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Review

Adopting biological control for ornamental crops in greenhouses

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Abstract

This review addresses economic issues relating to the adoption of biological control methods by greenhouse growers who produce predominantly ornamental crops. Adoption of biological control for ornamental crops in greenhouses is interesting and unique, because the controlled greenhouse environment allows use of management strategies generally not feasible in traditional agricultural production and because aesthetic thresholds are important for ornamental markets. Selected literature is presented. The economic decision is outlined and important factors that impact adoption rates are identified and discussed.

Keywords: Economics, Biological control, Adoption, Greenhouse, Ornamentals

Introduction

Biologically based technologies for pest control have a popular appeal because of the potential to beneficially exploit pest systems with relatively low probability of harmful effects on human health and the environment [1].[1] Greenhouse growers are reportedly interested in biological control because of (1) reduced chemical exposure for the grower, labourers and applicator; (2) issues related to pest resistance; (3) interest in reducing pesticide residue on marketed products; (4) continued and anticipated government restrictions on pesticide use; and (5) lower risk of environmental pollution [2]. Based on a survey of floriculture producers across the USA, approximately 50% of the growers surveyed currently use or have used biological controls in their floriculture production system [3]. Indeed, Opit *et al*. [4] demonstrated that biological control strategies are feasible under commercial greenhouse conditions for bedding plants. However, biologically based technologies are not always easily adopted by the growers who bear the direct cost and burden of implementing the technology. Hence, it is critical to understand better the decision process and factors that influence adoption rates for ornamental crops.

Pest management in ornamental greenhouse crops is distinct from pest control of traditional agricultural field crops. Because the production environment of interest is a controlled greenhouse, horticultural management (fertilizer or irrigation) and pest management (chemical or biological) generally not feasible in traditional agricultural production are practiced at frequent time intervals. Through this process, growers make important tradeoffs among horticultural and pest practices to keep plant quality and visual levels of insects (pest or predators) at acceptable levels for consumers [5]. It is interesting then to explore some of the issues that greenhouse growers face when adopting biological controls, ranging from firm behaviour to sourcing inputs (i.e. costs) and generating revenue from ornamental plants. In addition, information on if and how much specific factors influence the adoption of biological controls may offer insight into better design policies needed to provide guidance in efforts to promote more effective and efficient pest control.

The purpose of the current review is to examine adoption of biological control methods by greenhouse

[1]Biological control is taken to mean the use of living organisms, such as predators, parasitoids and pathogens, to control pest insects, weeds, or diseases (see [1]).

growers who produce predominantly ornamental crops and those factors that impact their adoption rate. The remaining sections of the review are organized as follows. First, background information is provided and selected literature is presented. Second, alternatives and extensions of the literature are discussed. Third, concluding remarks are offered.

Background

Greenhouse and nursery production is an important component of the US agricultural sector. Cash receipts were estimated at $17 billion in 2006 [6]. Although all states have commercial production of floriculture, the five largest states in receipts, California, Florida, Michigan, Texas and Oregon produced approximately 50% of the total value in 2006. While total production area has increased from 1998, the total number of growers has gradually declined from 1998 to 2006.

Production of ornamentals typically takes place in a complex, dynamic greenhouse environment with use of intensive inputs to achieve high aesthetic quality of plants. Greenhouse growers often produce and market a myriad of ornamental plants throughout the year from cut flowers to bedding plants, flower pot plants, bulb crops, foliage plants and nursery stock. The warm humid conditions and the abundance of plants in a greenhouse structure can create ideal conditions for pest problems. Major insect and mite pests include (but are not limited to) aphids, thrips, whiteflies and spider mites [7]. Domestic and international trade of greenhouse products and ornamental plants has provided important pathways for pests and diseases across the world, further exposing greenhouses to production risks. Early detection by scouting and monitoring the greenhouse and cultural practices are traditional keys for successful pest management. Gullino and Wardlow [8] identify pests and diseases related to the greenhouse production of ornamentals, as well as selected integrated pest management (IPM) programmes.

