; viz., the econometric measurement of the marginal product of pesticide. This econometric problem dates back to some of the earliest studies (Hillebrandt, 1960a, b; Headley, 1968) in the economics of pest control. Their reconsideration challenges what has become an accepted notion since the mid-1980s that the functional form describing production leads to an unambiguous directional bias in the econometric estimation of the marginal product of pesticide. Their analysis shows that, contrary to current perceptions in the economics of pesticides literature, sweeping econometric generalizations concerning the superiority of popular production function forms is not currently possible. They clarify misconceptions concerning the functional form issue and extend related econometric methods to account for critical biological features including pest numbers and phytotoxic effects of pesticides on crops. An empirical example illustrates their extensions to popular econometric practices.

In the second chapter in this section, Fernandez-Cornejo and Pho focus on the role of economic incentives in pesticide use, which has also been a traditional theme in the economics of pesticide use. Utilizing time series observations from 1945–1994, they provide the first direct econometric test of the induced innovation hypothesis as an explanation of the rapid increase in the use of commercial, chemical herbicides since the Second World War. The hypothesis tested is that relative prices are determinants of technical change and factor bias. A unique aspect of their econometric analysis is that it is based on quality-adjusted price and quantity data for both herbicide and labor variables. Their elasticity estimates tend to agree with the induced innovation hypothesis with respect to labor and land; however, the same cannot be said for herbicide/machinery substitution. Moreover, apparent inadequacies in their data series on private research expenditures also result in findings contrary to expectations. Their extensive data development and modeling effort highlights the difficulty in explaining the economic rationale behind one of the most obvious trends in pesticide use.

The third chapter by Davis and Tisdell looks at the status of farm-level decision strategies intended to promote efficient use of pesticides. They survey the economic threshold concept in agricultural pest management, including development of the concept in early works and recent extensions to account for multiple pest species and pest resistance to pesticides. Of special interest is their diagrammatic rendering of some steps toward producer optimal decision making in a multiple pest context. They appraise the potential for applying more sophisticated management methods versus routine efforts to reduce pesticide use in the livestock industry.

Wiebers, Metcalfe, and Zilberman continue the focus on understanding pesticide use by quantifying the expected difference in insecticide use per acre between growers who rely on pesticide salesmen as pest control advisors versus grower treatment recommendations in California tomato production. Their conceptual framework posits relationships between different pest control variables leading to a limited dependent variable econometric model. The model is estimated using data from a survey of tomato growers in six northern California counties. Results of estimation suggest that insecticide treatment recommendations from pest control advisors involve more insecticide use than growers' own treatment decisions. Based on the empirical analysis, some novel suggestions to reduce pesticide use include separating the sale of pesticides from pest control advice and raising pest control advisors' perceptions of grower expertise by improving grower training related to pest control.

B. Sustainable Food Supply

The section on sustainable food supply contains two chapters from both European and North American perspectives. In the first chapter in this section, Michelsen provides a current economic perspective on organic farming in Europe and, in particular, addresses the variation in responses to the Common Organic Farming Policies introduced by the EU member countries in 1992. The variation in the development of organic farming in member countries is significant in terms of farm size, production, and regional distribution, although the focus of Michelsen's analysis is on the differential impact of policy on the number of organic farms in member countries. The policies Mitchelsen examines include a common EU-wide definition of organic farming concomitant with certification and the obligation of member countries to provide some level of financial support for organic farmers. Michelsen explains the variation with institutional and organizational theory. He provides empirical analysis of the impact of various policy instruments on the growth of organic farming, the presence of institutional conditions for policy change, and comparison of institutional interrelationships with regard to organic farming policy.

In the second chapter in this section, Klonsky and Smith provide a unique analysis of the economics underlying the rapidly growing organic food industry in California, a state that accounts for more than half of organic vegetable production in the United States. They observe that aggregate growth figures tend to mask the significant changes in the composition of the organic farming sector that occur due to the substantial entry of new and exit of existing organic farms. Using detailed data from California's organic farming registration program gathered for the period 1992–1997, they use a random utility econometric model to compare farms that entered and exited the organic sector during this period. An important finding of their analysis is that entering organic farms are likely to be small compared to existing members of the organic industry. They discuss implications of the recently enacted federal organic certification program for entry and successful marketing by new organic producers and for the private certification industry.

