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By

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ABSTRACT

AN EVALUATION OF
DOMESTIC CHICKENS AND GEESE
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By

Michael Sean Clark

This dissertation reports a study of free-range domestic chickens and geese as insect pest and weed biological control agents. The study is comprised of four parts: 1) an evaluation of the compatibility of the birds in an experimental, non-chemical agroecosystem; 2) an assessment of the effectiveness of the birds as biological control agents through an evaluation of their effects on insect pests, weeds, crop damage, and crop productivity; 3) an assessment of the impact of the birds on beneficial soil invertebrates including epigeic predators and earthworms; and 4) a survey of small farmers' views on using free-range chickens and geese as biological control agents. The four sub-studies comprise chapters three through six, respectively.

Free-range domestic chickens and geese were evaluated as components of a non-chemical, potato-intercropped, apple orchard. Both chickens and geese were found to be compatible in the system but provided different benefits and had different requirements. Chickens were omnivorous, highly active throughout the day, and dispersed throughout the available area. In contrast, geese were strictly herbivorous, less active, and usually remained close to their coop and water source. Geese substantially reduced vegetation biomass under the trees and around the potatoes without damaging either of the crops. Chickens reduced non-crop vegetation biomass slightly but also were observed to consume several insect species, including Japanese beetle and Colorado potato beetle, suggesting that they could be used to control certain insect pests. Factors influencing the feasibility of integrating domestic chickens or geese into agroecosystems are discussed.

The effects of the chickens and geese on insect pests and weeds were evaluated in the same experimental, nonchemical agroecosystem. The objective was to assess the potential of these domestic bird species as biological control agents. Four insect pests were focused on in this study: plum curculio (*Conotrachelus nenuphar*), apple maggot (*Rhagoletis pomonella*), Japanese beetle (*Popillia japonica*), and Colorado potato beetle (*Leptinotarsa decemlineata*). Chickens were found to feed on several potential crop pests, including Japanese beetle. Although Japanese beetle abundance on apple trees was reduced in the presence of chickens, no reduction in the percentage of damaged fruit was found. Possible explanations for the lack of a crop protection effect are discussed. Furthermore, chickens were found to have no effect on weed abundance or crop productivity. In contrast, geese were found to be effective weeders. Their feeding activities reduced weed abundance and led to greater potato plant growth and yields compared to a minimally-weeded control. In addition, the activities of geese indirectly resulted in a reduction in apple fruit damage by plum curculio and a higher percentage of pest-free fruit. The possible reasons for this effect are discussed. The potential compatibility of geese with several vegetable crops and the economics of using geese as weed management agents are assessed.

The effects of the chickens and geese on the abundance of beneficial soil macroinvertebrates was assessed. Two groups of organisms were studied: epigeic predators and earthworms. Pitfall traps were used to sample epigeic predators. The presence of the birds resulted in a reduction in spider (Araneae) and harvestmen (Opiliones) activity, but no reduction in ground beetle (Carabidae) or rove beetle (Staphylinidae)

activity. The reason for these differential effects may be attributable to differences in the diurnal activity patterns of these invertebrates. Overall, the effects of the birds on epigeic predators were relatively minor in comparison to intercropping practices in the orchard. No significant effects on earthworm abundance due to the birds was found. However, earthworm abundance in the orchard and surrounding areas was highly correlated with soil organic matter (r =0.78) and the relative distance of the sample from an old field which had never been tilled (r =-0.77). A statistical model based on these two factors accounted for most of the variance in earthworm abundance.

Six farmers with experience raising domestic birds were interviewed to determine their perceptions of the feasibility of using chickens and geese as biological control agents. The farmers generally believed that domestic birds had potential as biological control agents, however, none of these growers specifically used the birds for this purpose on a regular basis. The reasons for this non-use were primarily due to a lack of efficient management systems or grower experience. Many other reasons for keeping domestic birds were mentioned: egg production, food and waste recycling, aesthetics, meat production, manure fertilizer source, and general enjoyment. All of the farmers expressed interest in better utilizing domestic birds for biological control. Future research directions are suggested based upon these interviews.

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INTRODUCTION

Industrial-based agriculture has been both a blessing and burden to human society. It has allowed, if not driven, rapid population growth in many parts of the world, the development of specialized occupations other than food procurement, and the creation of complex and amazing human civilizations. At the same time industrial agriculture has been accompanied by human overpopulation and caused localized and global environmental degradation. The current predicament facing modern industrial agriculture resides in the fact that resource- and energy-intensive food production methods developed in recent decades bring with them more than higher yields. The external costs have included contamination of ground and surface waters with nutrients and pesticides, ecosystem and wildlife destruction, human exposure to carcinogens, soil loss to erosion, and renewable and non-renewable resource depletion. At the same time, the exponentially growing human population will require still greater rates of food production. Can methods be developed and utilized to meet the growing human food demand without wreaking havoc on our global life support system?

The goal of this thesis project is to contribute to the development of ecologically-based food production methods. The primary differences between industrial and ecological approaches to food production are that the former is based upon the idea that problems in agriculture can be solved with various types of manufactured inputs, such as pesticides and fertilizers, while the later is based upon the idea that problems can be solved through an understanding of ecological systems, through resource conservation, and by living within reasonable limits. The industrial agricultural paradigm is clearly dominant in the United States. The trend toward greater labor and capital efficiency and higher yields has resulted in a system where less than 2% of the population grows the food for everyone and there is still surplus to trade on the world market. No other country in the world has reached this level of labor efficiency.

Ecological agriculture differs from the industrial approach in a fundamental way and is typically exemplified by "organic farmers." Although the primary goal is still to produce food, other important goals include the replacement of purchased, off-farm inputs with knowledge of farm ecology, systems integration for holistic resource management, and minimization of waste and environmental degradation and pollution. Barriers to this type of farming are social and economic as well as ecological in nature. Therefore, in addition to a purely ecological analysis, I have attempted to integrate some social, economic, and philosophical elements into my approach toward this research problem. The redesign of agroecosystems for sustainable food production requires a multidisciplinary approach. Although the primary focus of this research project has been entomological in nature, effort has been made to give reasonable attention to the rest of the system as well so that the results can be interpreted within a broader context than is generally possible with strictly disciplinary research.

The overall objective of this research was to evaluate domestic birds as components of ecologically-based agricultural systems. Domestic birds might serve several functions in human-managed ecosystems including biological control agents, nutrient cyclers, and scavengers. Like most microlivestock, domestic birds are relatively easy to manage, require little capital investment, and are important as a food worldwide. Thus, there may be potential for domestic birds to be used as biological control agents in some types of agroecosystems. The specific objectives of this research project were:

1) To assess the compatibility of domestic birds in a diverse, ecologically-managed food production system.

2) To measure the direct and indirect effects of domestic chickens and geese on insect pests, weeds, and crops in an experimental integrated agroecosystem.

3) To evaluate the potential effects of domestic chickens and geese on beneficial non-target, soil-dwelling invertebrates.

4) To assess the potential for domestic birds play a role in biological pest management through interviews with experienced, small farmers.

CHAPTER 1

AN ECOLOGICAL PERSPECTIVE ON MODERN AGRICULTURE: A LITERATURE REVIEW

Agriculture is dependent upon a variety of biotic and abiotic environmental characteristics as well as local, regional, and global ecosystem processes. Climate is probably the most important factor affecting agricultural systems over large spatial and temporal scales (Rice and Vandermeer, 1990). Climate, or long-term rainfall and temperature patterns, determine the possible range of farming systems for an area. Human technology can alter this range but only within the limits of available renewable and non-renewable resources. Soil characteristics are highly dependent upon climatic history. Water, in its liquid and solid form, physically and chemically breaks down geological parent material to create soil. Water also degrades soil by leaching nutrients from it. For example, the soils of the tropics are much older (100,000 to 1 million years old) and less fertile than the soils of the temperate region (10,000 to 40,000 years old) which were formed mostly during the last glaciation period that ended 10,000 years ago. Water has leached most the nutrients from tropical soils (Rice and Vandermeer, 1990).

Biotic factors affecting agriculture are also highly dependent upon climate. The composition and effects of agricultural pests, including herbivorous insects, crop pathogens, and native plant competitors, are determined to a large extent by climate. For example, pest populations in the wet humid tropics are maintained at relatively consistent levels throughout the year due to the lack of seasonality whereas in the temperate region they are characterized by relatively consistent seasonal patterns and are only problematic during the warmer months (Rice and Vandermeer, 1990). Agriculture is influenced by local biotic landscape features as well. For example, the composition of surrounding vegetation and the proximity of field edges have been commonly shown to influence pest insect population levels and crop damage (Landis, 1994). Humans have adapted agriculture to local and regional biotic and abiotic environmental factors through cropping system modifications, crop and animal breeding, soil amendment additions, irrigation systems, and pest suppression and management tactics.

In addition to being affected by the environment, agriculture has been the cause of dramatic local, regional, and global ecological changes. Cultivated land is estimated to cover approximately 16 million km^2 or 10% of the 147 million km^2 of global land surface (Vitousek et al., 1986). Richards (1990) estimates that the amount of global land surface used for growing crops has increased by 466% since 1700. In North America this increase is estimated to be 6667%. Although global land conversion into cropland is accelerating, there is estmated to be less than 19×10^6 km^2 of total land suitable for rainfed agriculture (Meyer and Turner, 1992). In addition to displacing native ecosystems, including forests, wetlands, and grasslands, agriculture is having substantial effects on soil, water, energy, mineral, and biological resources on a global scale (Meyer and Turner, 1992).

SOIL RESOURCES

The negative effects of agriculture on soil are primarily due to water and wind erosion and occasionally to contamination by agricultural chemicals. The vulnerability of soils to erosion varies considerably yet it is a serious problem worldwide. The effects of soil erosion include reduced soil productivity, increased fertilizer costs for compensation, sediment deposition in surface waters which reduces suitability for food production, recreation, and drinking, and eutrophication of surface waters (Soule et al., 1990). Even with state and federal efforts to control soil erosion in the United States, it remains a serious problem in some areas due to the use of continuous row cropping, fewer rotations with perennials, price support programs, and the enlargement of farms without an increase in the number of managers (National Research Council, 1989).

Soil contamination is sometimes caused by the accumulation of pesticides or the products of pesticide breakdown. Most pesticides applied to crops end up in the soil and may stay there for variable lengths of time depending upon the compound, soil abiotic and biotic composition, and amount of rainfall. Pesticides are removed from soils through breakdown by microorganisms and sunlight, water flow through the soil, wind, and volatization (Edwards, 1993). The effects of pesticides on soil organisms vary considerably among taxonomic groups and is dependent upon the chemical compound used and the frequency of application. The effects on ecosystem functions include reductions in soil respiration, organic matter degradation, and nutrient cycling (Edwards, 1993).

WATER RESOURCES

The effects of agriculture on water resources result partially from inadequate management of soil resources. Agricultural lands contribute sediments, nutrients, minerals, and pesticides to surface waters and nutrients and pesticides to groundwater. It is estimated that 50 to 70% of nutrients, primarily nitrogen and phosphorus, reaching surface waters are from agricultural lands (National Research Council, 1989). Nitrogen, in the form of nitrate from fertilizers, is a common contaminant of drinking water and, in addition to phosphorus, contributes to eutrophication in surface waters worldwide (Soule et al., 1990; Spalding and Exner, 1993; Sharpley and Meyer, 1994). Phosphorus is usually present in small quantities in surface waters and is the primary cause of eutrophication when it is abundant. It generally binds to soil particles and is therefore not readily carried into surface waters except where soil erosion is high.

Pesticides have been found in surface water and groundwater throughout the United States (National Research Council, 1989). It is estimated that over 50% of the United States population obtains its drinking water from groundwater and that 10.4% of community wells and 4.2% of private wells have detectable levels of pesticides (Curtis et al., 1993). Pesticides in groundwater are especially problematic because of the difficulty and expense of decontaminating those water sources. Pesticides found in surface waters are most common in areas with intensive row cropping of corn and soybeans (National Research Council, 1989). The environmental effects of pesticides in aquatic ecosystems is not well known. In general, aquatic organisms are more susceptible to pesticides than those in terrestrial ecosystems (Edwards, 1993).

Irrigation, a seemingly harmless activity, has also resulted in the degredation and depletion of soil and water resources. Clearly, irrigation has led to substantial increases in crop productivity and allowed for production in areas that would otherwise be unsuitable. At the same time it has led to salinization of ground and surface waters in many areas. When water used for irrigation evaporates the dissolved salts remain and become concentrated. These salts either remain in the soil or return to rivers and lakes as runoff. Major rivers in the United States, including the Rio Grande and the Colorado, are severely salinized by irrigation (National Research Council, 1989; Soule and Piper, 1992). Depletion of groundwater reserves has also resulted from irrigation. About 25% of renewable groundwater is being used faster than it naturally replenishes (Soule and Piper, 1992). Some fossil aquifers, which are non-renewable resources, are being rapidly depleted as well. The familiar Ogallala aquifer, which lies beneath seven western states, supports 40% of grain fed cattle in the United States. Yet, at current usage rates this aquifer may be practically exhausted in less than 50 years (Soule and Piper, 1992).

