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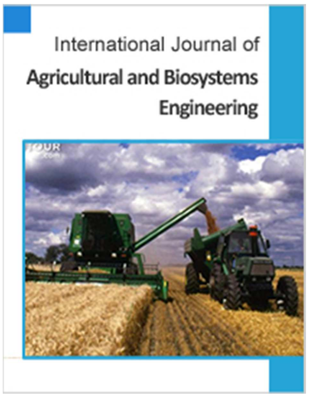

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New Potential for Ecological Economics in US Agriculture: Old Theories, New Applications

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Abstract
There is long-standing tension between the theories and methods espoused by scholars researching and writing about applied ecological economic principles AND the actual strategies practically employed by organic farmers and others committed to ecologically-sound agricultural practices. Recent trends including changes in consumer demand and preferences, changes in farm scale, and changes in the demographic composition of contemporary US farmers make the potential adoption of ecological agricultural principles far more economically rational due to an upward shift in prices due to higher demand for organic products and an increase in small-scale farms wishing to produce these products. Using biological control of the soybean aphid (*Aphis glycines* Matsumura) that only recently (2000) arrived in North America as an example, this essay argues for greater attention to financial analyses of ecological economic methods so as to increase their adoption by commercial farmers.

1. Introduction

There is a significant gap between the fundamental theories put forward by scholars throughout the world working at universities and institutes promoting ecological economics in agriculture *and* the development and promotion of economically viable and sustainable options that can actually be profitably employed by farmers. Over the past half-century, research has consistently and persuasively identified the damage caused by "conventional" farming systems and the potential of ecological economic agriculture to address these issues [1], [2], [3], [4], [5]. Erosion, ground and surface water pollution, air pollution, loss of species diversity, declining soil structure and fertility, and polluted grains, fruits, and vegetables are some of the major persistent problems challenging farmers, citizens and consumers. Most of these issues are common to all nations. Proponents of ecological economic principles in agriculture have offered countless critiques of high-energy high-input farming systems highly dependent on fossil fuels and derived inorganic chemicals, but most of these critics would also agree that the development of practical and sustainable applications for specific crops produced under specific conditions in specific places has NOT kept pace with the ideals and concerns established in related theories. Both theory and applications are vital, but few scholars dispute the fact that new sustainable production systems (including economic sustainability) must be developed and promoted if genuine contributions are to be made and real change in conventional agricultural production systems is to be achieved.
The purpose of this essay is to identify a few recent sustainable innovations in pest management in the US.

Hopefully, this case study will serve as an example of both the complexities and potential benefits of ecological economic agriculture. Prior to this, the essay identifies concurrent changes that effect the debate related to sustainable ecological economic solutions within the United States. Specifically, these include: changes in consumer demand and preferences, changes in farm scale, and changes in the demographic composition of contemporary US farmers. These shifts, taken together, potentially make the adoption of sustainable practices at once more feasible and more economically rational due to an upward shift in prices due to higher demand for organic products. While research in sustainable production options has been on-going for decades, participation by agricultural sciences researchers in US land-grant institutions and USDA-funded research related to sustainable farming practices has increased dramatically in the past two decades because a new generation of farm operators are requesting help in these areas.

2. A Need for Ecological Economic Analyses of Potential Sustainable Farming Practices

As global agriculture systems become ever-more inclusive and extensive, international commodity prices increasingly drive the production decisions made daily by individual farms in virtually every nation. The critical challenge is to develop effective production systems that reflect a commitment to ecological economic agricultural principles while allowing farmers to remain fiscally competitive. This is a very daunting task and the most significant challenge facing ecological economics as an area of research and innovation. It is one thing to offer critiques of current production practices for most commodities while teaching in the classroom or as commentaries in scholarly journals or books, but quite a different challenge to develop practical sustainable practices that reflect these ideals while allowing farms and farmers to make acceptable returns to their investments.

Simply put, sustainable practices in agriculture must be evaluated to determine if they are cost-effective at current production scales or farmers will have no reason to adopt such practices. Strategies that have proven effective in small-scale experiments using test plots or field trials must be economically rational given current production scales and market conditions. All production decisions are made by farmers throughout the world, including those in the US, based on prevailing market conditions. Any sustainable innovations to the production process must make “dollars and sense”. The rapid globalization of the food system requires that any new production methods must meet supply-demand conditions for both domestic and international prices. In important aspect of the adoption of sustainable practices is the assessment of relative costs of these new systems and the promotion of these studies in popular journals.