Production of ornamentals has depended heavily on the use of chemical pesticides, in part because of the marketing requirements of floriculture crops. While most agricultural resources have been managed for their yield of food and fibre, floriculture crops have been managed for their aesthetic value, which is diminished by the visual presence of pests as well as by the damage that they cause. Therefore, high-quality plants with no pests have been a goal of many floriculture producers. A consumer survey conducted in North Carolina reported that plant quality was the most important factor in selecting a garden centre [9]. Respondents to a plant nursery firm survey revealed that increasing saleable plants was the most important issue for pest management in Florida ornamental nurseries [10]. These findings indicate that plant quality is an especially important factor in marketing floriculture products, and that successful management of pests is a critical factor in achieving high quality.

Regulation of pesticide use has had direct impact of pest control choices by the grower. Many of the pesticides used by floriculture producers are currently being scrutinized by the Environmental Protection Agency because of the Food Quality Protection Act or because of pest resistance issues, and may be restricted or eliminated for use in the near future [11]. Hence, developing economically feasible alternative pest management strategies is becoming increasingly important to policy-makers and industry.

The decision by growers to adopt biological controls is as equally complex and dynamic as the production process within the greenhouse. The individual decision is guided by expected revenues from outputs and expected costs of inputs, as well as the grower/firms objectives, information set and risk preferences, which in turn are influenced by marketing agreements, aggregate supply and demand, input markets and government actions. Figure 1 presents a schematic of such factors that are likely to impact the adoption decision. Most components of this figure have been introduced above or will be further addressed below in the literature and discussion sections.

Selected Literature

The purpose of this section is to review selected articles related to the adoption of technology in the agricultural sector. The intent is to provide an overview to better understand issues relating to the adoption of biological control. Feder *et al.* [12] focused on adopting agricultural innovations in developing countries. They reported that constraints to rapid adoption of innovations include (but are not limited to) farm size, limited access to information and aversion to risk. Feder [13] suggested that pesticide application can be viewed as an insurance mechanism against potential pest damage and that a major determinant for pesticide use is the degree of uncertainty related to damage rate per pest, degree of infestation and pesticide effectiveness. Also, limited access to information constitutes an incentive for the creation of markets to lessen uncertainty, as demonstrated by the proliferation of pesticide consultant agencies during the past few decades. Harper *et al.* [14] examined factors influencing the adoption of insect management technology, including dissemination of information during extension activities at field days. Fernandez-Cornejo *et al.* [15] investigated the adoption of IPM techniques for vegetable growers across three states. They found that adopters were less risk averse and used more managerial time on farm activities. In addition, larger, irrigated family operated farms were more likely to adopt IPM technologies. Llewellyn *et al.* [16] reported that herbicide resistance and the producer's subjective expectations of future availability of effective new herbicides were significant in explaining