ENERGY AND NUTRIENT RESOURCES

Industrial agriculture is highly dependent upon fossil fuel inputs. Although only 3-6% of the total energy consumed in developed nations is used in food production, fossil fuel use has contributed to dramatic yield increases over the last several decades (Pimentel and Dazhong, 1990; Stout, 1993). In a historical analysis of corn production in the United States, Pimentel and Dazhong (1990) found that yield has increased 3.5-fold since 1700 while energy inputs increased 15-fold. Thus, energy efficiency (output/input) has decreased from 10.5 in 1700 to 2.5 in 1983. This type of analysis is somewhat misleading in several respects. Loomis (1984) has criticized this analysis because it neglects to consider the embodied energy of workers in the calculation of the energy of human labor. Loomis states that the energy required for overall human care, for example child care, recreation, and retirement, should be included in such analysis. Furthermore, this analysis neglects to consider overall production efficiency (including solar energy inputs) and the consequences for land use. When solar energy inputs are included in the analysis, modern corn systems are more efficient at converting solar energy into food grain than primitive systems (Pimentel and Dazhong, 1990). Furthermore, the amount of land needed for a given yield is less when fossil-based inputs are used (Loomis and Connor, 1992).

The environmental concerns over energy use in agriculture include the effects of fossil fuel combustion on the atmosphere, hydrosphere, and geosphere and uncertainty over the future of agriculture as more nations adopt industrial production methods and fossil fuel reserves are depleted. Although agricultural production utilizes a relatively small fraction of total energy, food systems use 15-20% of the total energy consumed in industrialized nations (Pimentel and Dazhong, 1990; Stout, 1993). Processing, packaging, distribution, and preparation require more energy than production and are largely responsible for the fact that more than 10 units of commercial energy are used for each unit of nutritional energy consumed (Giampietro and Pimentel, 1992). In developing nations only 3-5 units of energy are used for each unit of nutritional energy consumed. It has been estimated that energy requirements could be cut in half if a greater proportion of the population worked on farms; however, the cost of human labor has become so expensive relative to fossil energy that such a change is considered economically impossible (Pimentel and Dazhong, 1990).

Petroleum production, which peaked in 1979, will likely remain the dominant source of fuel only for the next 2-3 decades (Stout, 1993). By the middle of the twenty-first century petroleum reserves will be exhausted (Loomis and Connor, 1992). Although several hundred years-worth of coal exists, it is bulky and causes considerable air pollution (Loomis and Connor, 1992). Thus, it appears that solar, wind, hydroelectric, and geothermal energy production will play a larger role in the future. It is also possible that the relative costs of human labor will become more competitive with fossil fuels and industrial societies may return to more agrarian-based economies.

Nutrients are added to agroecosystems because they are removed in harvested products and lost to erosion, leaching, denitrification, and volatilization. Synthetic fertilizers, animal feed, and animal manure are typically added for nutrient replenishment. In industrial societies most nutrients eventually end up in landfills or surface waters although a small fraction is recycled back to farms as sewage sludge (King, 1990). Environmental degredation due to nutrient runoff has been discussed. However, there is also concern over the lifetime of resource reserves used for fertilizer production. Nitrogen fertilizer production is strictly dependent upon fossil fuel reserves. In fact, nitrogen fertilizer accounts for 30% of the energy consumed in modern corn production (Pimentel and Dazhong, 1990). Potassium and phosphorus are mined from geological deposits and therefore also have finite quantities for use in industrial agriculture. Based upon current usage trends the deposits of both of these minerals may be used up in less than 100 years (King, 1990).

BIOLOGICAL RESOURCES

The effects of industrial agriculture on biological resources have included wildlife habitat destruction, extinction of species, loss of crop and domestic animal genetic diversity, and the selection for resistant pests. While the amount of land used for agriculture has increased dramatically since 1700, forested land has decreased globally by about 15%. Current trends indicate that deforestation has stabilized in developed nations while it continues in the tropics (Meyer and Turner, 1992).

The primary reasons for deforestation include the expansion of cultivated and pasture lands and the extraction of timber and fuelwood (Meyer and Turner, 1992). Thus, food production and preparation are largely responsible for forest loss. The consequences of these trends for biological diversity are difficult to determine. Nonetheless, current extinction rates are estimated to be several orders of magnitude above background levels (Vitousek, 1992).

The loss of biodiversity includes that of crop plants and domestic animals. Local landraces or varieties have been developed over hundreds or thousands of years of selection by humans. Recent advances in plant breeding have resulted in high-yielding varieties which have replaced local varieties in areas thoughout the world. There is concern that the loss of local varieties is endangering the global food supply because current commercial varieties have a narrow genetic base. The Irish potato famine of the mid-1800s provides an example of the potential consequences of low crop genetic diversity. Europe's entire potato crop at that time had been developed from only two samples from South America, both of which were susceptible to late blight, *Phytophthora infestans* (Soule and Piper, 1992). Similarly, in 1970 southern corn leaf blight destroyed 15% of the corn crop in the United States because most major varieties were developed from the same susceptible genetic source (Luna and House, 1990; Soule and Piper, 1992).

Although agricultural pests are generally not considered to be biological resources, the evolution of pesticide resistance has clearly demonstrated that susceptible pests should be treated as a resource. Heavy reliance on chemical pesticides has led to the evolution of pesticide resistance in rodents, arthropod pests, weeds, and plant pathogens. Today at least 500 arthropod pest species have evolved resistance to pesticides (Gould, 1991; Kim, 1993). A significant number of weed and plant pathogen species have also evolved resistance to one or more pesticides. An important consequence of this is that greater quantities of pesticides have been required to control resistant pests. Although resistance in some pests has evolved in response to cultural and biological control measures, the vast majority of cases has resulted from complete reliance on chemical pesticides for pest management.

AGRICULTURAL SUSTAINABILITY

The sustainability of modern agricultural practices and systems has been fiercely debated for the last three decades. At the global level the central issue is whether or not the exploding human population can be fed with agricultural methods which do not lead to environmental degredation and resource depletion. There is ample evidence that if current trends in agricultural industrialization continue human life-support systems will be irreparably damaged and lead to greater human suffering (Brown and Kane 1994; Soule and Piper, 1992; Meadows et al., 1992). At the same time, human population growth continues to accelerate and is estimated to reach 8.9 billion by 2030 (Brown and Kane, 1994). Based upon recent food production trends, global demand is expected to greatly exceed production within several decades (Brown and Kane, 1994).

At national, regional, and local levels issues related to agricultural sustainability differ and are often complicated by diverse interests. Ultimately the concern over agricultural sustainability is a concern over human welfare. Although physical aspects of human welfare, such as nutrition and freedom from disease, seem relatively easy to measure, other aspects, such as happiness and quality of life, do not. This has led, in part, to the extreme divisiveness of issues related to agriculture and human welfare in the public forum. Even issues related to the effects of pesticides on human health are far from settled. Experts continue to argue over the validity of past studies and the relative risks of human activities and choices on long-term human health and societal welfare (York, 1991; Loomis and Connor, 1992; Merwin and Pritts, 1993; Pimentel et al. 1993; Schuman 1993). Although a variety of diverse indicators have been used to assess human quality of life, the most common are economic, such as annual income and gross national product (GNP). There are certainly many other elements important to human well-being but none are as easy to measure as the economic indicators. Nevertheless, the potential consequences of agricultural technologies on human welfare need to be considered beyond the short-term economic effects.

Certainly the primary purpose of agriculture is to produce food, fiber, and other materials for human use. But, to farmers, their families, and rural communities, it is also a source of income and a way of life. Many people consider family farms and traditional farming methods part of this nation's heritage. However, the production capacities of traditional farming methods are dwarfed by the immense capabilities of industrial methods. The use of chemical fertilizers, pesticides, and machinery has resulted in dramatic increases in farmer productivity and in a steady decline in the size of farming populations and rural society as a whole. The industrialization of agriculture and food production systems has led to many changes in rural society and there is considerable disagreement over whether the results have been desirable or destructive.

According to Pradgett and Petrzelka (1994) the emphasis on increased production and new technology has led to a system characterized by competition, self-interest, and short-term visions. Only those farmers who invested in new technologies and enlarged their operations have been able to survive. The loss of farms has resulted in a shrinking farming population and the economic collapse of many rural areas. It has also been argued, however, that the exodus from rural areas to the cities during this century resulted from dissatisfaction with the tedious and exhausting life on farms, especially prior to the introduction of new technologies. Urban areas offered a greater chance for prosperity than many farmers could obtain growing food (Loomis, 1984).

In market economies the values of society are suppose to be reflected in the way that individuals spend money . Thus, if society valued traditional agriculture and family farms, theoretically it could maintain them through the market (White et al., 1994). Similarly, if society wants agriculture to move in a more sustainable direction now it should be able to bring about such change though the market system. But with the immense diversity of products on the market and the social and physical distancing between producer and consumers it appears that most consumers are unaware of the processes behind food production. Furthermore, because market costs do not necessarily reflect true costs, consumers do not have enough information for making informed decisions. In addition, many ecologists and at least some economists acknowledge that a market system based upon perpetual economic growth and consumption is in conflict with the concept of sustainability (Hall, 1990; Daly, 1993; White et al., 1994). There are few incentives in a market economy to conserve resources, prevent pollution, or preserve rural communities (Hardin, 1968). Therefore, in order to achieve more sustainable agricultural systems more emphasis is needed on community and cooperation as well as a long-term vision of the future (Lacy, 1994; Pradgett and Petrzelka, 1994). Such changes are not likely to occur without policies which increase the incentives for farming more sustainably.

Agricultural sustainability is a combination of overlapping goals rather than a specific set of practices. These goals generally include improving environmental, social, and economic aspects of food production. The relative importance put on particular goals varies greatly. White et al. (1994) describe sustainability as "an essential but fluid goal that continually retreats into the future ahead of us." Although the concept of agricultural sustainability is somewhat vague and subjective, environmental degredation, resource depletion, and the subsequent effects on human welfare are not. Therefore steps must be taken to move toward generally accepted goals. The more commonly cited goals for increasing agricultural sustainability include: reducing pesticide use, improving soil conservation, increasing nutrient conservation and recycling, improving economic stability, reducing fossil fuel dependence, maintaining or increasing production efficiency, and enhancing quality of life.

THE ROLES of DOMESTIC ANIMALS in AGRICULTURAL SUSTAINABILITY

Animals were important sources of food, clothing, and shelther for humans long before domestication began about 12,000 years ago. However, with domestication came an expansion of the roles and importance of animals in human society. During the last several thousand years animals, including dogs, cattle, horses, goats, sheep, poultry, and others, have been used for many purposes beyond simply serving the basic human needs. These have included traction, transportation, hauling, guarding, recreation, herding, and companionship. Thus, with domestication the relationship between humans and domestic animals was fundamentally transformed from that of predator and prey to that of mutualism.

Today, the discussions and debates on sustainability have focused much attention on the roles of domestic animals in agriculture and the larger food system, particularly in industrialized nations. The issues of concern can be categorized into three basic areas: ecological, nutritional, and ethical. Most of the issues are directly or indirectly related to the industrialization of animal production.

Ecological concerns over domestic animals stem largely from the resource inefficiencies in industrialized production systems and the environmental deterioration that seems to accompany most production systems. Industrial animal production is extremely energy intensive (Hall et al., 1992). According to Pimentel (1984), in the United States it takes 7-88 kcal of fossil energy to produce 1 kcal of animal protein while it takes only 0.7-3 kcal of fossil energy to produce 1 kcal of plant protein. Animal production is also land intensive, with nearly one quarter of the earth's land surface used for pasturing animals (Rifkin, 1992). Worldwide, animal production, particularly that of cattle, has been a cause of deforestation, desertification, water contamination, soil erosion, and global warming (Rifkin, 1992; Pimentel et al., 1995).

Animal production has also been criticized on nutritional grounds because animal protein is not a necessary component of the human diet (Pimentel, 1984; Robbins, 1987; Lappe, 1991) yet most edible grain in industrialized nations is feed to cattle and other animals. This system results in reduced food production efficiency and the loss of potential nutritional energy for human consumption. Furthermore, many of the "diseases of affluence," such as heart disease, some types of cancer, and diabetes, that have become so common in wealthy, industrialized nations are attributed to diets high in fat and cholesterol which typically means diets high in animal products (Robbins, 1987; Lappe, 1991).

The ethical considerations are the most difficult to deal with from a scientific perspective. Nonetheless, they have been central issues in the sustainable agriculture movement. Essentially there are two levels of concern. The more general or mainstream concern is animal welfare under human care. Agricultural industrialization has been accompanied by the removal of animals from relatively natural settings and subsequent placement into largely artificial environments which, while providing opportunities for increased production, commonly result in increased stress and behavioral deprivation (Robbins, 1987; Kiley-Worthington, 1993). Domestic animal welfare has received attention from scientists and attempts have been made to develop objective methods of welfare assessment and more humane producition systems (e.g. Dawkins, 1983; Appleby and Hughes, 1991).