By way of example, consider the different types of agricultural production now found in the United States because markets for many agricultural products are changing as younger more discerning consumers desire different products. These are often related to organic or non-GMO choices, but other movements such as those for “local foods”, “free range” chickens and livestock, and “macro-biotics” have all impacted regional and national commodity markets of some extent. Some of these changes provide significant opportunities. Demand for organic products including fruits, vegetables, grains, cotton, and soybeans is increasing, and US farmers have been quick to see the potential benefits of meeting this demand when shifts to sustainable practices make economic sense.

In some nations, subsidies of various types have been used to promote sustainable practices. To a large extent, the US has avoided this type of subsidy (even though we employ many other types!) although perhaps one could argue that CRP (crop land reserve program) that removes ecologically fragile lands from productions contributes to overall environmental protection. Importantly, however, the US currently does not have large-scale programs that make direct payments for the adoption of sustainable practices. To be sure, subsidies of many types will alter market equilibrium for any commodity for specific times and places, offering temporary increases in income to farmers. Reliance on subsidies to promote innovations in sustainable farming is at best a short-term solution which typically becomes increasingly costly over time. From a theoretical perspective, this may seem like putting “the cart before the horse”, given that ideally the economics of crop production must become a part of the ecological system, not the other way around. In practice, however, farmers cannot become part of the solution if they cannot produce a competitive product; if they cannot stay in business.

Sound ecological farming strategies must be not only economically viable, but they must be devised to function effectively at the appropriate scale of existing farm operations. Some strategies will not transfer across scales. Large commodity grain operations are fundamentally different than smaller specialty crop operations (organic vegetation, fruit, hops, etc.).

3. Important Trends in US Agriculture that Influence the Adoption of Sustainable Farming Practices

There are a number of important trends in the US farm sector and product markets that have potential effects on the pace of adoption of sustainable farming practices and ecological economic practices. First among these is the growing interest in the US in organic products—not just fruits and vegetables, but in grains, beans, meat, dairy, poultry, honey and eggs as well. Consumer interest and participation in markets for these products is evidenced by a virtual explosion in the numbers of “farmer’s markets” and in the numbers of consumers who regularly shop at these venues. Community supported agricultural operations (CSAs) where consumer's contract for diverse agricultural products directly with farm operators have also seen fast growth in participation. Certainly not all vendors or farm families participating in these marketing options are "organic" farms, but many are and interest in more effective certification programs to add credibility to these operations which may have higher prices is growing as well. I do not wish to enter the debate on the actual health benefits of organic products vis-à-vis products grown in conventional ways. That is a debate best left to nutritional experts, but there is, without doubt, a price premium for these crops that might allow higher production costs as well—suggesting the organic market offers potential benefits for the expansion of ecological economic practices.

Farmers in the US and many other nations are increasingly responding to the demands of the growing group of consumers who are typically willing to pay more for organic products. This in turn stimulated the need for practical research and applications of sustainable methods that must be used by producers to qualify for full "organic" status. Table 1 provides a list of common agricultural products and the share of production estimated to be "organic" for each group of products based on a 2011 survey by USDA [6]. Long considered a "niche" market, "organic foods" are rapidly gaining market share, and are often produced on very small farms by US standards (below 5 hectares) with produce sold at farmers' markets or other local venues directly to consumers. This trend means that practices associated with sustainable crop management for small-scale specialty crop growers are being developed by farmers and researchers and importantly promoted by farmer's cooperatives or other local farm associations through training programs to meet these requirements. The organic sector grew from $3.2 billion in 2008 to $5.5 billion in 2014, demonstrating that there is increased demand for organic products and opportunities for growth [7]. The five most valuable organic products identified in order of highest sales were milk, eggs, broiler chickens, lettuce, and apples. The vegetable and fruit sectors have increased in their importance to the organic sector as a whole, making up 42% of organic sales in 2014.