C. Demand for Sustainable Food Production

The section on demand for sustainable food production provides a clear transition to policy issues. Padel, Lampkin, Dabbert, and Foster provide a comprehensive review of organic farming policies in the European Union with the aim of assessing whether and how organic farming can contribute to existing policy objectives. In their approach to policy evaluation, they take as the foundation for policy analysis the actual and proclaimed objectives of politicians, such as maintaining farm income, minimizing environmental consequences of farming, and enhancing rural development. Existing empirical evidence sheds light on factors driving sustainable food production, especially political demand for a cleaner environment.

Vanzetti and Wynen focus on the demand for domestic versus imported food products. They question whether environmental concerns should always contribute to the demand for domestic food products. Vanzetti and Wynen make the case that, contrary to some popular contentions, trade can contribute to a more environmentally sound way of supplying agricultural products to consumers. They illustrate their case with an example from the international wheat trade.

D. Policy

The last section of this volume focuses on policy related to pesticides and sustainable food production. In the first chapter in this section, Lynch and Carpenter present an economic analysis of regulated use in California of a chemical replacement for the fumigant methyl bromide. They compare three different policies (quotas, first come – first serve, and highest-value) for restricting use of 1,3-D at the township level based upon the criteria of efficiency and distributional (crop and county) impacts, using a putty-clay production framework and a model of constrained grower decision-making. An especially interesting finding of the analysis is that a quota based on historical use maximizes the aggregate value of 1,3-D in several different California counties.

The final two chapters in this section provide an interesting contrast in methodologies for economic evaluation of pesticide policies that account for human health considerations explicitly. Wilson, in the second chapter in this section, uses contingent valuation to measure the costs of farmer exposure to pesticide in Sri Lanka and finds the cost to be significant. He shows that willingness to pay increases with adverse farmer experience in handling pesticides, concluding that government intervention to educate growers about the hazards of pesticide may be valuable public health policy.

In the final chapter, Sunding and Zivin pursue a different approach to measuring the cost of pesticide exposure. They combine economic and toxicological information in an analytical framework for comparing the economic efficiency of pesticide regulatory policies. Explicitly incorporating contamination, exposure, and dose response factors in their analysis suggests that policies that affect both contamination and exposure are more efficient than policies that affect only one factor.

REFERENCES

Altieri, M. A., Davis, J., & Burroughs, K. (1983). Some Agroecological and Socio-economic Features of Organic Farming in California. *Biological Agriculture and Horticulture*, *1*, 97–107.

AMAP (1998). *Assessment Report: Arctic Pollution Issues*. Oslo, Norway: Arctic Monitoring and Assessment Program.

Baker, B. P. (1987). Incentives and Institutions to Reduce Pesticide Contamination of Ground Water. In: D. M. Fairchild (Ed.), *Ground Water Quality and Agricultural Practices* (pp. 345–355). Ann Arbor: Lewis Publishers.

Baker, B. P. (1988). *Organic Agriculture: Technological and Institutional Needs*. Santa Cruz, CA: California Certified Organic Growers.

Baker, B. P. (1989). Pest Control and the Public Interest: Crop Protection in California. *UCLA Journal of Environmental Law and Policy.*

Bartlett, B. R. (1956). Natural Predators. Can Selective Insecticides Help to Preserve Biotic Control? *Agri. Chem.*, *11*(2), 42–44, 107–109.

Bottrell, D. R. (1979). *Integrated Pest Management*. White House, Washington, D.C.: President's Council on Environmental Quality.

Burrows, T. M. (1983). Pesticide Demand and Integrated Pest Management: A Limited Dependent Variable Analysis. *American Journal of Agricultural Economics*, *65*, 806–810.

Carlson, G. A. (1970). A Theoretic Approach to Crop Disease Prediction and Control. *American Journal of Agricultural Economics*, *52*(2), 216–223.

Carlson, G. A., & Castle, E. N. (1972). Economics of Pest Control. *Pest Control Strategies for the Future*. Washington, D.C.: National Academy of Sciences, 79–99.

Carlson, G. A. (1977). Long run productivity of insecticides. *American Journal of Agricultural Economics*, *59*(3), 543–548.

Carlson, G. A. (1980). Economic and Biological Variables Affecting Demand for Publicly and Privately Provided Pest Information. *American Journal of Agricultural Economics*. *62*(5), 1001–1006.

Carlson, G. A. (1988a). Economics of Biological Control of Pests. *American Journal of Alternative Agriculture*, *3*, 110–116.

Carlson, G. A. (1988b). Economic Adjustment to Sustainable Agriculture: Discussion. *American Journal of Agricultural Economics*, *70*(5), 1175–1176.

Carson, R. (1962). *Silent Spring*. Boston: Houghton Mifflin.