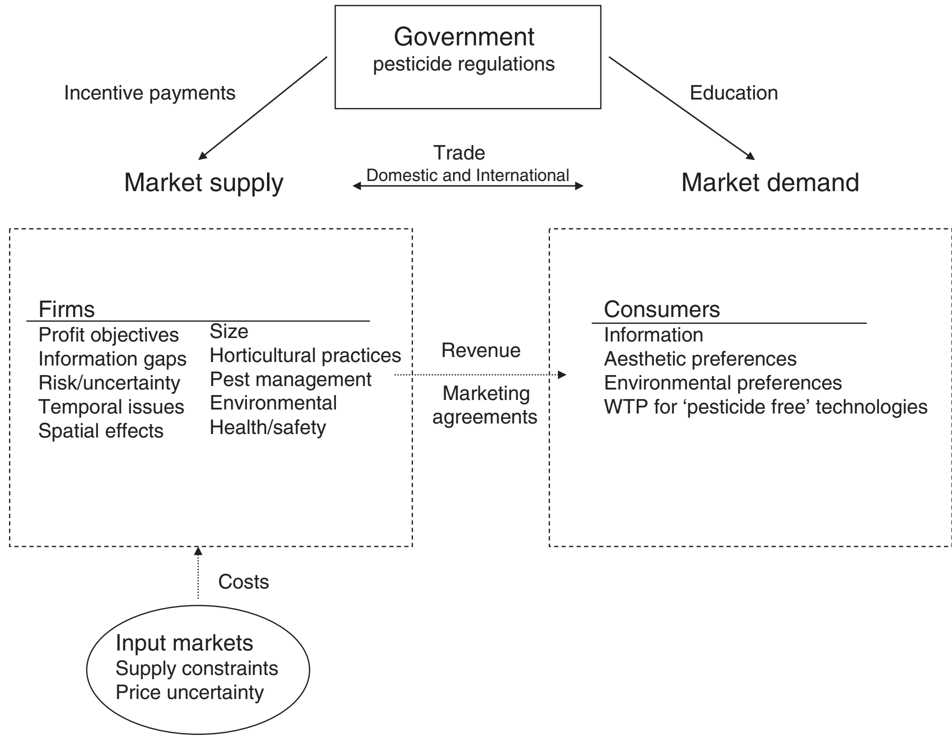

Figure 1 Economic framework and factors effecting adoption of biological control methods

integrated weed management practices, concluding that integrated weed management is information-intensive and it involves intertemporal resource management decisions.

Schumacher [3] has provided one of the most complete surveys and comprehensive analysis of US greenhouse production and economics to date. The remainder of the current section summarizes results from this research. In total, 1336 greenhouse growers in 21 states were surveyed. The average age of the grower was 49 years old. The average size (in terms of sales) for the greenhouse enterprise was $509 000, with mean profitability (the ratio of net income to sales) of 19.07%. A large number of the firms used scouting (85%) and most of the greenhouse firms in the sample were located in the Midwest, Northeast and South (77%). Pesticide costs averaged $4345.45 across the sample of greenhouse enterprises.

To gather further survey information about greenhouses, growers were also provided with a list of important factors that contributed to their decisions *not* to use biological controls to suppress pests in their greenhouses. The response options to each of these statements included strongly agree, agree, no opinion, disagree and strongly disagree. The percent of respondents who strongly agreed or agreed to these factors are presented in Table 1. Sixty percent of the growers indicated that the use of biological controls was not practical to implement, 42% believed that the cost of biological controls were too high, 37% indicated that the use of biological controls required special skills and knowledge that they did not have and 36% believed that biological controls were not effective. These responses reaffirm past studies and identify further factors that need to be addressed to enhance producers to adopt biological controls.

Table 1 Important factors in decision not to use biological controls

	Percentage[1]
Costs of biological controls are too high	42%
Biological controls are not effective	36%
Biological controls result in lower yields	19%
Biological controls are too labour-intensive	26%
The use of biological controls is not practical to implement in my greenhouse	60%
The use of biological controls requires special skills and knowledge that I do not have	37%

[1]The percentage represents the percentage of respondents who strongly agreed or agreed.

Respondents were also presented with a number of questions eliciting attitudes and perceptions about use of pesticides and biological control methods. Results from these questions are presented in Table 2. Sixty-seven percent of the respondents indicated that they would prefer to use biological technologies to control pests if profits remained the same and 55% of the respondents indicated that they would like to learn more about

Table 2 Grower perceptions

	Percentage[1]
Would like to learn more about biological control	55%
Likelihood of pest damage is lessened with scouting	87%
If profits remained the same, would prefer biological control methods	67%
Chemical pesticides are a threat to environment	47%
Government regulations will substantially reduce use of pesticides within the next 15 years	76%
The use of biological control methods in my greenhouse will increase significantly in 5–10 years	42%

[1]The percentage represents the percentage of respondents who strongly agreed or agreed.

biological control. Additionally, 42% of the respondents indicated that the use of biological control methods in their greenhouse would increase significantly in 5–10 years [3]. These responses indicate that producers would prefer to use biological controls, and they perceive that the use of biological controls in their greenhouse will increase in the future.