Table 1. *Important organic products for the United States: 2013, [8].*

	Total U.S. Cropland		**Certified organic**	
Crop	**Acres**	**Share of total**	**Acres**	**Share of total**
	Thousands	**Percent**	**Thousands**	**Percent**
Corn	91,900	30	234.5	12
Soybeans	78,000	26	132.4	7
Hay	61,600	20	786	39
Wheat	54,400	18	344.6	17
Fruit and nuts	4,000	1	154.8	8
Vegetables	2,800	1	160.7	8
Rice	2,700	1	48.5	2
Barley	2,600	1	63.9	3
Oats	2,500	1	62	3
Dry beans, peas & lentils	2,100	1	46.5	2
Total, selected crops	302,500	100	2,034	100

According to the 2014 Organic Production Survey released by USDA's National Agriculture Statistics Service (NASS), in 2014 there were 14,093 organic farms producing on 3.7 million acres. At the other end of the production scale, higher prices for organic grains and beans have encouraged a limited number of large-scale field crop producers in the US to also investigate effective measures for sustainable organic farming. Just as high fuel prices in the 1970s led to wide-spread adoption of no-till or minimum tillage practices, growing national and international consumer demand for organics has motivated some large-scale US farmers to try to shift to sustainable practices that promote soil fertility and improved soil structure, and/or reduce or eliminate the use of inorganic pesticides and fungicides. While there has not been a wholesale (large) shift in standard production practices for most large agribusiness operations producing grain, beans, tobacco or cotton in the US, there is definitely interest among some of these operations if the returns are acceptable.

As farmers seek advice on how to make a possible shift to organic production, they seek the advice of farm extension agencies which in turn look to agricultural science researchers at the nation's influential land grant institutions and other agricultural service agencies such as farm extension offices. Researchers at these institutions seek funding for this research from the US Department of Agriculture and other agencies. Some of this research, for soybeans, will be discussed in some detail later in the essay, but it is important to note that research for sustainable practices is currently underway in the US from crops ranging from apples to blueberries to cotton to wheat.

A second important trend is the rapid growth of small-scale farms in the US, particularly the growth of small farms operated by women. The number of US farm operations run by women (principal operators) as of 2012 was 14%, but if the definition is expanded to include women farm operators (non-principal), this number increases to 30%. In states in the Northeast, Southwest, and West women comprise significantly larger shares [9]. In 2012, the number of women farmers in the United States was 969,672. This was a 2 percent decrease in women farmers since 2007, when the last agriculture census was conducted. Statistically, women support consumption of organic produce as a means of protecting family health at higher rates than men (21% higher) [10], and often women farmers are more cognizant of the growing organic trend and have been early adopters in many parts of the United States.

Turning quickly to the overall general importance of small farms in US agriculture, according to the most recent 2012 US Agricultural Census, 69% of US farms with holdings below 179 acres (72.44 hectares) account for only 9% of US cropland [11]. At the other end of the spectrum, the largest 4% of farms that manage 2,000 acres or more (>809.37 hectares) own 55% of US farm land. Many of the farms in the smallest categories report sales of under $10,000/year, but account for a growing number of organic farms wishing to employ sustainable practices. Small farms and the diverse products they produce matter not only in economic terms but also because they represent potential engines of change with respect to ecological economic practices in agriculture and are vitally important to the culture of rural America as well [12].

International scholars often associate the US farm sector with massive large scale land and capital-intensive operations but this impression is only partly correct. Over the last several decades, American farmers are splitting into two groups—increasingly they are operators of either very large agribusinesses that are increasing in the number of acres farmed but growing only slightly in absolute number, or very small farms (relative, but typically below 30 ha.) that are surprisingly increasing in number. Medium size farms are declining in number. This is a classic case where the mean farm size in acres (434 acres or 175.63 hectares in 2012) does not reflect reality. Big farms are getting bigger while small farms are quickly growing in number (Figure 1).