A more difficult ethical concern for agricultural science is the morality of killing animals for human food. Advocates of vegetarianism often point to the ecological, nutritional, as well as the ethical points when defending their position. One's stance however on the ethics of killing other species for human use is a moral question and science really has little to offer on the issue. Ethical arguments against animal consumption are at least somewhat flawed from an ecological point of view in that it is impossible to live without destroying the life or potential life of another organism (Kiley-Worthington, 1993). Furthermore, the ecological consequences of not slaughtering the domestic animals we now have would be catastrophic. Ironically, the condemnation of animal consumption also perpetuates the fallacy that humans are somehow separated from nature (Lappe, 1991), a perception that many argue is one of the root causes of current ecological problems.

Although animal production in agriculture, particularly industrialized agriculture, has been criticized on a variety of grounds, there are many potential roles for domestic animals in ecologically-based agriculture and food systems. Although there is no clear right and wrong way to raise animals, when viewed from an ecological perspective, animals can perform functions that would otherwise be more difficult or even impossible without them. In one analysis, Bender (1994) concluded that animals play an important role in achieving fundamental goals of ecologically-based farming including soil conservation, pesticide elimination, financial stability, and nutrient cycling. Much of the land that is in pasture is used as such because it is unsuitable for cropping. Thus, these lands are maintained in forage plants which provide protection against soil erosion and feed animals. Animals convert lignocellulosic plant materials such as forage crops, crop residues, and byproducts, which are essentially non-competitive, renewable resources, into food for human consumption (Parker, 1990). Furthermore, the proper management of manure produced by domestic animals aids in nutrient cycling processes on farms and within localized regions. Thus, the integration of crop and animal systems can provide complementary and synergistic effects by allowing for the efficient utilization of on-farm resources. In addition, animals can be used for vegetation management by grazing in agroforesty systems and for biological weed control (Parker, 1990).

The suitability of animals in agriculture and food systems will depend upon local and regional ecological factors, including soils, climate, and energy resources, as well as the particular socioeconomic conditions and societal values. While animals and their products will not be appropriate under all circumstances, the integration of crops and animals into well-managed systems can provide flexibility, diversity, and stability for agriculture and food systems.

PEST MANAGEMENT and AGRICULTURAL SUSTAINABILITY

Although pest management is only one element of agricultural management it directly or indirectly influences all of the goals stated for improving sustainability. Pest management practices directly affect pesticide use, crop productivity, fossil fuel use, and economic performance. Soil and nutrient conservation are indirectly influenced by insect, weed, and pathogen management practices. The development of sustainable pest management strategies needs to be integrated with management approaches for soil fertility, marketing, labor, and other elements of farm management. Probably the two key issues for pest management are reducing pesticide use while simultaneously maintaining or increasing productivity. Careful analyses of all economic and noneconomic costs and benefits are required to assess current and future pest management methods within a holistic perspective.

It has been estimated that 35% of global crop and livestock productivity is lost to pests, primarily insects, weeds, and pathogens (Pimentel, 1991). In the United States this estimate is 37% with insects, weeds, and pathogens accounting for relatively equal proportions (Pimentel, 1991). Although pesticide use has increased dramatically over the last half of this century, total crop and livestock losses to pests have remained steady or increased slightly (Osteen, 1993). Pimentel et al. (1993) estimate that in the United States about $4 billion are spent annually for chemical control to protect about $16 billion in crops from insects, pathogens, and weeds. However, the environmental and social costs associated with pesticide use were estimated to be $8 billion with the most significant costs attributed to bird losses, groundwater contamination, pesticide resistance in pests, crop losses, and public health impacts. Thus, it was calculated that for every 3 dollars spent by society on pesticides 4 dollars are made. In contrast, it has been estimated that for every dollar spent on biological control $30 to $100 have been made (Hoy, 1992).

Reductions in pesticide use now and in the near future will depend primarily on the development of cultural and biological control methods. However, most integrated pest management (IPM) programs have focused on making pesticide use more cost effective through more efficient use, rather than replacement and integration of alternatives. In fact, global pesticide use is expected to increase from the current 2.5 billion kg to over 3 billion kg applied annually by 2000 (Pimentel, 1991). North America and Europe currently account for nearly 80% of all pesticides applied. As more developing nations attempt to adopt industrial agricultural methods, pesticides will play a larger role in other parts of the world. Yet, most of the rest of the world currently depends largely on nonchemical pest management and there are opportunities to slow the current trend toward pesticide use with a combination of traditional methods and newly developed technologies and knowledge.

The substitution of biological and cultural management methods for pesticides is based on the idea that ecological knowledge can be substituted for purchased inputs (Luna and House, 1990). Current crop losses are high in spite of increased pesticide use and have been attributed to a variety of causes, including lack of crop rotations, more susceptible varieties, increase in monocultures, reduced crop diversity, loss of natural enemies from pesticides, reduced sanitation, higher cosmetic standards, and pesticide resistance (Pimentel et al., 1993). In an analysis of currently available pesticide alternatives, Pimentel et al. (1993b) concluded that pesticide use could be reduced by 50% in the United States without a significant loss in production, as is currently being done in Denmark, The Netherlands, Sweden, and Ontario, Canada. In that analysis, methods for pesticide reduction included greater use of scouting, crop rotation, resistant and vigorous varieties, sanitation, insect pathogens, mulch, cultivation, forcasting, spot treatments, and biological control.

It has been argued by agricultural scientists in a variety of disciplines that industrial agroecosystems need to be dramatically redesigned to be more sustainable (Edens and Haynes, 1982; Hill and MacRae, 1992; Edwards et al., 1993; Altieri, 1994). This argument seems particularly valid in the area of crop protection. Based upon ecological theory it has been hypothesized that pests could be better managed by increasing biological diversity in agroecosystems. According to Edwards et al. (1993) the use of pesticides in industrial food production systems has replaced the functions of biodiversity in traditional agroecosystems. They suggest that research should be done to "design practical integrated systems of crops and animals that can be adapted to regions, minimize energy-based inputs and have long-term sustainability." Similarly, Hill and MacRae (1992) state that farms should be "made more ecologically and economically diverse, resource self-reliant and self regulating." These authors suggest that designing agroecosystems with greater biological diversity is required to sustainably manage pest problems. The idea that diversification reduces pest problems is supported by two current hypotheses (Risch et al., 1983; Andow, 1991). One is that crop plants are less apparent and predictable in more diverse environments (resource concentration hypothesis) (Vandermeer, 1989; Roltsch and Gage, 1990; Andow, 1991) and the other is that more diverse habitats have a greater diversity and abundance of natural enemies (enemies hypothesis) (Letourneau, 1987; Russell, 1989). Neither of these hypotheses hold up universally but both have been demonstrated to be valid under a variety of cropping systems.

In order to maintain a holistic approach in the analysis of agroecosystem redesign the views of critics should also be considered. Loomis (1984), for example, claims that increasing on-farm diversity would lead to production inefficiencies because more machinery would be needed, greater knowledge and management skills would be required, and there would be greater risks and smaller returns. This view is based upon an economic way of thinking which emphasizes the importance of capital, technology, and growth and largely ignores the importance of biological and physical resources and ecological processes. Ironically, sustainable agriculture advocates also claim that greater knowledge and management are required; however, they propose that these can replace purchased inputs, leading to greater efficiency, and thus, enhanced sustainability.

These issues surrounding agroecosystem diversity, stability, and efficiency in pest management, as well as in other facets of food production, are quite complex and still not well understood. The knowledge and skills of a farmer are critical to managing diverse operations. And, assuming a farmer has adequate knowledge and skill, the stability of diversified systems should be less susceptible to ecological and economic uncertainties. Whether or not more machinery would be required for diversified systems would depend on the composition and structure of the farm and larger food system and cannot be easily generalized. Only if it is assumed that there are adequate soil, water, mineral, energy, nutrient, and biological resources and an essentially endless assimilative capacity of the global ecosystem to maintain industrial-based agriculture indefinitely, or at least over the next few centuries, do Loomis' claims appear valid. Nelson (1995, p.148) succinctly described this disagreement between the ecological and economic points of view in stating that, "Economists can point to a 200-year history of mistaken predictions of food, energy, timber, and other dire crises sure to occur in the near future. Yet, the fact that these predictions essentially all proved wrong does not guarantee that they must always be erroneous." In this sense, the economic point of view is understandable, but, in a world of shrinking resources and deteriorating ecosystems, agricultural diversification on farms, landscapes, and regions seems to be a logical approach to designing more sustainable agroecosystems, especially in the arena of pest management.

CHAPTER 2

THE SPECIFIC CONTEXT OF THIS PEST MANAGEMENT PROBLEM: A LITERATURE REVIEW

The experimental agroecosystem focused on in this research project has been designed for ecologically-based management with several assumptions in mind. The first assumption is that on-farm diversity provides production stability in an environment which is only partially predictable. Secondly, food production should not lead to environmental degradation. Finally, farming should be a desirable, safe, and stable occupation. These assumptions may be contentious, however all research, especially in applied science, is based upon implicit or explicit assumptions and values. It is therefore important to identify and examine these assumptions prior to conducting research as well as during the interpretation of results.

The experimental agroecosystem used for this research is located at the Kellogg Biological Station, Michigan State University. It is a 2-ha apple orchard planted in 1983 with disease-resistant varieties and managed without the use of pesticides. This has allowed the pasturing of domestic birds and the use of the orchard alleys for intercropping annuals. Potato has been used as a model intercrop for this research project primarily because of the ease in producing it, its presumed compatibility with domestic birds, the current problems with controlling Colorado potato beetle in commercial production, and evidence in the literature that chickens have been used to control this pest. Under conventional orchard management pasturing domestic birds and intercropping annual crops is generally not possible.

CURRENT STATUS OF APPLE PEST MANAGEMENT

Apples are generally considered to be a high-value crop which need to be blemish-free to be marketed today. Since 1945 increasing importance has been placed on the cosmetic appearance of fruits and vegetables, not only by consumers but also by the USDA, retailers, and wholesalers. Although the general public prefers visually "perfect" produce, most people are largely unaware of the connection between improved cosmetic appearance and increased pesticided use (Pimentel et al., 1993c; van Ravenswaay, 1994). Nevertheless, efforts have been made in recent decades to reduce pesticide use on apples and other fruits. These efforts have been driven not only by environmental and health concerns over pesticide use, but also by increasing pesticide costs, evolution of resistance in many pests, and decreasing availability of pesticides because of fewer registration renewals (Prokopy and Croft, 1994).

The adoption of IPM practices by apple growers has been increasing since the early 1970s and is currently widespread (Whalon and Croft, 1984), but pesticide use remains high. According to Prokopy (1994), this is because most commercial growers practice chemical-based IPM. Prokopy describes four levels of integrated pest management in apple. With each increasing level there is greater integration, which begins with the development of management strategies for individual pests and ends with the "blending of concerns of all those having vital interest in pest management: researchers, extension personnel, private consultants, industry, growers, processors and distributors, consumers, neighbors of growers, environmentalists, and local as well as federal government regulatory agencies." According to Prokopy, few commercial orchards are beyond the first level of apple IPM.

According to estimates presented by Pimentel et al. (1993b), 7 million kg of insecticides are applied to apples in the U.S. annually with 96% of hectarage being treated. Studies have shown that when pesticide applications are discontinued in conventionallymanaged orchards or when orchards are left unmanaged, insect damage to fruit can be extremely high (Glass and Lienk, 1971; Madsen and Madsen, 1982; Reissig et al., 1984; Prokopy, 1991). The most important insect pests in northeastern and north central North America are codling moth (*Cydia pomonella* L.), apple maggot (*Rhagoletis pomonella* Walsh), and plum curculio (*Conotrachelus nenuphar* Herbst). These three species can damage nearly 100% of the fruit during a growing season if unmanaged.

Alternative control measures for these pests have been evaluated and the results are variable. For example, Pfeiffer et al. (1993) found that pheromone mating disruption can reduce codling moth damage. However, under high pest pressure, damage levels still may be unacceptable for many commercial growers. Reissig et al. (1984) concluded that small blocks of disease-resistant apples could not be grown in northeastern North America without the use of insecticides. However, they stated that alternatives including insect growth regulators for internal-feeding Lepidoptera like codling moth, orchard sanitation and sticky red spheres for apple maggot, and disease-resistant apple varieties could be used to reduce the amount of pesticides used. The literature concerning alternatives to pesticides in apple production suggests that increasing the feasibility of low-chemical or nonchemical apple production in northeastern and north central North America depends upon not only maintaining low levels of damage by codling moth, apple maggot, and plum curculio but also reducing the costs and labor demands of alternative practices and systems (Pimentel et al., 1983; Prokopy, 1991; Agnello et al., 1994).