Casey, J. E., Lacewell, R. D., & Sterling, W. (1975). An Example of Economically Feasible Opportunities for Reducing Pesticide Use in Commercial Agriculture (Cotton). *Journal of Environmental Quality*, *4*(1), 60–64.

Cook, R. L. (1988). *Marketing Organic Commodities in California: Structure and Obstacles to Expansion*. Davis, CA: University of California Agricultural Extension Service.

Council on Environmental Quality (1972). *Integrated Pest Management*. Washington, D.C.: Office of the President.

Frisbie, R. E., & Adkisson, P. L. (1985). *Integrated Pest Management on Major Agricultural Systems*. College Station: Texas Agricultural Experiment Station, MP-1616.

Hall, D. C. (1977a). *An Economic and Institutional Evaluation of Integrated Pest Management*. Washington, D.C.: Environmental Protection Agency, Contract No. 68–01–2982, and Ph.D. dissertation, University of California Berkeley, November, 1–216.

Hall, D. C. (1977b). The Profitability of Integrated Pest Management: Case Studies for Cotton and Citrus in the San Joaquin Valley. *Bulletin of the Entomological Society of America*, *23*(4), 267–274.

Hall, D. C., & Norgaard, R. B. (1973). On the Timing and Application of Pesticides. *American Journal of Agricultural Economics*, *55*(2), 198–201.

Hall, D. C., & Norgaard, R. B. (1974). On the Timing and Application of Pesticides: Rejoinder. *American Journal of Agricultural Economics*, *56*(3), 644–645.

Hall, D. C., Norgaard, R. B., & True, P. K. (1975). The Performance of Independent Pest Management Consultants in San Joaquin Cotton and Citrus. *California Agriculture*, *29*(10), 12–14.

Hall, D. C. (1977a). The Profitability of Integrated Pest Management: Case Studies for Cotton and Citrus in the San Joaquin Valley. *Bulletin of the Entomological Society of America*, *23*(4), 267–274.

Hall, D. C. (1977b). *An Economic and Institutional Evaluation of Integrated Pest Management*. Environmental Protection Agency, Contract No. 68-01-2982, 216 pp. and Ph.D. dissertation, University of California Berkeley.

Hall, D. C. (1978). The Profitability of Integrated Pest Management. *California Agriculture*, *32*(2), 10.

Hall, D. C., & Duncan, G. M. (1984). Econometric Evaluation of New Technology with an Application to Integrated Pest Management. *American Journal of Agricultural Economics*, *66*(5), 624–633.

Hall, D. C., Baker, B., Franco, J., & Jolly, D. A. (1989). Organic Food and Sustainable Agriculture. *Contemporary Policy Issues*, *7*(4), 47–72.

Harper, C. R., & Zilberman, D. (1989). Pest Externalities from Agricultural Inputs. *American Journal of Agricultural Economics*, *71*(3), 692–702.

Harper, C. R., & Zilberman, D. (1992). Pesticides and Worker Safety. *American Journal of Agricultural Economics*, *74*(1), 68–78.

Headley, J. C. (1968). Estimating the Productivity of Agricultural Pesticides. *American Journal of Agricultural Economics*, *50*(1), 13–23.

Headley, J. C. (1971). Defining the Economic Threshold. *Pest Control Strategies for the Future* (pp. 100–108). Washington, D.C.: National Academy of Sciences.

Hillebrandt, P. M. (1960a). The Economic Theory of the Use of Pesticides: Part I. *Journal of Agricultural Economics*, *13*(4), 464–472.

Hillebrandt, P. M. (1960b). The Economic Theory of the Use of Pesticides: Part II. *Journal of Agricultural Economics*, *14*(1), 52–61.

Huffaker, C. B., & Croft, B. A. (1978). Integrated Pest Management in the United States. *California Agriculture*, *32*(2), 6–7.

Menell, P. S. (1991). The Limitations of Legal Institutions for Addressing Environmental Risks. *Journal of Economic Perspectives*, (Summer), 93–113.

Moffitt, L. J. (1993). Integrated Pest Management and Water Quality. *Contemporary Policy Issues*, *11*(2), 113–120.

Natural Resources Defense Council (1989). *Intolerable Risk: Pesticides in our Children's Food*. San Francisco: Natural Resources Defense Council.

OECD (1991). *The State of the Environment*. Paris: OECD.

OECD (1993). *Agricultural and Environmental Policy Integration: Recent Progress and New Directions*. Paris: OECD.