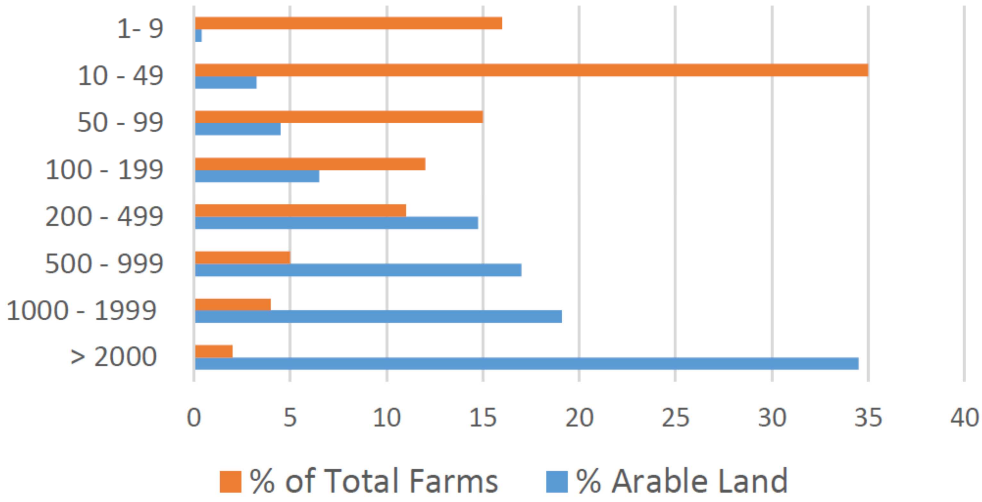

Figure 1. *Percentage shares of the number of farms and arable farm land by farm-size categories for the United States: 2012, [13].*

Based on the most recent (2012) survey of US farms, many of these small farms are recent arrivals to farming who work off-farm or have pensions from previous careers. These small farms are sometimes called “lifestyle farms”, but this term seems increasingly outdated. Many of these farms produce a limited number of products targeting consumers desiring organic products that are sold on-site or at farmers markets or through CSAs [14]. As the number of these operations grows, these farm operators also require new information and training, further influencing farm extension services and research into sustainable organic practices. In addition, cooperatives—always an important part of the US farm sector-- are now forming around interests related to organic sustainable practices. Some sustainable practices and strategies can be adopted by both large and small scale farmers, others cannot. There is little doubt, however than this growing interest has encouraged more research into a broader range of sustainable practices and the more effective promotion and evaluation of these strategies.

Greater interest in organic foods and commodities, and the growth in the number of small farm operations that are directly targeting these consumers has led to a significant expansion of basic research which is presented in new journals and increasingly promoted and popularized by farm extension agencies and outreach programs offers by major agricultural universities throughout the nation. Table 2 provides a summary of some of the most commonly used cultivation practices employed by organic farmers participating in the 2012 U.S. Agricultural Census.

Table 2. *Conservation practices used by farms participating in the 2014 USA Organic Agriculture Survey and the percentage of organic farmers using these methods, [15].*

Total survey was 14,093 farms	# of Farms Using:	% of Farms Using:
Green or Animal Manures	9,409	67
Buffer Strips	9,259	66
Organic Mulch or Compost	7,082	50
Water Management Practices	7,505	53
No-Till or Minimum-Till	5,724	41
Select Planting Locations to Avoid Pests	5,405	38
Pest-Resistant Varieties	5,035	36
Maintain Beneficial Insect/Vertebrate Habitat	4,840	34
Biological Pest Management	4,779	34
Planting to Avoid Cross-Contamination	3,768	26
Released Beneficial Organisms	2,388	16

4. Ecological Economic Assessment of Biological Controls for Field Crop Production

One of the greatest challenges to US field crop production is the management of insect pests and nematodes. Pimental estimates that as of 2004, US farmers used a combined 500 million kg. Including more than 600 types of pesticides at a total cost of over ten billion dollars [16]. Despite this massive investment, insects were estimated to still destroy about 13% of crop production.

As global markets especially in wheat, soybeans and a lesser extent corn grow more competitive, managing the costs associated with pest management become a critical issue for all US farmers, organic or inorganic, large and small. As interest in organic sustainable production of grains, soybeans and cotton expands for export markets (EU, China, Japan, Korea), and for the reasons introduced earlier, research by agricultural scientists at major land grant universities dissemination of this information through farm extension offices and farmers' cooperatives has increased dramatically. Of course, major agri-businesses such as Monsanto, Dow, Syngenta and Sumitomo play an important and vital role in this as well—and this should not be overlooked or discounted, particularly with respect to the development of genetically modified varieties, but also in seeking ways to reduce farm chemical applications. Critics of these firms often are unaware of the massive research efforts sponsored by these firms. However controversial these firms and the development and production of GM crops may be, even the harshest critics of these important technologies will agree pesticide use with many of these crops decline considerably or is eliminated entirely in some cases for specific pests (i.e. GM corn resistance of corn borers). The debate on the benefits and potential risks associated with GM crops is not a focus of this essay but it is ironic that GM crops often reduce the need for chemical pesticides, or sometimes even herbicides, yet few supporters of organic agriculture support GM research even at the current levels of development.