Apple production systems which do not depend on pesticides need to maximize biological control, host plant resistance, cultural management, ecological knowledge, and efficiency of design. Biological controls for codling moth, plum curculio, and apple maggot have been investigated but require further attention. A few studies have shown that indigenous predators and parasitoids can have an impact on the mortality levels of these pests (Leius 1967; Subinprasert ,1987; Hagley and Allen, 1988; Allen and Hagley, 1990). However, studies need to be conducted to evaluate how habitat manipulations can be used to enhance predator populations and their effectiveness against pests. Cultural practices, such as removing apple drops, mulching, pruning, and conserving habitat for beneficial arthropods and insectivorous birds, may aid in reducing pest pressure and also need further attention. Methods to manage ground vegetation effectively could involve the use of low-maintenance ground covers and domestic animal grazing. Fungicides, which are currently applied to 90% of apple hectarage (Pimentel et al., 1993b), could be virtually eliminated by using disease resistant varieties (Reissig et al., 1984; Prokopy, 1991). Tactics which take advantage of pest behavior, such as the use of sticky red spheres and pheromone disruption, will also need further development to be more efficiently utilized in nonchemical production.

Apple Pests Considered in this Study

Plum Curculio, *Conotrachelus nenuphar* (Herbst)

Plum curculio is native to eastern North America and feeds on a variety of pome and stone fruits. Its damage to apple fruit includes cresent-shaped ovipostion scars on the surface, feeding damage from the adults, internal feeding damage from the larvae, and premature drop of internally-damaged fruit caused by the release of pectic enzymes and cellulase released by the larvae (Racette et al., 1992). The actual yield loss due to premature drop from plum curculio larval damage is not known because its occurrence coincides with the natural fruit abcission commonly known as "June drop" (Racette et al., 1992). The ovipostion scars commonly seen on mature fruit are cosmetic injuries. The presence of such scars at harvest are not indications of larvae within the fruit, but rather of failed larval survival. The newly emerged larvae are commonly crushed by the rapidly growing fruit, leaving surface scars without internal damage. Nevertheless, due to the strict cosmetic standards for fruits, including apples, such surface damage is generally not tolerated by wholesalers, retailers, processors, or consumers.

Plum curculio has been found to overwinter under the fallen leaves of deciduous forests, especially thick litter layers, and may also overwinter under other types of ground debris in and around orchards, although evidence for this is lacking (Lafleur et al., 1987; Racette et al., 1992). In Michigan it usually migrates into apple orchards just prior to or at bloom and peaks in activity approximately two weeks after petal fall (Brunner and Howitt, 1981; Lafleur and Hill ,1987). This migration may take several days to several weeks (Racette et al., 1992).

Chouinard et al. (1993) observed the activities and behaviors exhibited by adult plum curculio once arriving to an orchard. They found that it spends most of its time (65-90% of observations) resting. Resting usually occurs on the ground (83% of total observations, n=1433) and is most common from 0000 and 1200 hours. The two most frequently observed activities were crawling and feeding. Crawling was observed equally both in trees and on the ground while feeding was observed mostly in the trees. Activities which were infrequently observed included mating, aggregating, flying, and egg laying. Overall activity was positively correlated with an increase in relative humidity and a decrease in the air saturation deficit, which is the drying capacity of the atmosphere based on temperature and humidity. Their observations indicated that flying and dropping from the trees followed by crawling were important means of within-orchard dispersal.

Current control methods for plum curculio are almost exclusively chemical in commercial orchards (Racette et al., 1992). One possibility for reducing insecticide applications for this pest is through fruit monitoring to appropriately timed sprays. Monitoring along orchard perimeters is an efficient means of early detection so that damage can be minimized (U.S. Department of Agriculture, 1990). Cultural management which may reduce plum curculio pressure include habitat management, sanitation, cultivar selection, and mechanical control (Racette et al., 1992). Habitat management includes establishing orchards as far from forests as possible, in areas of low humidity, and at least 160-200 m away from wild hosts such as *Crataegus* spp., *Prunus* spp., and *Amelanchier* spp. Sanitation basically consists of removing fallen apples from the orchard. It has been suggested that ground-feeding birds or pigs might be used for this task (Lafleur and Hill, 1987; Racette et al., 1992)

Biological control of plum curculio is currently limited by a lack of knowledge about the ecology of this insect (Racette et al., 1992; Vincent and Roy, 1992). A variety of predators, parastoids, and pathogens of plum curculio have been identified, however they fail to prevent damage to the degree which the market requires. According to a study by Vincent and Roy (1992) plum curculio damage to fruit in an unsprayed orchard in Quebec averaged 48% with a peak at 86% over a 13-year period. Glass and Lienk (1971) observed fruit damage from plum curculio to range from 1%-46% during a 10-year period after insecticides were discontinued in a small orchard in New York. These studies indicate that natural control of plum curculio by natural enemies indigenous to orchard systems do not provide an acceptable degree of control by modern standards. Further research is needed to develop management methods which enhance the populations of indigenous natural enemies, identify habitat manipulations which make indigenous natural enemies more effective, and find which natural enemies might be useful in augmentative or classical biological control.

Apple Maggot (*Rhagoletis pomonella* Walsh)

The apple maggot is an indigenous North American species whose native host is hawthorn (*Crataegus* spp.). It was first reported to infest apple in the Hudson Valley of New York in the mid-1800s (Bush, 1992). It has since become one of the most important insect pests of apple in the northeastern and north central regions of the United States and in southeastern Canada (Prokopy and Croft, 1994). The damage to fruit results from the feeding activities of the larva. Eggs are laid by the female fly just under the surface of the fruit skin. After hatching, the larvae burrow into the fruit flesh, leaving a brown trail.

Many of the eggs do not hatch, but soft, dimple-like areas may be left on the fruit surface. Fruit damaged by apple maggot larvae frequently drop prematurely (Howitt, 1993).

In most commercial orchards, apple maggot numbers are reduced with insecticides; up to four applications may be needed per growing season. Yellow rectangle and red sphere traps can be used to monitor adult populations for more precise timing of pesticide applications (Prokopy and Croft, 1994). Odor attractants can be used as baits to increase catch rates with both of these traps. Duan and Prokopy (1995) reported that nearly acceptable commercial-level control of apple maggot was achieved (1-3% damaged fruit) with pesticide-treated, baited red spheres in commercial orchards in western Massachusetts. Moreover, Prokopy (1991) has found that apple maggot can be managed without pesticides (less that 1% damage) in small-scale orchards using unbaited sticky red spheres. This method, however, is labor intensive because it requires at least one sphere per tree.

Natural enemies are considered to be ineffective at controlling apple maggot populations in pesticide-treated and nonchemical orchards (Vincent and Roy, 1992). Part of the reason for this may be attributed to the recent shift of this species onto apple as a host plant. It is possible that this host shift has released this species from its predators and parastoids and, in effect, provided it with "enemy-free space." Feder (1995) has found support for this senario in a study of two braconid parasitoids of apple maggot. He found parasitism to be considerably less on apple compared to hawthorn. Apple provided more physical protection for the developing apple maggot larvae because of the larger fruit size. In addition, the parastoids were not well synchronized with apple maggot on apple. Feder also found that competition with other fruit infesting insects on hawthorn forced apple maggot larvae to feed closer to the fruit surface, making it more vulnerable to parasitoids. The effect of predators on apple maggot has not been well studied. Allen and Hagley (1990) found that a wide variety of epigeic predators, including carabids, staphylinids, ants, and spiders, fed upon apple maggot larvae and pupae in the field. However, the importance of these predators as mortality agents of apple maggot is still not known.

Japanese Beetle (*Popillia japonica* Newman)

Japanese beetle was introduced into the United States sometime before 1916 when it was discovered in New Jersey (Johnson and Lyon, 1991). It has since spread throughout most of the eastern half of the United States and southeastern Canada. This extremely polyphagous species is known to feed on nearly 300 plant species. Although apple is one of its food plants, Japanese beetle is generally considered to be a minor pest on this crop (Howitt 1993). In fact, it is not even mentioned as a pest in many apple management guides (e.g. U.S. Department of Agriculture, 1990; Johnson and Herr, 1995). Nevertheless, it has been found to be an abundant pest at the Kellogg Biological Station orchard (Stuart Gage, personal communication), damaging both foliage and fruit. Although the reasons for its high population densities at this site are unclear, it may be at least partially due to the lack of insecticide treatments and the relatively early-maturing varieties present. In commercial orchards, Japanese beetle populations would likely be held at lower levels by insecticides applied for other pests such as apple maggot.

Japanese beetle adults emerge from the soil in mid-summer and live from 30-45 days. The beetles, which are strong flyers, are most active in warm weather. Males and females tend to congregate on food plants, where they mate. Females are capable of producing 40-60 eggs, which are deposited in the soil (Johnson and Lyon, 1991). The eggs hatch within a few weeks and the larvae (grubs) begin feeding on plant roots. In fall, larvae burrow down deeper into the soil and form overwintering cells where they remain until spring (Davidson and Lyon, 1987).

Most efforts at biological control have focused on the larvae as a turf grass pest. A variety of agents, including bacteria, fungi, protozoans, nematodes, and insects, have been used. One commonly used biological control agent is *Bacillus popilliae* Dutky, which infects the larvae of this and other scarabaeids. This microbial control agent is commonly termed "milky disease" because of the hemolymph color in infected larvae (Maddox, 1994). Parasitic wasps (Tiphiidae) and flies (Tachinidae), which attack the adult stage have been introduced in some areas for control (Davidson and Lyon, 1987). Terry et al. (1993) found that epigeic predators, such as carabids and staphylinids, consume Japanese beetle eggs and that when the insecticides carbaryl and isazofos are used, predator abundance and predation decrease. Some small mammals, birds, and reptiles are also predators of Japanese beetle (Johnson and Lyon, 1991). Based upon experience in other crops, the potential for biological management of Japanese beetle in apple appears to be high.

Weeds in Apple Production

The management of weeds or groundcovers in apple orchards is important for maintaining adequate levels of nutrients and water. Competition between apple trees and weeds for these resources can result in reduced fruit yields (Rupp and Anderson, 1985; Raese, 1990). However, in situations where nutrients and water are abundant, controlling vegetation beneath apple trees may not lead to higher yields or increased growth.

Orchard floors are managed with a variety of practices which include herbicide applications, clean cultivation, mowing, planting cover crops, and mulching. The practice or combination of practices used can have important effects on seasonal labor requirements, nutrient management, and pest and beneficial insect population dynamics. For example, mulching can be as effective as herbicides in controlling weeds (Niggli et al., 1990) but is generally very labor intensive, not only because of the mulch application but also because it usually must be removed for winter to prevent rodent damage (Prokopy, 1991).

The effects of weed and groundcover management on insect pests and beneficials has recently received increased attention from researchers and growers. Nevertheless, very few generalizations that can be made. Although weed species differ in their attractiveness to beneficials and pests, some researchers have tentatively concluded that a high diversity of plant species on the orchard floor leads to a reduced level of pest damage (Altieri 1994). A review of the literature by Bugg and Waddington (1994) provides some support for this idea. They re-analyzed data from Leius (1967) and found that in his study apple orchards with greater plant species richness had increased levels of parasitism on codling moth and tent caterpillar. Nevertheless, there is concern that some plant species are harmful to apple production. Coli and Ciurlino (1990) mentioned that legumes such as vetch and alfalfa can cause increased tarnished plant bug damage and that dandelions can be a source of virus and compete with apple trees for pollinators. Clearly, more research is needed, but from a holistic point of view it can be cautiously concluded that a diverse ground cover has benefits over clean tillage or complete herbicide burndown. These benefits include soil conservation and habitat conservation for parasitoids, predators, and soil invertebrates important in cycling nutrients and maintaining soil structure. The effects of different practices, such as mowing, mulching, and manuring, may have important effects as well, and might be integrated with a strip management approach for greater habitat stability.

CURRENT STATUS OF POTATO PEST MANAGEMENT

Industrial potato production methods as practiced in the North America and Europe are very chemical intensive. Many of the problems which typify commercial potato production are exacerbated by continuous cropping or short rotations. Vereijken and Van Loon (1991) consider potato the most environmentally damaging crop grown in the Netherlands because of the large quantities of insecticides, herbicides, nematicides, and fungicides used on it. Currently, insecticides are used on 96%, herbicides on 97%, and fungicides on 96% of U.S. potato hectarage (Pimentel et al., 1993b). Problems encountered in potato production vary considerably with climate, year, season, and location. In addition, nonchemical or organic growers do not necessarily encounter the same sets of problems that conventional growers experience (Peacock and Norton, 1990). Attempts at developing low-chemical or nonchemical practices for potato production have had varying degrees of success. Pimentel et al. (1983) concluded that organic potato production would be considerably less energy and labor efficient than conventional production. This is due to the assumption that the replacement of herbicides would require five tractor cultivations per growing season and that no effective replacements for insecticides and fungicides existed. Under these constraints 50% of the crop would be lost to insect pests and disease.