Schumacher [3] took additional steps and empirically analysed the adoption process in a greenhouse setting for ornamentals. She reported several factors affected biological control in a greenhouse setting. Incentive payments to move from chemical to biological pest control had a positive effect on adoption. Profitability also was significant but had a negative effect on adoption, implying more profitable growers were less likely to adopt biological controls. This is consistent with the hypothesis that more profitable firms are not as likely to adopt biological controls, viewing the technology as not practical or cost effective. Age was found to be significant at the 5% significance level and to have a negative effect on adoption, implying that younger growers were more likely to adopt new technology. Similarly, size was found to be significant at the 5% significance level and have a negative effect on adoption, which is consistent with the hypothesis that larger growers would be less likely to adopt biological control methods. Scouting was reported to have a positive impact on adoption (but was not significant). The insignificance of the scouting variable was not overly surprising for this sample, given that 85% of the growers have some sort of scouting protocol as a standard operation procedure. In contrast, location (discrete variable for firms located in the Midwest, Northeast or South) negatively impacted adoption (but again not significant). The insignificance of the location variable may be because greenhouses were operated in controlled environments so that exogenous factors are minimized.

Incentive payments (i.e. mean willingness-to-accept) for a greenhouse grower to move from chemical to biological pest control were estimated at approximately $13 000 or 2.1% of firm sales, which would induce 67% of greenhouse growers sampled to adopt biological control methods. These results suggest that providing incentive payments to the majority of growers to adopt biological control methods would be costly. However, smaller incentives targeted to specific groups of individuals could still induce a significant number of greenhouse growers to adopt biological control technologies [3].

Discussion

Technology adoption is a complex process culminating in an individual or firm decision. Given that a biological control strategy is scientifically feasible, the successful grower is most likely to adopt the strategy if it is an economically feasible decision for the greenhouse. The adoption decision is economically feasible for the grower if expected profits are greater than zero (i.e. expected revenues are greater than expected costs). If growers habitually make decisions where expected profits are less than zero the greenhouse will not be a viable business in the longer run. Moffit [17] provides a good overview of break-even pest control (i.e. revenues equal costs implying profit is zero), while Schumacher *et al.* [5] identifies marginal pest thresholds (i.e. intertemporal profit maximization behaviour). In practice, growers may exhibit infra-marginal behaviour, meaning they may operate at some point above break-even profit but below profit maximization, for various reasons. For instance, they may be attempting to voluntarily internalize certain social costs of pest control (e.g. pest resistance). In the end, the specific profit objective will depend on preferences of the individual grower.

In reality, numerous factors impact revenues and costs of a greenhouse and hence the adoption decision. Several factors identified from above and from more recent literature on technology adoption warrant further discussion. Although we summarize each separately below, it is evident – and should not be surprising – that there is overlap in content.

Size

In traditional agriculture, conventional wisdom is that technology adoption is positively related to firm size [12]. Indeed, Fernandez-Cornejo *et al.* [15] reported that larger, irrigated family farms were more likely to adopt IPM techniques for vegetables. Klotz *et al.* [18] and Foltz and Chang [19] found similar results, as farmers owning larger dairy herds were more likely to adopt a hormone that induced more milk production in cows. Moreover, Abdulai and Huffman [20] found that farm size was positively correlated with the likelihood of adopting cross-bred cows in Tanzania.

However, other empirical findings suggest firm size and the likelihood of adoption are not necessarily positively correlated. Feder [21] found that the effect of farm size was dependent on the degree of risk aversion. The adoption of a new technology increased as farm size increased if absolute risk aversion was decreasing, but declined if relative risk aversion increased with income. Schumacher [3] found greenhouse size to be statistically significant and to have a negative effect on adoption, suggesting that larger growers would be less likely to adopt biological control methods. One plausible (but certainly not necessary) explanation is that larger growers produce more varieties of greenhouse crops within given enclosures, which leads to more complex biological systems, possibly discouraging biological control adoption.