Setting aside this contentious debate, efforts to develop sustainable pest management strategies that allow cost-effective production of field crops such as corn, wheat and soybeans should be highlighted. While there are many different aspects to these research efforts, one major focus has been on the development and encouragement of insect *predator-prey* relations that can potentially bring crop pests under control without the use of inorganic insecticides. In the academic literature, this has come to be called "*natural enemy*" research. Most simply, the goal of natural enemy research is to determine the most efficient and cost effective means to encourage predatory action whereby predator insects can be used to control (not eliminate!) field crop pests such as aphids, mites, thrips and other damaging herbivorous pests that feed on field crops as well as fruits, vegetables, and other horticultural specialty crops. Breeding for total resistance encourages mutation for insect populations to survive.

Biological control of agricultural pests in the USA is both a sustainable and profitable trend. A study by Warner and Getz identified twenty-two North American insectaries (insect-producing companies) that as of 2006 were producing 38 natural enemy species with annual sales of $23.3 million at wholesale value [17]. Such numbers reflect the wide-spread interest in these technologies in the US and Canada. Further, high quality journals such as *Biological Control, Journal of Economic Entomology* and *Agricultural Ecosystems and Environment* are now available to promote specific studies to a wide audience. Few US farmers may read these journals on a regular basis, but agricultural science researchers and farm extension agents do, and summaries of this work are routinely published in the magazines and trade publications that farmers do read!

As noted earlier in the paper, the issue of scale of production (field size) is again a vital aspect of natural enemy research [18]. As fields grow larger in size (reducing tillage, planting, and harvest costs of fuel and labor), it becomes more difficult to assure access to the interior of the large field by released, commercially-produced, predatory insects such as beetles, parasitoid wasps and spiders where they can access their prey(insect pests). The research is complex, requiring a firm understanding of not only these predator-prey relations, but also the environments in which predatory insects can be encouraged to develop sustainable populations in areas adjacent to, or within, large fields, and the distances each predator species will naturally travel for feeding. The research must also determine which predatory insects feed most efficiently and are capable of reproduction and over-wintering in any given location. At present most research is focused on alterations of the land scape, sometimes called "farmscaping" to achieve these goals through the introduction of strips of land within the fields or in "buffer zones" proximate to the fields that are naturally, or artificially, populated with native predatory species that are already adapted to the local climate regime [19], [20].

Walton and Isaacs note that not all farms can afford to give up valuable crop land for "farmscaping", but found that for blueberries; conservation planting of host plants (for predator insects) in areas adjacent for fields was also effective [21]. The introduction of some *invasive* (non-native) predatory insects is also an important area of research as will be shown in the next section devoted to the management of the soybean aphid which only recently arrived in North America, but this is of course more controversial [22].

Typically, large scale research projects and actual farm applications involve the development of strips of land (which means a loss of area under cultivation) extending through large fields and planted with appropriate host perennial grasses and shrubs that will allow the development of sustainable populations of predatory insects. Increasing the number of crops in a standard crop rotation and the use of cover crops was also found effective and does not necessarily lead to "yield penalties" (i.e. yield reductions) [23]. Cullen et al. (2008) call for greater attention to cost-benefit analyses of biological control methods and provide a very useful methodology for such studies [24].

5. A Case Study of a Cost-Effective Sustainable Farming Practice: Treatment of the Invasive Soybean Aphid (*Aphis glycines*)

The Soybean Aphid (*Aphis glycines*, SBA hereafter) is thought to have arrived in North America in or around 2000. Before the discovery of the soybean aphid in North America, few farmers applied insecticides to soybeans. By 2004, soybean aphid was present in 21 states and two Canadian provinces, encompassing 80% of the soybean production area in North America [25]. There are a number of excellent studies regarding various aspects of the North American SBA invasion [26], [27], [28].

Prior to the arrival of the SBA, most farmers did not routinely use insecticide on soybeans. Once the SBA quickly spread throughout most soybean producing areas of North America in only NINE years, treatment with foliar pesticides was required—driving up costs both for spraying and field inspection. As research efforts expanded, treatment through the encouragement of natural predation has been found to be a cost-effective means of controlling damage of soybeans by the SBA [29].