Potato Pests Considered in this Study

Colorado Potato Beetle (*Leptinotarsa decemlineata* Say)

According to a survey presented by Radcliffe et al. (1991) Colorado potato beetle is considered to be the most important insect pest of potatoes in northeastern North America. It is believed that Colorado potato beetle inhabited central Mexico and fed upon *Solanum angustifolium* Mill. and *Solanum rostratum* Dunal prior to becoming a pest of potatoes in the United States (Casagrande, 1987). Potatoes were introduced into Virginia in the early 1600s and spread westward. In 1859, Colorado potato beetle was found on potatoes in Nebraska. The widespread cultivation of potatoes allowed this pest to spread eastward reaching the Atlantic coast by 1874. Although a variety of cultural control methods were used during this time, acceptible control apparently was not obtained until the discovery of the insecticidal properties of Paris green, a paint pigment. Additional compounds, including lead arsenate and calcium arsenate, were added to the arsenal. Although there was little evidence of resistance to these compounds the availability of the relatively inexpensive compound, DDT, led growers to switch to using it during the 1940s. Resistance to DDT was soon recognized. New chemicals were developed and became available but the rate of resistance development increased. During the 30-year period between 1954 to 1984, 14 new chemicals were introduced for use against Colorado potato beetle on Long Island, New York, an area particularly hard hit by this pest. According to Casagrande (1987), Colorado potato beetle evolved resistance to all except one of those chemicals during that period.

New methods of control which are currently being implemented include the use of tractor-mounted flamers and genetically-engineered potato plants which produce the delta endotoxin of *Bacillus thuringiensis*. The widespread effectiveness and utility of these approaches remains to be seen. Resistance to the *B. thuringiensis* delta endotoxin has already been artificially selected for in one laboratory population of Colorado potato beetle. Whalon et al. (1993) obtained a strain of Colorado potato beetle which was 59 times more resistant to the *B. thuringiensis* delta endotoxin than an unselected stain in just 12 generations. If the use of these transgenic plants becomes widespread, selection pressure for resistance will be intense.

According to some researchers, nonchemical management practices, including crop rotation, host-plant resistance, and biological control, have been either under-utilized by growers or underdeveloped by researchers (Casagrande, 1987; Hare, 1990). Prospects for enhancing populations of endemic natural enemies through cultural practices appear to be good. Many common generalist predators will feed on at least one stage of Colorado potato beetle (Casagrande, 1987; Groden et al., 1990; Riechert and Bishop, 1990; Hazzard et al., 1991; Nordlund et al., 1991). Brust (1994) found that mulching potatoes led to an increase in soil-dwelling predators, particularly carabids, and an increase in Colorado potato beetle mortality. Furthermore, he observed greater egg and early instar mortality, presumably by coccinelids and chrysopids, in mulched compared to unmulched potatoes. Consequently, defoliation was over two times greater and yields 30% less in unmulched potatoes compared to mulched potatoes. Similarly, Riechert & Bishop (1990) found lower numbers of Colorado potato beetles, flea beetles, aphids, and leafhoppers and less defoliation on mulched compared to unmulched potatoes. Spiders, which showed dramatic increases in population due to the mulch, appeared to be the most important predatory arthropod group in this study. Stoner (1993) also reported that mulch around potato plants reduced Colorado potato beetle defoliation, which led to increased yields relative to a control. She, however, did not determine if natural enemies were responsible for these effects.

Other studies have evaluated augmentative releases of predators for biological control. Biever & Chauvin (1992) found that releases of two predaceous stinkbugs, *Podisus maculiventris* (Say) and *Perillus bioculatus* (F.), could substantially reduce Colorado potato beetle populations in the field and lead to yields 65% higher than if left untreated. Hough-Goldstein and Whalen (1993) also found releases of *P. bioculatus* to reduce Colorado potato beetle abundance and defoliation.

The potential to use biological-based strategies to manage Colorado potato beetle appear to be good. Possible constraints may include the high cost for purchased natural enemies, inflexibility in cropping practices because of specialized machinery, and a lack of market incentives to use nonchemical approaches. Nevertheless, from a biological perspective, practices such as altering the timing of planting and variety, crop rotation, intercropping, cover cropping, and mulching, provide adequate tools for developing integrated management systems for Colorado potato beetle (Casagrande, 1987; Vereijken and Van Loon, 1991).

Weeds in Potato Production

Weed management in commericial potato production, as in most commercial field crop and vegetable systems, is primarily dependent upon herbicides (Bellinder and Wallace, 1991). Potato plants are poor competitors with weeds, especially during the early part of the season. Weeds not only compete for water, nutrients, space, and light, but also present problems for harvesting operations. Mechanical cultivation and reduced tillage are alternative means of weeds management but these practices do not always result in adequate yields. This is because cultivation causes soil water loss and, over time results in soil compaction. Reduced-tillage potato systems can effectively reduce weed germination but require hilling to get adequate yields (Bellinder and Wallace, 1991). Hilling, however, results in weed germination.

The integration of cover cropping practices and mulching holds promise for reducing input requirements, including pesticides, and reducing soil erosion. Cover crops and mulches can suppress weeds by reducing soil temperatures and, in some cases, releasing allelochemicals which inhibit weed germination and growth. For example, the allelopathic compounds released by rye mulch can reduce growth in redroot pigweed and barnyardgrass (Bellinder and Wallace, 1991). In addition to weed control, mulches also provide habitat for beneficial arthropods (as discussed above). Thus, the integration of mulching practices may provide dual benefits in potato pest management.

FREE-RANGE DOMESTIC BIRDS as BIOLOGICAL PEST CONTROL AGENTS

There are many potential environmental and economic benefits in free-ranging or pasturing domestic birds which are not obtainable with high-density, confined poultry and egg production systems. Many of the problems associated with high-density, confinement systems, such as pest and disease outbreaks (Axtell and Arends, 1990), antibiotic resistance in bacteria (Ojeniyi, 1985), waste disposal costs and environmental pollution risks (Pope, 1991; Sims and Wolf, 1994), and issues related to animal welfare (Appleby and Hughes, 1991), are either non-existent or of considerably less importance in free-range production systems. The benefits from free-range production may go beyond simple avoidance of these problems when the bird production enterprise is integrated with other agricultural production systems and may include sanitation, soil fertility maintanence, and insect pest and weed management. Domestic birds, when used in conjuction with modern rotational grazing technologies, may be especially useful as insect pest and weed management agents.

Chickens, as meat and eggs, are an important source of food worldwide (National Research Council, 1991). Production systems range from backyard scavenger flocks to high-density confinement operations. In the United States the small scale poultry and eggs producers have become inceasingly rare as their ability to compete with large producers has been diminished. There are exceptions to this rule however, and successful producers demonstrate that small-scale production is still potentially viable (Traupman, 1990; Salatin, 1991). Three practices which contribute to the profitability of small farming operations include: 1) reducing input costs; 2) diversifying and integrating production operations; and 3) direct marketing. Based upon these three criteria small-scale poultry and egg operations can be profitable and environmentally sound, while playing important ecological roles on diversified farms including nutrient cycling, waste recycling, and biological control.

The effectiveness of chickens as biological control agents has been only minimally studied. Although it seems to be common knowledge among many older farmers that chickens eat insect pests there is very little documented evidence for this. One crop pest for which chickens have been used as biocontrol agents is the Colorado potato beetle (*Leptinotarsa decemlineata*). As mentioned, Colorado potato beetle is the most serious pest of potatoes the United States and has developed resistance to nearly every insecticide used against it (Radcliffe et al., 1991). During the mid-1800s, shortly after this insect had become a pest on potatoes, there were reports of successful and unsuccessful attempts at using chickens to control it. According to one farmer's testimony chickens could be trained to eat the beetles (Casagrande, 1987). However, recent research has demonstrated that the beetles and larvae are distasteful to young chicks of at least one common commerial breed (Hough-Goldstein et al., 1993).

Another insect pest for which chickens have been used as a biological control agent is the plum curculio (*Conotrachelus nenuphar*). As mentioned above, it has been suggested that ground-feeding domestic birds or pigs could be used to remove pest-infested apple drops (Lafleur and Hill, 1987; Racette et al., 1992). There is some evidence in the literature that domestic birds, including chickens, may also directly feed upon plum curculio while it is on the ground (Racette et al., 1992; VABF, 1993). However, there is still no experimental evidence that chickens can reduce damage by plum curculio.

Domestic geese have historically been used as weeders in a variety of crops. The most common uses have been in cotton, fruit orchards, and nursury plantings (Hoare, 1928; Mayton et al., 1945; Johnson, 1960; Holderread, 1981; Gillen and Scifres, 1991). Geese also have been found to be useful as weeders in strawberries (Cramer, 1992) and may be compatible with a variety of other crops, including some high-value vegetables. Research is needed to determine which crops and at which growth stages geese may be compatible and used as weed biocontrol agents. This type of information would be useful to diversified, small farmers and market gardeners who might be willing and able to integrate geese into their operation to reduce hand weeding and/or herbicide use.

CHAPTER 3

THE COMPATIBILITY OF DOMESTIC BIRDS WITH A NONCHEMICAL AGROECOSYSTEM

INTRODUCTION

Increasing interest in developing sustainable food production methods has prompted research into a variety of alternative and traditional agricultural practices such as biodynamic farming, intercropping, companion planting, mulching, manuring, and crop rotation. A common characteristic among all of these practices is the integration of multiple production components, each intended to interact with and benefit the entire agroecosystem (Dazhong and Pimentel, 1986; Altieri, 1987; Ruddle and Zhong, 1988; Vandermeer, 1989, 1995; Mollison, 1990; Crews and Gliessman, 1991; Dazhong et al., 1992). The benefits of such integrated production methods over conventional production methods can include reduced waste, fewer external input requirements, increased energy efficiency, higher soil fertility, and greater ecological and economic stability (Lockeretz et al., 1981; Wagstaff, 1987; Edwards, 1989; Smolik et al., 1993; Reganold et al., 1993).

My discussions with farmers in the Great Lakes region of the United States and Canada have revealed that domestic birds are sometimes integrated into organic orchards. In addition, information in the scientific, popular, and local farming literature indicates that domestic birds are used as integral parts of orchard and non-orchard systems (Fuan, 1985; Rodale Institute, 1990; Traupman, 1990; Salatin, 1991; Cramer, 1992; VABF, 1993). However, we have found few experimental investigations of the role that birds play in such systems (Mayton et al., 1945).

This chapter reports findings on two objectives: 1) to describe the behavior of domestic chickens and geese in a potato-intercropped, apple orchard and 2) to determine the impact of the birds on plants within the system, including crops and non-crops. In addition, I discuss factors which may present opportunities for or barriers to domestic bird integration into different types of agroecosystems.

MATERIALS AND METHODS

The Orchard System

A 0.5 ha block located in an apple orchard at Michigan State University's Kellogg Biological Station in southwestern portion of the state was used for this study. The orchard was planted in 1983 with the disease resistant varieties ' Redfree,' ' Priscilla,' and ' Liberty' on M.26 rootstocks and has been managed without the use of pesticides since its establishment. While the orchard has sustained heavy insect damage during some years, disease pressure has been low. This has allowed the orchard alleys to be used for intercropping annuals, including potatoes, tomatoes, and beans, and for pasturing domestic fowl, including chickens and geese. Under conventional orchard management this would not have been possible due to the intensive spray schedule which requires that the alleys be used for tractor traffic. The use of pesticides would also have been incompatible with the birds.

In 1993 Barred Plymouth Rock chickens, a breed of *Gallus domesticus*, and African geese, a domestic breed of *Anser cygnoides* (Silversides et al. 1988), were evaluated as components of an potato-intercropped, apple orchard. The selection of these birds for the experiment was based on recommendations from area farmers and on small-scale test trials with several varieties of domestic birds in the orchard from 1990 to 1992.

Experimental Design

Twelve plots were randomly established in the block for three treatments with four replications. Plots were 16.8m by 9.9m and consisted of three rows of three apple trees and two inter-row alleys (Fig. 3-1). The trees in two of the rows were 'Redfree' and the third were 'Priscilla.' The tree spacings were 3.3 m and the row spacings were 6.5 m. The alleys were planted in potatoes ('Red Pontiac') on 18 May with 30-cm plant spacings and 75-cm row spacings. This allowed three rows of potatoes to be planted within each alley such that the outside potato rows were not directly beneath the canopy of the apple trees. In one randomly-selected alley of each plot the potato plants were mulched to a depth of 15 cm with recently cut rye (*Secale cereale* var.'Wheeler') which was collected from a field adjacent to the orchard, creating mulched and unmulched subtreatments. The potatoes were handweeded on 11 June and hand weeded and hilled on 17 June.

The three main treatments included 1) placing 15 chickens per plot (chicken treatment); 2) placing 11 geese per plot (goose treatment); and 3) a control with no birds (control). Plots with chickens or geese were surrounded with 1.5 m-high plastic fencing with 6 cm mesh. On 2 July, the birds, at 6 weeks old and with an approximately equal number of males and females, were introduced into the designated plots. On 17 July, 3 geese were removed from each plot of the goose treatment, setting the population at 8 per plot. The birds were maintained in the plots until 6 August.

The birds were kept in coops (1.2 X 1.2 m) at night and released to free range from approximately 7:00 am until 9:00 pm (EST). The coops were located on either the eastern or western perimeter of the plots (Fig.3-1). The birds were provided with small amounts of cracked corn and poultry starter immediately after being released from the coops in the morning and approximately 10min before being put into the coops at night. The purpose of the morning feeding was to train the birds to disperse out into the plots to find food, while the night feeding was used to get the birds to return to the coop. The coop was closed each night to protect the birds from predators. Water was provided in buckets and watering cans and replaced as needed (usually 2 times per day).