Empirical findings related to size conflict and remain unclear. Schumacher and Marsh [22] found evidence for increasing returns to scale for greenhouse firms, which implies average costs tend to decline in US greenhouses as output increases. This is consistent with larger production areas and fewer firms, as reported in aggregate statistics for the USA. Hence, because of the mixed results presented in the literature and because larger greenhouses seem to be the future trend, the relationship between firm size and technology adoption should be a focus of further investigation.

Uncertainty and Risk

The effect of uncertainty and risk in the likelihood of adopting biological pest control is in part attributable to informational gaps. Indeed, biological control strategies are typically complex in nature and require intensive information and knowledge of the insect and plant system. In most cases, knowledge of these systems has to be acquired by learning or experience. Schumacher [3] reported that 37% of the survey respondents indicate the use of biological controls requires special skills and knowledge that they do not possess, indicating that learning is important. Heibert [23] viewed adoption as a decision problem under uncertainty and developed a model to examine the effect of learning on the adoption decision. Feder and O'Mara [24] showed that uncertainty declines with the learning and experience. Indeed, in agriculture the notion that innovations are perceived to be more risky than traditional practices, has received considerable support [12]. Not surprisingly then innovators and early adopters of IPM are believed to be more inclined to take risks. Cameron [25] demonstrated that grower's experience played a role in adoption. She analysed the adoption of new high-yielding varieties in India, and demonstrated that a household experiencing a higher average profit per acre was more likely to use the new seed than a household not experiencing such profits. Baerenklau [26] demonstrated that new information in updating farmers' beliefs affected the expected returns from adopting rotational grazing and non-native forage varieties by dairy Wisconsin farmers. Hence, because growers make decisions on perceived risk, education is important to reduce uncertainty and to increase adoption rates when feasible. Furthermore, realizing the nature of a grower's risk perception has implications for rates of adoption [16].

Uncertainty in other aspects of production might also affect the likelihood of adopting a new technology. For instance, consider uncertainty in expected outcomes. Feder [21] demonstrated that increased variability in the expected yields of new crops induced lower allocation of land to the new technology. Uncertainty might also be associated with input and output prices. Carey and Zilberman [27] analysed the adoption of new irrigation systems by cotton farmers in California and found that water and cotton price fluctuations played a role. The larger the degree of uncertainty in future water prices, the larger the expected benefit from the new technology must be for the farmer to invest. Finally, uncertainty related with investment costs also affects the likelihood of adoption. Purvis *et al*. [28] demonstrated that the more uncertainty involved in investment costs the more likely farmers would postpone adoption.

Incentive Payments

Schumacher [3] reported significant impacts of incentive payments on the willingness-to-accept for a greenhouse grower to move from chemical to biological pest control. The relevance of this outcome cannot be overstated from a policy perspective. It suggests that incentive payments by governments or other programmes may be successful in inducing growers to increase adoption of biological over chemical controls. In other research, Isik [29] conducted a study dealing with the effect of government incentives (i.e. cost-sharing programmes) on the adoption of site-specific technologies that are environmentally friendly. His results implied that government incentives were most effective when immediately offered to farmers and guaranteed to be removed soon. Given this, and interests in pesticide-free or organically grown products, incentive payments for growers to shift to biological control strategies deserve further research and investigation.

Consumers

Consumer preferences and choice are particularly important in demand for (and hence sales of) ornamental plants. Prices and income remain key determinants of ornamental choices. However, unlike food consumption, nutritional benefits do not drive purchasing decisions. Rather, consumers make purchases of ornamentals based on perceived quality of the plant. And, it is well known that plant damage remains a key indicator of plant quality.

Popular belief is that consumers also have a low tolerance for visual presence of any type of insect, including beneficial insects. In other words, presence of an insect on a plant is often perceived as a signal of lower quality that leads to a lower willingness to pay (WTP) for the product by the consumer. Schumacher *et al*. [5] economically identified aesthetic benefits derived from the visual presence of pests and predators in production of ornamental greenhouse crops. Their analysis suggests that educating consumers about the benefits of predators on ornamental crops (i.e. acceptance) could result in fewer applications of pesticides and an increase in the use of natural enemies by greenhouse floriculture producers.