OECD (1994a). *Towards Sustainable Agricultural Production: Cleaner Technologies*. Paris: OECD.

OECD (1994b). *Environmental Taxes in OECD Countries*. Paris: OECD.

Opschoor, J. B., & Pearce, D. W. (1991). *Persistent Pollutants: Economics and Policy.* Boston, MA: Kluwer Academic Publishers.

Osteen, C. D., Bradley, E. B., & Moffitt, L. J. (1981). *The Economics of Agricultural Pest Control: An Annotated Bibliography, 1960–1980*. Washington, D.C.: United States Department of Agriculture, Economic Research Service, Bibliographies and Literature of Agriculture Series No. 14, January.

Raloff, J. (1996). The pesticide shuffle. *Science News*, *149*(March 16), 174.

Reichelderfer-Smith, K. H., & Bender, F. E. (1979). Application of a Simulative Approach to Evaluating Alternative Methods for the Control of Agricultural Pests. *American Journal of Agricultural Economics*, *61*(2), 258–267.

Shoemaker, C. (1973a). Optimization of Agricultural Pest Management, Part I. *Mathematical Biosciences*, *16*, 143–175.

Shoemaker, C. (1973b). Optimization of Agricultural Pest Management, Part II. *Mathematical Biosciences*, *17*, 357–365.

Shortle, J. S., & Abler, D. G. (1999). Agriculture and the Environment. In: J. C. J. M. van den Bergh (Ed.), *Handbook of Environmental and Resource Economics* (pp. 159–176). Cheltenham, U.K.: Edward Elgar.

Smith, R. F (1978). Development of Integrated Pest Management in California. *California Agriculture*, *32*(2), 5.

Smith, R. F., Apple, J. L., & Bottrell, D. G. (1976). The Origins of Integrated Pest Management Concepts for Agricultural Crops. In: Apple and Smith (Eds), *Integrated Pest Management* (pp. 1–16). New York: Plenum Publishing Co.

Stern, V. M., Smith, R. F., van den Bosch, R., & Hagen, K. S. (1959). The Integrated Control Concept. *Hilgardia*, *29*(2), 81–101.

Tietenberg, T. (1988). *Environmental and Natural Resource Economics* (2nd ed.). Glenview, Illinois: Scott, Foresman and Company.

USDA (annually). *The Pesticide Review*, Washington, D.C.: United States Department of Agriculture.

Van den Bosch, R. (1978). *The Pesticide Conspiracy.* Garden City, New York: Doubleday & Company.

Van den Bosch, R., Reynolds, T., & Dietrick, E. J. (1953). Systox on Cotton. *California Agriculture*, *7*(4), 9.

Van den Bosch, R., & Dietrick, E. J. (1953). Further Notes on Hypera brunneipennis and its Parasite, Bathyplectes curculionis. *Journal of Economic Entomology*, *66*(6), 1114.

Van den Bosch, R., & Dietrick, E. J. (1957). Insectary Propagation of the Squash Bug and its Parasite Trichopoda pennipes Febr. *Journal of Entomology*, *50*(5), 627–629.

Van den Bosch, R., Schlinger, E. I., & Dietrick, E. J. (1957). Imported Parasites Established: Natural Enemies of Spotted Alfalfa Aphid Brought from the Middle East in 1955–56 Now Established in California. *California Agriculture*, *11*(7), 11–12.

Van den Bosch, R., Schlinger, E. I., & Dietrick, E. J. (1959). Biological Notes on the Predacious Earwig Labidura riperia (Pallas), A Recent Immigrant to California (Permatera: Labiduridae). *Journal of Economic Entomology*, *52*(2), 247–249.

Van den Bosch, R., Schlinger, E. I., Dietrick, E. J., & Hall, I. M. (1959). The Role of Imported Parasites in the Biological Control of the Spotted Alfalfa Aphid in California. *Journal of Entomology, 52*(1), 142–154.

Van den Bosch, R., Schlinger, E. I., Dietrick, E. J., Hagen, K. S., & Holloway, J. E. (1959). The Colonization and Establishment of Imported Parasites of the Spotted Alfalfa Aphid in California. *Journal of Economic Entomology, 52*(2), 247–249.

Willey, W. R. Z. (1974). *The Diffusion of Pest Management Information Technology.* Ph.D. dissertation, University of California Berkeley.

Zilberman, D., Schmitz, A., Casterline, G., Lichtenberg, E., & Siebert, J. B. (1991). The Economics of Pesticide Use and Regulation. *Science*, *253*(5019), 518–522.