Behavior Observations

Structured observations of the chickens and geese were conducted on arbitrarily-selected days at arbitrarily-selected times between 8:00 am and 8:00 pm except during rain. Bird behavior was sampled by observing the whole flock of birds in a particular plot for 5 min and recording the occurrence of the following activities: foraging, drinking, and resting. Due to the difficulty in tracking individual birds for 5 min the entire flock within each plot was treated as the sampling unit rather than individual birds. A total of 12 sets of four, 5-min observations were collected for each bird treatment. These were grouped into four, 3-hr time periods: morning (8:00 am - 10:59 am), mid-day (11:00 am -1:59 pm), afternoon (2:00 pm - 4:59 pm), and evening (5:00 pm - 8:00 pm), which resulted in 5, 2, 2, and 3 observation sets for the morning, mid-day, afternoon, and evening periods, respectively. The frequencies of activity occurrence were based on the percentage of observations in which a particular activity was observed to be performed by at least one bird in the plot. When possible, observers also recorded what foraging birds were eating.

Plot maps, which were used to record bird locations within the plots, were divided into 25 sectors (Fig. 3-1). This allowed observers to simply indicate the presence or absense of birds for each sector. These data were used to estimate the extent of bird dispersion throughout the plots, determinine if the birds preferred a particular habitat within the plot (apple row or potato alley), and measure the tendency of the birds to roam to the side of the plot distal to the coop . Bird dispersion was determined by calculating the percentage of plot sectors occupied by the birds at a particular time of day (Fig. 3-1). Habitat preference was evaluated by comparing the frequency of occurrence of birds in the tree row versus the potato alleys. The tendency of the birds to roam away from the coop was evaluated by comparing the frequency of occurrence of the birds in the half of the plot containing the coop versus the half without the coop (Fig. 3-1).

Plant Sampling

Above-ground, non-crop vegetation biomass was sampled in the apple rows and potato alleys on 22 July by cutting at ground level and removing all vegetation within randomly-selected 1 m^2 quadrats. Weed biomass in the potato alleys was sampled at a single, randomly-selected location along the middle potato row of each subplot. Ground cover biomass within the tree rows was sampled in a single, random location in the middle tree row of each plot. Plants were separated into grasses and broadleafs, dried for 48 hr, and weighed. Potato tuber fresh weight was sampled on 30 July by digging and weighing all potatoes in the center 2 m of each row, resulting in 6 m of potato row sampled for each subplot. Apple fruit fresh weight was sampled by weighing all fruit from each tree at harvest. Most of the 'Priscilla' trees did not bear fruit. Therefore comparsons were limited to 'Redfree' trees only. Non-crop biomass, potato tuber fresh weight, and apple fresh weight in the chicken and goose treatments were compared statistically to the Control using the one-tailed Mann Whitney test (Zar, 1984). In the figures the following p-values are indicated by one, two, and three asterisks, respectively: $0.10 \geq p > 0.05$; $0.05 \geq p > 0.025$; and $0.025 \geq p > 0.01$.

RESULTS

The observations of chicken and goose activity patterns indicate that the chickens spent consistently more time foraging than resting and drinking while for the geese this varied more with the time of day (Fig. 3-2). The chickens were observed to forage throughout the day whereas the geese foraged most during the morning and evening and least at mid-day. As may be expected for the geese, resting and drinking were highest at mid-day. Although systematic observations were not conducted during rain we noticed that chickens tended to seek shelter under trees or in the coop during rain while geese appeared unaffected.

Chicken dispersion in the plots was consistently greater than goose dispersion (Fig. 3-3). During morning and afternoon observations chickens occupied between 25% and 35% of the plots with peak dispersion at 9:00 am and 10:00 am. While geese dispersion peaked at the same time, the geese remained in a tightly clustered flock occupying less than 15% of the plot. Chickens were observed to come together into tighter flocks during mid-day and evening (Fig. 3-3).

Observations indicated that chickens and geese consistently occupied apple rows throughout the day (Fig. 4). Chickens were also commonly observed in the potato alleys. In contrast, the geese were observed less frequently in the potato alleys (Fig. 3-4). Geese also tended to remain in the half of the plot which contained the coop while chickens were observed to consistently roam on both sides of the plot, especially during mid-day and afternoon (Fig. 3-5).

Observations of foraging birds indicated that the chickens were omnivorous, feeding on insects and plants, while the geese were strictly herbivorous (Table 3-1). Chickens were seen feeding on some plants but were more frequently observed feeding on invertebrates on or near the soil surface. Most of the time it was impossible to see what types of organisms were being preyed upon; therefore the Table 1 is incomplete, likely representing only a small fraction of the items consumed. Goose forage, because it was solely plants, was more easily identified and included grasses and broadleaf plants. Interestingly, geese were observed to actively pursue some flying insects for short distances (less than 1 m), however a successful catch was not seen. Food preferences were not quantified but it appeared that the geese preferred grasses (Poaceae spp.), common dandelion (*Taraxacum officinale*), and common plantain (*Plantago major*). Common ragweed (*Ambrosia artemisiifolia*) and common lambsquarter (*Chenopodium album*) were only consumed when more preferable plants were unavailable. Canada thistle

(*Cirisium arvense*) was fed upon only as a seedling. Although chickens and geese were seen feeding on unearthed potato tubers neither were observed feeding on potato plants. Occasionally, geese were seen feeding on apple leaves on low-hanging branches and on recently dropped fruit on the ground. By contrast, chickens were seen feeding on low-hanging fruit on the trees, however, they were never seen in the trees feeding on fruit.

Groundcover biomass in the tree rows was substantially reduced in the goose treatment compared to the control (Fig. 3-6). This reduction was primarily due to a reduction in grass, supporting the observation that grasses were a preferred forage. A slight reduction in groundcover biomass was also measured in the chicken treatment, however it was not statistically significant. Weed biomass in the potato alleys followed a similar trend, being slightly reduced in the chicken treatment and substantially reduced in the goose treatment compared to the control (Fig. 3-7).

Although weed biomass in the potato alleys varied considerably across the treatments, potato tuber yields were statistically similar among the treatments. The pooled mean yield for the three treatments was 6.02 ± 0.3 kg per m of potato row (equivalent to 4754 kg/ha [or 4231 lbs/acre] of intercropped orchard). The lack of treatment effect was probably due to the extensive hand weeding in all treatments prior to the introduction of the birds into the plots, giving the potato plants in all three treatments a competitive advantage over the weeds (Bellinder and Wallace, 1991). Colorado potato beetle (*Leptinotarsa decemlineata*), the most important potato pest in Michigan, was not present in this experiment until late July (greater than 60 days after planting) and therefore probably had no influence on yield (Zehnder and Evanylo, 1989).

Apple yields in all treatments were low in 1993 due to a lack of fruit thinning which has caused the orchard to alternate biennially with high and low yields. Mean apple fruit yield was greater in the chicken and goose treatments than in the control, however the differences were statistically significant only for the goose treatment (Fig. 3-8). This yield increase was apparently due to the reduction in weed competition in the goose treatment (Rupp and Anderson, 1985; Raese, 1990).

DISCUSSION

If the compatibility of the birds in this agroecosystem is assessed only on ground cover management and weed control the geese would appear to be ideal components. However, a variety of other factors, some of which were addressed in this study, need appropriate consideration. The compatibility of the birds in this or any type of agroecosystem will depend upon some factors which are general and predictable and others which are local and unique. In this study, plots were relatively small and the results obtained are not likely to be representative of larger plots. Mayton et al. (1945) observed chickens and geese to effectively control nutgrass in small plots but found that they provided inadequate control in large plots because the birds would not range far enough from the coop. A problem such as this, however, may be managed by rotational grazing within smaller paddocks.

According to Gillen and Scifres (1991, p. 370), "the successful use of ... selective grazing is more an art than a science, which usually disallows quantifying necessary procedures to reach an end result except in selected cases." A number of variables in this study, including bird density, bird age, paddock size, supplemental feeding, and date of introduction, could have a substantial influence on the results of experimental grazing evaluations and it was not feasible to evaluate all of the possible combinations. We chose values for these variables based on our previous experience and limitations. However, they are not necessarily the optima for this system or any other.

According to Mollison (1988) the suitability of introducing domestic birds into a production system depends upon 1) the behavior of the birds, 2) the nutritional requirements of the birds and the provisions within the system, and 3) the interactions between the birds and the rest of the system, including the crops, non-crop plants, other animals, and people. If bird compatibility is evaluated according to these criteria then the differences between the chickens and geese become more obvious than the similarities. The feeding behavior of the chickens is omnivorous while that of the geese is herbivorous. The chickens were active throughout the day, stayed fairly well dispersed, and required a minimal amount of human attention and labor for management. In contrast, the geese tended to be active mostly during the morning and evening and stayed in a flock which was less inclined to move away from the coop. However, when foraging, the geese consumed large amounts of vegetation. The geese also consumed large amounts of water and this demand for water required a relatively high level of human attention and labor in this experimental system.

The relatively spacious and complex environment within the orchard provided a greater degree of welfare for the birds than would be possible under conventional bird production systems (Appleby and Hughes, 1991). The trees provided shade for the chickens and geese and roosting places for the chickens. We did not determine if the food provisions within the system would be adequate to sustain the birds without supplemental feeding. To address this question would require knowledge of the specific objectives of the farmer. If the goal was to maximize the use of the birds as ground cover or weed management agents then supplemental feeding could be minimized or possibly even eliminated. If the birds were intended for egg production or to be sold as meat adequate supplemental feeding would be required.

The interactions between the geese and weeds suggest that geese could be managed as weed control agents under a variety of circumstances. By contrast, chickens would need to be stocked at greater densities than were used in this experiment if weed control was the goal. However, in addition to weed control, chickens may provide biological control for some insect pests. They were observed commonly to feed upon Japanese beetle (*Popillia japonica*) and occasionally feed on Colorado potato beetle. Although chickens have been described as effective insect predators (Hoare, 1928), there is some evidence that certain insects, including Colorado potato beetle, are unpalatible (Hough-Goldstein et al., 1993). However, we found that chickens in this study readily consumed Colorado potato beetles, even when alternative food sources were available.

Assuming that adequate human management is feasible and that a reliable source of water is available, chickens and geese appear to be highly compatible in this experimental agroecosystem according to Mollison's criteria. However, ecological compatiblity alone does not mean that bird integration is economically feasible under current market conditions. Although it is difficult to assess the economics of an experimental system such as this one there are several characteristics of this type of integrated production system which may make bird introduction feasible. If a rotational grazing system can be used effectively the birds might eliminate needs for herbicide applications or mowing; operations which can represent a substantial portion of the management costs. For example, in a small low-input apple orchard which relied on mowing and mulching for weed control, these operations accounted for 25% and 40% of total labor and material costs, respectively (Prokopy, 1991). Although the birds do require a high level of human attention, they could be managed to provide marketable products, such as eggs and meat, which could offset the labor costs. In addition, the birds could play an important role in nutrient cycling, reducing the need for external fertilizers. Clearly, the scale of the farming operation will have an important influence on the feasibility of domestic bird introduction. Domestic birds in orchards or other agroecosystems require relatively close human management, for protection of the birds and crops and for the efficient use of the birds, making bird integration more amenable to operations already accustomed to high labor inputs.

The development of ecologically-based, non-chemical food production systems will require that agroecosystems be designed so that they are more energy efficient, are economically stable, produce little or no pollution, require less therapeutic intervention to maintain pests at acceptable levels, and are compatible with the needs and philosophies of the producer and consumers (Edens and Haynes, 1982; Vereijken, 1989; Hill and MacRae, 1992). Although these criteria have been used in designing this experimental agroecosystem the relative emphases put on each criterion will undoubtedly differ from those identified by farmers themselves. The objectives in this study were to start to understand the interactions between three components: domestic birds, potato plants, and apple trees. Although this experiment indicates that these components are compatible and may benefit each other in various ways (Fig. 3-9), the practicality of such a system from a farmer's perspective will ultimately depend upon numerous social, economic, philosophical, and organizational factors both within and beyond the farm.

Table 3-1. A list of food items observed to be consumed by chickens and geese in the potato-intercropped, apple orchard in 1993.

Common Name	Scientific Name	Notes[a]
Chickens		
Colorado potato beetle	*Leptinotarsa decemlineata*	adults, larvae
Japanese beetle	*Popillia japonica*	adults
ant	Formicidae sp.	adults, larvae
ground beetle	Carabidae sp.	adult
rove beetle	Staphylinidae sp.	adult
tomato hornworm	*Manduca quinquemaculata*	larvae
apple	*Malus pumila*	fruit on tree or ground
potato	*Solanum tuberosum*	unearthed tubers
grass	Poaceae spp.	
birdsfoot trefoil	*Lotus corniculatus*	
earthworm	Lumbricidae spp.	
Geese		
grass	Poaceae spp.	
common dandelion	*Taraxacum officinale*	
common plantain	*Plantago major*	
common lambsquarter	*Chenopodium album*	
redroot pigweed	*Amaranthus retroflexus*	
common ragweed	*Ambrosia artemisiifolia*	
Canada thistle	*Cirisium arvense*	seedlings
curly dock	*Rumex crispus*	
apple	*Malus pumila*	fruit on ground
potato	*Solanum tuberosum*	unearthed tubers
bean	*Phaseolus vulgarus*	

[a] Indicates the specific life stage or part of the item consumed or the circumstances during the consumption.