Consumer WTP for ornamental products with health-conscious and environmentally friendly attributes has further implications. For example, Roosen *et al*. [30] examine consumers' WTP for changes of pesticide applications on apples. They found that consumer perceptions of product attributes changed if pesticides were removed from production, and this was reflected in WTP changes. Meanwhile, Loureiro *et al*. [31] examined WTP for eco-labelled apples, reporting a small premium for apples produced with environmentally sound management practices. Alencastro [32] investigated eco-labels and preferences for marine ornamentals, finding that information relating to marine ecosystem protection impacted significantly on consumer preferences. These findings suggest labelling of ornamentals related to pesticide-free status or application of biological control and the impacts on consumer WTP may be a relevant topic for research.

Input Markets and Constraints

To practically and effectively apply a biological control strategy the greenhouse must be able to reliably source the biological control insect or agent (and other complementary inputs) in a cost-effective and timely manner from the supply chain. Inadequate supplies can limit greenhouse acquisition of the pest control input. Inadequate supplies can engender thin markets inducing volatility in prices, and hence expenditures, for the input; potentially rendering the biological control strategy economically unfeasible. Hence, well-functioning markets for biological control agents as inputs to greenhouses are important to growers. Moreover, market information is relevant to researchers setting priorities and providing recommendations to growers.

Marketing Agreements

The role of marketing agreements or contracts can influence pest-control decisions and outcomes (e.g. [33]). Marketing arrangements between growers and customers often reduce volatility in price received by the grower, but place the burden of quality risk on the grower. Extremely stringent marketing arrangements coupled with a very risk-averse grower often results in decisions to apply chemical as opposed to biological controls.

Ornamental crops can be marketed through a variety of channels that reflect differences in standards, required volumes, seasonality, pricing and quality levels. These channels include brokers, restaurants, farmer markets, florists, grocery stores, mail order, on-farm, subscriptions and wholesalers [34]. Thus, the details of the marketing arrangement can directly or indirectly impact grower profitability and, hence, decisions to adopt biological controls.

Spatial Effects

Spatial effects play a role in insect dynamics and adoption of technologies. For example, Marsh *et al*. [35] found spatial effects significant in insect–virus transmission relationships in agricultural production. Harper *et al*. [14] found spillover effects influenced producer's adoption rates. Greenhouse growers confront spillover effects from insects within the greenhouse itself, whether these are positive or negative spillovers. The degree of spillovers can depend on the structure of the greenhouse itself, plant–insect systems, environment and management practices. Spillover effects could also arise as an insect invasion from outside the production environment.

Adoption rates are also impacted spatially among individual growers [36]. In other words, in addition to exogenous spillover effects, neighbourhood influences among individual growers can influence adoption of technologies. For instance, the presence of one innovative grower in a location may increase the likelihood of spawning another. Or more generally, it may indicate that spatially close growers are more alike in their managerial practices. In fact, Foster and Rosenzweig [37] in their study of adoption of high-yielding rice and wheat varieties in India found that farmers with experienced neighbours obtained larger profits than farmers relying on own experience only. Also, they found that having experienced neighbours advanced the rate of adoption by about a year. Abdulai and Huffman [20] identified positive externalities across neighbouring farms more at a village level than at a regional level in their analysis of crossbred-cow technology adoption in Tanzania. However, Baerenklau [26] found weak statistic and economic evidence of peer-group effects on expected returns from adopting rotational grazing and non-native forage varieties by Wisconsin dairy farms. In all, results suggest that spatial information can capture spillover or neighbourhood effects that are relevant to researchers and policy-makers.