SBA was quickly selected for "natural enemy" research in part because of its recent arrival, the additional costs incurred for treatment, and its significant impact on crop yields. However, the fact that the SBA has minimal impact on soybean production in Japan and China specifically because it is kept in check by natural predation was also an important consideration. The underlying logic of these experiments in predator-pest management was that if it was kept in check in its region of origin without pesticides, the damage inflicted by SBA in North America could be limited through the introduction and or promotion of predatory insects in this region as well. In East Asia, more than a dozen general predator insects feed on the SBA. In North America, this is also true, but the homogenous landscape of extensive soybean/corn fields kept predator populations from accessing the SBA. In Japan, for example, the more diverse rural landscape of mixed land use and forested areas in proximity to fields allowed predator insects' access to the SBA.

In North America, research determined that alterations of the landscape through the use of permanent or semi-permanent strips of perennial grasses and herbaceous shrubs could bring the predatory insects into closer proximity to the SBA and thus provide cost-effective biological control. The more varied the landscape, vis-à-vis areas with only soybean/corn fields, the greater the level of biological control [30]. Through publications, on-line information, and the work of farm extension in all affected states, information on "natural enemy" control of SBA was provided to farmers.

Initially, when the SBA first appeared, all farms treated soybean fields with conventional inorganic pesticides. Of course, some large scale farms—especially in the US South--still use this method. On the other hand, a growing research effort has shown—in large scale studies on actual farm fields—that the density of SBA can be reduced to acceptable levels through the use of predatory insects such as parasitoid wasps and beetles IF changes are made to the landscape ecology and these predator insect populations are encouraged to increase naturally or are introduced. Specifically, Gardiner et al. found in a study of 26 sites spread over four states of the US middle-west that alterations in the landscape, through the introduction or development of natural areas where predator arthropod populations could develop, reduced SBA densities per plant even as far as 1.5 km from the field tests sites [31]. The utility of any combination of predators for biological control collapses once aphids have colonized from 75-80% of plants. At this point, predator insects simply cannot keep up, and applications of foliar insecticides must be used. The problem with these applications however is that these insecticides are usually lethal to large proportions of the predator insects, meaning that biological control in subsequent years will of course be significantly reduced. Timing is indeed everything! Proper field scouting could limit damage to the crop and the predatory insect population.

Currently, in the US Midwest—the major soybean producing area of the nation--most insect pests of Soybeans including the SBA are attacked by natural enemies or biological control agents, with few consistent problems [32]. This occurred in the first 13 years after the SBA was first identified in North America. As noted above, when outbreaks are extreme (.75-80% of plants), biological controls alone will not be effective. However, with proper landscape alterations and sufficient stocking of predatory insects, less extreme infestations are routinely being controlled biologically.

6. Conclusion

It is of course very ironic that many of the biological "checks and balances" that are currently under investigation in the US and throughout the world were mainstays in traditional agriculture in China and many other places for centuries. Through relay, inter-cropping and other multiple cropping systems, pest damage to specific crops grown in traditional multiple cropping systems was minimized.

With growing demand for food especially during the post WWII era, the shift to inorganic fertilizers and farm chemicals in the US gathered steam and spread throughout the world until it seemed almost impossible to agronomists and farmers to conceive of farming systems not based on petro-chemicals. To be sure, some large portion of strategic crops such as food and feed grains will always require inorganic nitrogen, phosphorous and potassium. As noted earlier, less than 1% of US soybeans are " certified organic" but increasingly it appears that with sufficient research in biological controls and conservation tillage that the "ecological footprint" of many agricultural production systems can, and will, be significantly reduced through a reduction in the use of pesticides and possibly fungicides in the future. Major markets such as those for the Republic of Korea, Japan and China are increasingly demanding organic soybeans, and more recently organic meat and poultry—at premium prices.

Of course, changing domestic market conditions in the US such as the demand for organic and "safe" food have brought these diverse ways of controlling pests by encouragement of their "natural enemies" into the "spotlight", and have resulted in an explosion of research reported and promoted in many new journals that report systematic research conducted by agricultural scientists in these areas. This represents a major shift in the thinking of US farmers and researchers. The widespread control of the SBA on soybeans (a major export crop of the US) in the US Midwest is an excellent example of what can be accomplished—and accomplished in a cost-effective way. Investments in assessment of bio-controls of the SBA occur because soybeans are "big business". It is an important start, but many more studies must be done. Assessment has not kept up with innovations, yet both are essential. There is every reason to believe these high-end markets for organics of all types will continue to expand—and ecological economic assessment of the many emerging sustainable biological controls must be at the heart of the movement. Farmers and growers must be able to base their investment and production decisions on sound data and studies.

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