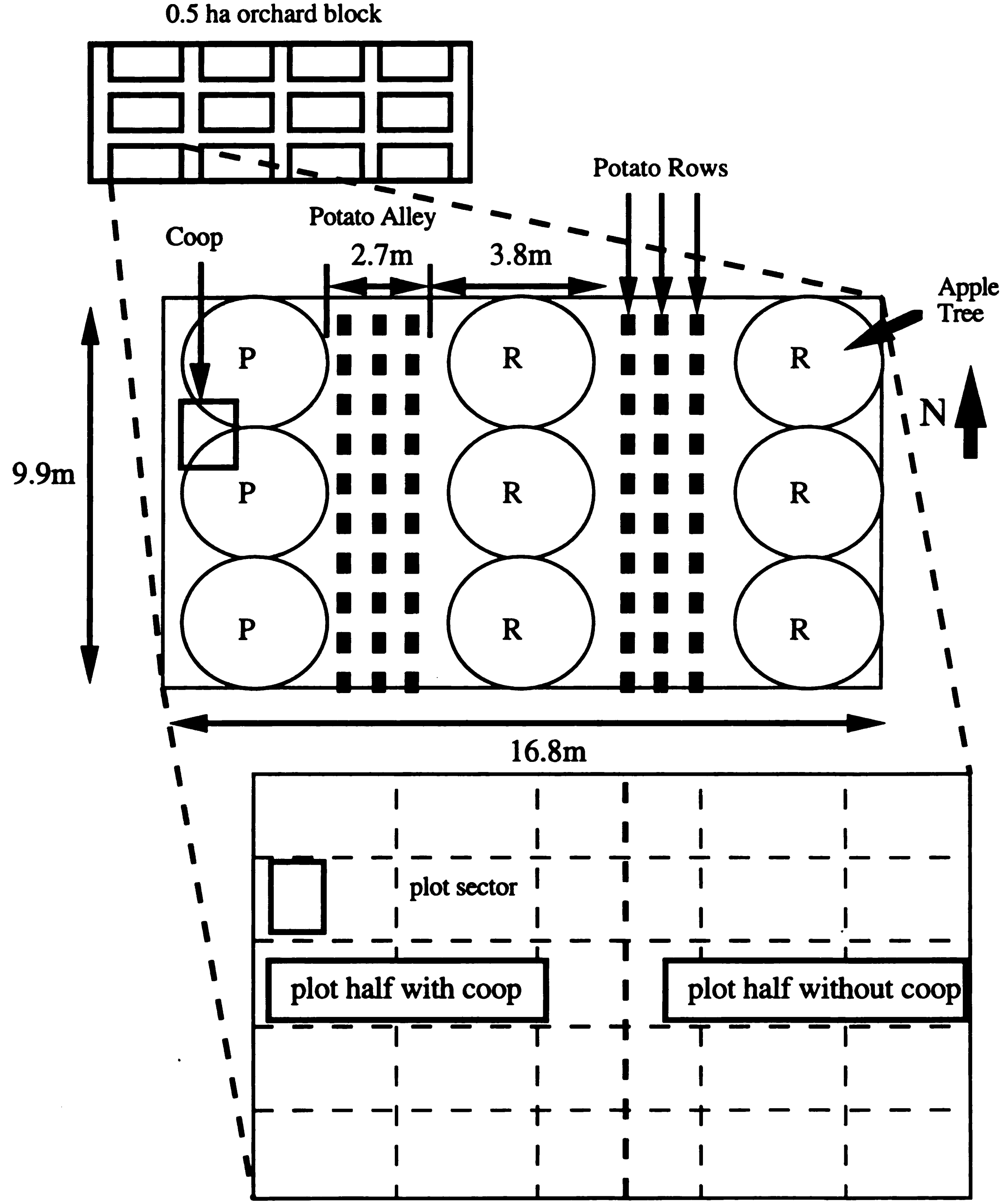

Figure 3-1. Map showing the experimental layout. Apple trees are designated P and R for 'Priscilla' and 'Redfree' respectively. One randomly-selected potato alley of each plot was mulched while the other was left unmulched.

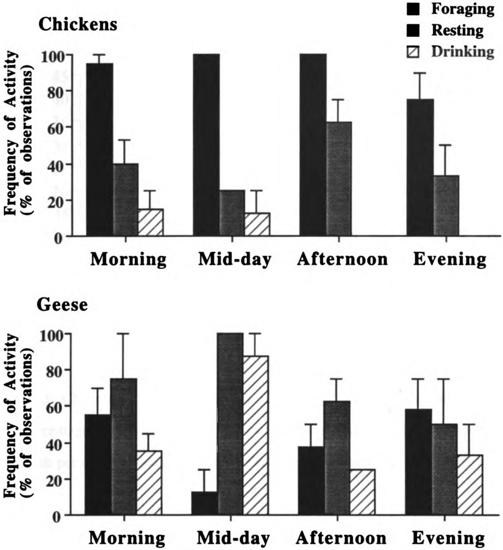

Figure 3-2. Chicken and goose activity patterns based on the mean percentage of observations in which birds were observed to be resting, foraging, and drinking. The time periods are morning (8:00am-10:59am, N=5), mid-day (11:00am-1:59pm, N=2), afternoon (2:00pm-4:59pm. N=2), and evening (5:00pm-8:00pm, N=3). Error bars are standard errors of the mean.

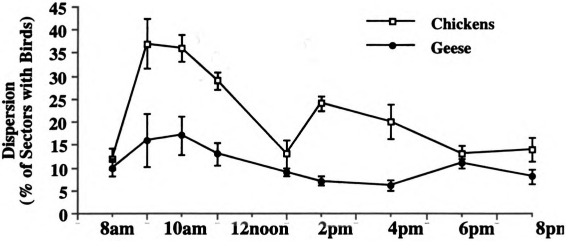

Figure 3-3. Chicken and goose dispersion within the orchard plots as indicated by the mean percentage of plot sectors occupied by birds at arbitrarily-selected times of day over a one-month period (N=4 for each mean). Error bars are standard errors of the mean.

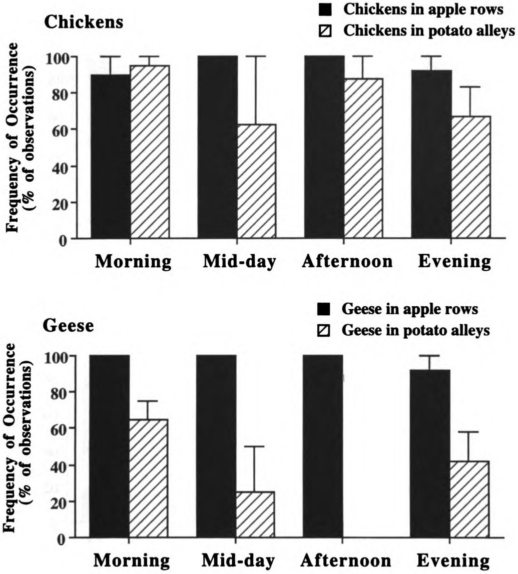

Figure 3-4. Frequency of chicken and goose occurrence in the apple rows and potato alleys as indicated by the mean percentage of observation periods in which the birds were observed in these habitats. The time periods are morning (8:00am-10:59am, N=5), mid-day (11:00am-1:59pm, N=2), afternoon (2:00pm-4:59pm. N=2), and evening (5:00pm-8:00pm, N=3). Error bars are standard errors of the mean.

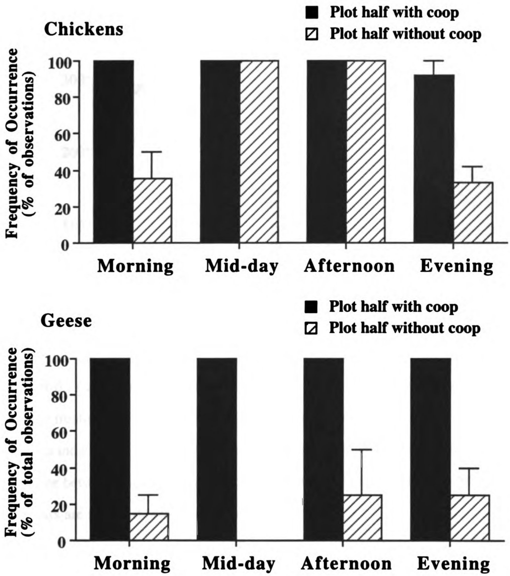

Figure 3-5. Frequency of chicken and goose occurrence in the plot half with the coop and the half without the coop as indicated by the mean percentage of observation periods in which the birds were observed in these areas. The time periods are morning (8:00am-10:59am, N=5), mid-day (11:00am-1:59pm, N=2), afternoon (2:00pm-4:59pm. N=2), and evening (5:00pm-8:00pm, N=3). Error bars are standard errors of the mean.

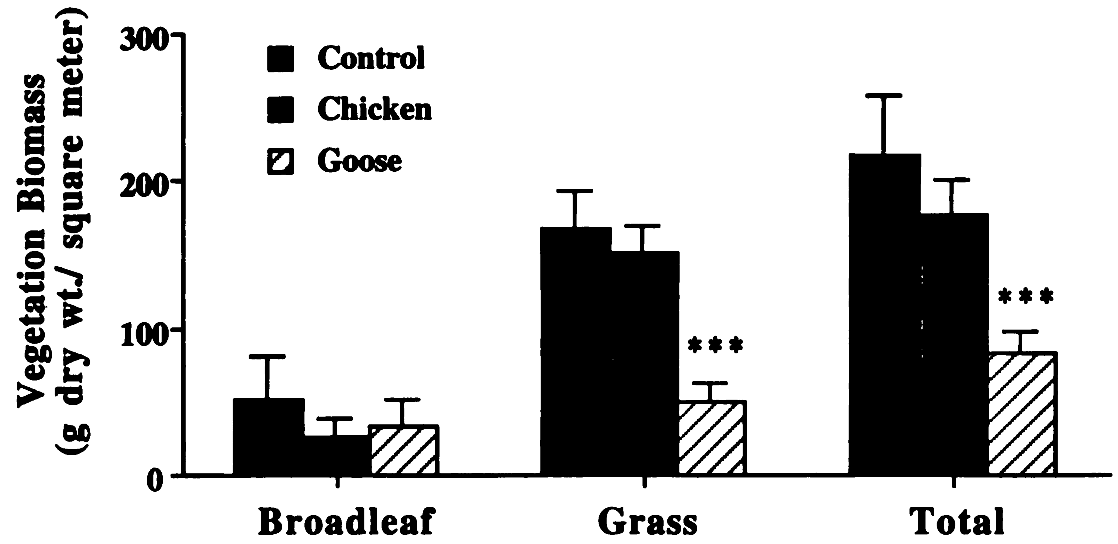

Figure 3-6. Above-ground vegetation biomass (grams dry wt./m^2) in the tree rows under the three treatments. Total biomass is broken down into grass and broadleaf weeds. Asterisks indicate the level of statistical significance (see Materials and Methods) of the difference between the Control and each bird treatment (one-tailed Mann-Whitney test). Error bars are standard errors of the mean.

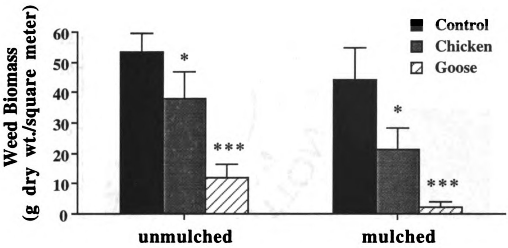

Figure 3-7. Above-ground weed biomass (grams dry wt./m^2) in mulched and unmulched potatoes under the three treatments. Asterisks indicate the level of statistical significance (see Materials and Methods) of the difference between the control and each bird treatment (one-tailed Mann-Whitney test). Error bars are standard errors of the mean.

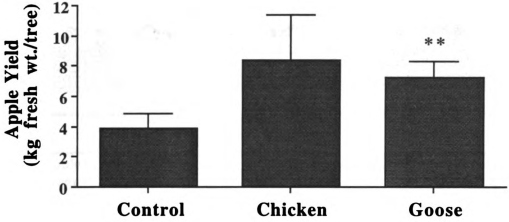

Figure 3-8. Apple fruit yield (kg fresh wt./tree) for 'Redfree' trees under the three treatments (1 kg = 2.2 lbs). Asterisks indicate the level of statistical significance (see Materials and Methods) of the difference between the control and each bird treatment (one-tailed Mann-Whitney test). Error bars are standard errors of the mean.