Time Effects

Time affects the adoption decision in several ways. The most commonly studied have been opportunity cost of managerial time, age of the technology, the reversible/irreversible nature of adopting, sequential nature of investment and the likelihood of postponing adoption. Given that successful biological pest control is information-intensive, then the presence of real opportunity costs to managerial time should come as no surprise. For example, Fernandez-Cornejo [38] reported on the off-farm income and technology adoption. In particular, he reported that adoption of innovations that saved managerial time was related to higher off-farm income. Smaller firms may be viewed as part of the household enterprise that combines both greenhouse and other income activities. Consequently, in research, household production approaches with focus on efficient time allocations has potential to provide insights into technology adoption.

Technology age and reversibility have an effect on the likelihood of adoption. Baerenklau and Knapp [39] in their study of sub-surface irrigation adoption by California cotton growers found that technology age affected positively the likelihood of adoption. They demonstrated that assuming 'irreversibility'; meaning that once a new technology is adopted, farmers will not go back to the old technology, significantly biases results against adoption. The magnitude of such biases depended on long-run expected input/output price levels, expected system lifetime and discount rates.

Additional factors might delay the adoption of a new technology, even if it proved profitable. Klotz *et al.* [18] demonstrated that when a new technology is relatively unknown and producers have the choice to wait until more information is available, immediate adoption might not occur because the net present value of waiting is higher than adopting. Purvis *et al.* [28] demonstrated that expected annual returns from new technology doubled when considering the value of waiting for realizing the investment.

Other Factors

From a more general economic perspective, profitability can be impacted by technologies that influence firm input or output, and at the same time can also be impacted by economic conditions and government policies. Price support schemes, market structure, taxes and subsidies, and input and output quotas are all aspects of reality [12].

Adoption of biological control practices might be also viewed as a selective partial process. In other words, growers might adopt portions of the technology rather than the whole package, seeking the best fit to their specific situations. Indeed, given the complexity and variability of innovative pest management practices, absolute adoption might not apply. Even in an apparent homogeneous environment (i.e. farms with similar socio-economic characteristics across a region) indigenous knowledge and individuals' capacity for experimentation and adaptation coupled with specific farm goals play a role in adoption. For example, farm-specific factors such as whether the farm is family or business oriented or the diversification of farm operations have an effect on the likelihood of adopting new pest management technologies [40].

Concluding Remarks

Pest control in a greenhouse environment is information-intensive and complex in nature. Adoption of biological control for greenhouse ornamentals is unique, in part, because of consumer demand for quality and aesthetic characteristics. Given that effective policy design to overcome barriers to adoption relies in part on information from research, the current review summarizes relevant insight into adoption of biological controls with emphasis on commercial greenhouses for ornamental crops.

Schumacher [3] finds that more profitable and larger greenhouse operations are less likely to adopt biological controls, whereas younger growers are more likely to adopt new technology. The mean willingness-to-accept for a greenhouse grower to move from chemical to biological pest control is approximately $13 000 or 2.1% of firm sales, which would induce 67% of greenhouse growers sampled to adopt biological control methods. These results suggest that providing incentive payments to the majority of growers to adopt biological control methods would be costly. However, smaller incentives targeted to specific groups of individuals could still induce a significant number of greenhouse growers to adopt biological control technologies.

There remain obstacles facing growers in their decision to adopt biological control methods. Many growers believe that biological controls are too costly and are not practical to implement in their greenhouse. Markets for biological controls can be thin, compromising the reliability of sourcing of inputs through the supply chain and inducing volatility in pricing. Alternatively, and on a positive note, growers have indicated that they would prefer to use biological controls if their profits remained the same. These points highlight that policy-makers need to balance tradeoffs between perceived and real barriers to adoption with anticipated current and future benefits of biological control to the industry and to society as a whole.

Findings indicate there is future potential for biological control methods in the greenhouse industry if perceptions, cost and practicality are addressed. Policies to educate growers and consumers and to fund research that develops practical and cost-effective biological control methods are potential alternatives or complements to an incentive payment system, which could lead to an increase of adoption of biological control methods by growers.

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