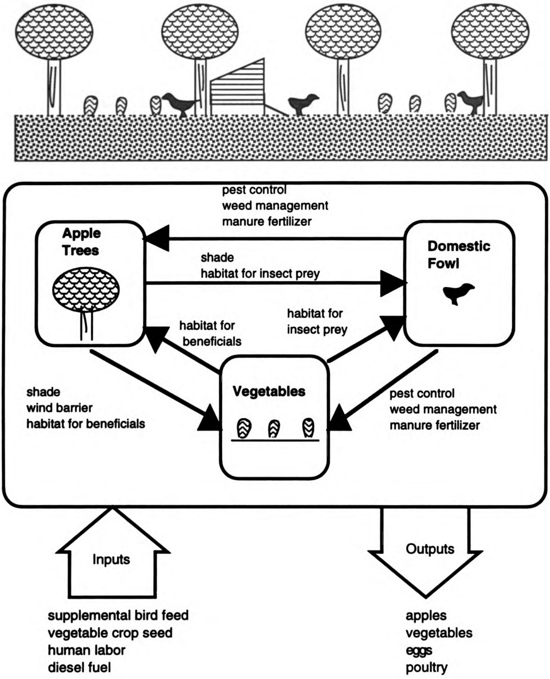

Figure 3-9. Conceptualization of an integrated agroecosystem based on the experimental agroecosystem in this study. The arrows indicate the potential beneficial interactions between the components of the system.

CHAPTER 4

EVALUATION OF FREE-RANGE CHICKENS AND GEESE FOR MANAGING INSECT PESTS AND WEEDS IN AN AGROECOSYSTEM

INTRODUCTION

The integration of animals into cropping systems has the potential to reduce the need for external farm inputs. Benefits can include nutrient cycling and conservation, utilization of crop residues, economic stability through market flexibility, and vegetation and weed management (King, 1990; Parker, 1990; Gillen and Scifres, 1991; Loomis and Connor, 1992; Bender, 1994). Most efforts at animal integration in the United States, however, have focused on large livestock, specifically cattle. However, smaller livestock species and breeds, sometimes termed microlivestock, have the potential to play a variety of roles on small farms and market gardens. These roles may include insect pest control, weed management, sanitation, as well as product diversification.

The use of livestock as biological control agents is relatively unusual in comparison to the use of arthropods and microbes. Reasons for this include the limited choices of species and lack of research on livestock for such purpose, as well as the relatively large investment of labor and land resources required in using such organisms. Furthermore, the use of livestock requires more managerial experience and skill. Nevertheless, small and large livestock have been successfully employed as biological control agents. Most examples are in the arena of weed management. These include using geese for weed control in strawberry (Cramer, 1992; Ware, 1995) and cotton (Mayton et al., 1945; Johnson, 1960). Recent experiments by Wurtz (1995) showed the potential for using geese as part of an integrated weed management strategy during the establishment of tree seedlings. Sheep and goats also have utility in weed management including grazing in orchards and woodlots (Shirley, 1992) and brush removal (Olkowski et al., 1991).

Documentation of insect pest management using livestock is extremely limited. There is anecdotal information suggesting that poultry can reduce the abundance of orchard pests (Hoare, 1928; Racette et al., 1991; VABF, 1993), Colorado potato beetle on potato (Casagrande, 1987), and flies in cattle pasture (Salatin 1991). However there is no experimental evidence to support these claims. Muscovy ducks have been shown experimentally to substantially reduce house fly populations in dairy and swine operations and appear to be an economically feasible option for this application (Glofcheskie and Surgeoner,1990; 1993).

The behaviors and activities of free-range domestic chickens and geese in a nonchemical food production system comprised of apple and potato were discussed in the previous chapter. Chickens were found to be omnivorous, feeding on weed seedlings, seeds, insects including several pest species, and soil invertebrates. Geese, by contrast, fed almost solely upon grasses and broadleaf weeds. Both chickens and geese were found to be compatible with the experimental agroecosystem and showed promise as insect pest and weed biological management agents in small-scale operations.

The purpose of this chapter is to report the results of experiments intended to measure the effectiveness of chickens and geese as biological pest management agents. The objectives were to: 1) measure the effects of free-range chickens and geese on the abundance of several important insect pests and on weeds in a non-chemical agricultural production system and; 2) assess the potential of these domestic birds as crop protection agents based on their effects on crop productivity and pest damage, the economics of their use, and their potential compatibility with other types of production systems.

MATERIALS AND METHODS

Study Site

All research was conducted during 1994 and 1995 in a 2-ha apple orchard at the Kellogg Biological Station, Hickory Corners, Michigan. The orchard, planted in 1983, consists of three disease-resistant varieties, 'Redfree,' 'Priscilla,' and 'Liberty,' on semi-dwarfing rootstocks (M.26). The trees are arranged in three blocks of 0.5 to 0.7 ha which represent high (430 trees per ha), medium (225 trees per ha), and low (110 trees per ha) tree planting densities. All three blocks have been managed without the use of pesticides since the establishment of the orchard. The trees are pruned annually and all cuttings are burned or removed from the orchard. The fruit is not thinned, therefore harvests alternate biennially between high and low yields. Apple drops have been removed from the orchard in years of heavy yield. In 1994, codling moth was managed in the orchard with pheromone disruption. The groundcover throughout the orchard consists primarily of orchard grass (*Dactylus glomerata*) and Kentucky bluegrass (*Poa pratensis*) but more than twenty other plant species are also present. The alleys of the high density block were intercropped with potatoes in 1993. Other vegetable crops, including beans and tomatoes, have been intercropped in smaller areas of the orchard in previous years.

Effects on insect pests and weeds

In 1994 the effects of domestic chickens and geese on insect pests and weeds were evaluated in the high density block of the orchard. The alleys were planted into potatoes (var. 'Red Pontiac') at 30-cm plant spacings and 75-cm row spacings on 6 May 1994. This arrangement allowed three rows of potatoes in each alley (Fig. 4-1). Nine plots, each measuring 28 m by 12 m, were established. Each plot consisted of five rows of four trees. Twelve of the trees were 'Redfree' and the remaining 8 trees were 'Priscilla' or a combination of 'Priscilla' and 'Liberty.' The plots were randomly allocated to one of three treatments: 1) with 20 Plymouth Barred Rock chickens per plot (chicken treatment); 2) with 7 African geese per plot (goose treatment); and 3) no birds (control). There were three replications of each treatment. On 14 May, the designated number of 6-week-old birds were introduced into the plots. The birds were allowed to free-range from 8am until 9pm each day and put into coops (1.2 m X1.2 m) located in the center of each plot at night. The flock within each plot was provided with 0.2 kg of grain-based commercial feed each morning and evening.

On the night of 18 May, 30 chickens and 11 geese were stolen from the experiment. The stolen geese were replaced the following day with geese of the same age. Replacement chickens of the same variety and age were not immediately available. Therefore, chicken densities were maintained at 10 birds per plot until 14 June when nine, 3-week-old White Plymouth Rock chickens were added to each plot. This set the densities at 19 chickens per plot. Over the course of the experiment, further chicken losses were incurred to predators including a red-tailed hawk (*Buteo jamaicensis*) and great horned owl (*Bubo virginianus*). These losses were monitored but not replaced. Final chicken densities on 5 August were 12 per plot.

The population dynamics of four insect pests, plum curculio (*Conotrachelus nenuphar*), apple maggot (*Rhagoletis pomonella*), Japanese beetle (*Popillia japonica*), and Colorado potato beetle (*Leptinotarsa decemlineata*), were monitored. The first three pests directly damage apple fruit while the last feeds upon potato foliage. Japanese beetle also feeds upon apple and potato foliage. These insects were selected because they are serious economic pests of these crops and have life cycles which include at least one stage which spends time on the soil surface where it could be vulnerable to chicken predation.

Four of the six trees in the center of each plot were designated for monitoring the three apple pests (Fig. 4-1). When possible, two of the trees were 'Redfree' and two were 'Priscilla.' In plots where one of the 'Priscilla' trees was missing or dying an additional 'Redfree' was monitored. Due to differences in life cycles of the pests and available sampling technologies different monitoring methods were used for each pest. Plum curculio was monitored indirectly by examining all fruit for oviposition and feeding damage on four branches per tree, each week during June. Apple maggot was sampled by counting the number of adults on sticky red spheres covered with adhesive. One sphere was hung 1.5 m high in each sampling tree on 26 June and sampled every 10 d until 5 August. Japanese beetle abundance was monitored directly by counting all beetles on each of the sampling trees every 5-10 days from 30 June until 5 August.

Colorado potato beetle larvae and adults were counted at eight designated areas in each plot. Each sub-sampling area consisted of three 1-m lengths of potato row, resulting in 24 m of row per plot. Counts were conducted every 5-10 days from 14 June until 29 July.

Potato growth and weed abundance were monitored by measuring the percent groundcover of potato and non-potato plants at four locations in each plot. Percent groundcover was measured using a 1 m^2 quadrat with wires forming a grid of 81 points which was centered over the middle potato row in each alley. The presence or absence of potato and non-potato foliage was determined at each grid point. The data from the four locations of each plot were pooled and used to calculate percent groundcover of potato plants and weeds.

Yields of apple fruit and potato tubers were measured at harvest. Apple fruit yield and damage assessments were restricted to 'Redfree' due to the uneven distribution of the other two varieties across the experimental site. Only apples on the trees, and not drops, were considered in yield determinations. On 18 August, the fruit from all trees in each plot was weighed and five apples from each tree were randomly selected for insect damage assessment. These were examined for damage by plum curculio, apple maggot, and Japanese beetle. In addition, damage by codling moth and tarnished plant bug were recorded. Fruit with no insect damage or blemishes of any kind were considered "pest-free." Potato yields were estimated on 3 August by digging and weighing the tubers of 6m of row in two of the four alleys of each plot. Insect pest and weeds abundance in the treatments were compared graphically with time-series data. Fruit yield and damage and potato yield were statistically compared using one-way analysis of variance followed by Tukey's multiple range test. P-values ≤ 0.10 were considered to be statistically significant.

Performance of an integrated bird system

In 1995 the performance of an integrated bird system which included free-range chickens and geese was evaluated in the high density orchard block. This experiment included two treatments with three replications: 1) free ranging chickens and geese in the system as needed for vegetation and insect pest management (bird treatment) and 2) using minimal hand weeding with no birds (control). The bird treatment and control were assigned to the plots which in 1994 had been used for the goose treatment and control respectively. Potatoes were planted on 3 May 1995 using the same protocol as described for the experiment in 1994.

A flock of seven, 5-week old geese was introduced to each plot of the bird treatment on 8 May. Within three weeks most of the preferred plant species (common dandelion, common plantain, and grass seedlings) had been eliminated by the geese. Therefore, on 28 May four geese were removed from each plot setting the density at three per plot. These geese were kept in the plots until 13 June. Three geese were put back into the bird treatment plots for five days in early July to eliminate emerging grass seedlings.

Following the removal of the geese on 13 June, a flock of 20, ten-week-old, Barred Plymouth Rock chickens were introduced into each plot of the bird treatment. (Prior to introduction the chicken flocks had been maintained in the areas of the orchard block which had been used for the chicken treatment in 1994.) The chicken flocks were kept in the plots until 1 August. However, during this time an average of six chickens per plot (30% of each flock) were lost to predators, primarily hawks and owls. Chicken flocks were maintained at equal densities by moving birds from undisturbed plots into plots where predation had occurred. In addition, four chickens were removed from each plot on 12 July for the feeding habit evaluation (described below). Thus, at the termination of the birds treatment on 1 August, each plot had a flock of 10 chickens.

A single hand weeding was performed in the bird treatment on 30 June to remove unpalatable weeds, primarily daisy fleabane (*Erigeron annuus*) and curly dock (*Rumex crispus*). Weed management in the control plots consisted of a single mowing in the tree rows and two cultivations in the potato alleys. Vegetation in the tree rows was cut to 15 cm using a gasoline-powered trimmer on 13 June. The first cultivation in the potatoes in the control plots was accomplished on 15 June using a rototiller in between the rows and a hand hoe within the rows. The second cultivation was completed on 5 July with a hand hoe due to wet soil conditions.

All variables related to insect and weed abundance and crop growth, yield, and damage were measured according to the protocols described for 1994, except: 1) plum curculio abundance which was not monitored in 1995; 2) percent groundcover of individual weed species was determined on one sampling date, 30 May; and 3) the weight of apple drops was determined for the four sampling trees of each plot and compared between the treatments as the percentage of total yield in order to correct for yield differences between plots. Potato yields were determined on 2 August and apple yields on 22 August. Insect pest abundance, weed abundance, fruit yield and damage, and potato yield were analyzed and compared as described for the 1994 experiment. In addition, all labor and material inputs for pest management in the two treatments were recorded. These values were scaled for a 1 ha system and used for an economic assessment.

Free-range chicken feeding habits

In the previous chapter I reported that determination of the feeding habits of free-range chickens by observation was more difficult than that of geese because the diet was comprised mostly of small insects and other invertebrates on the soil surface rather than plants. Thus, to identify items comprising the chicken diet, dissections were done on the digestive crops of chickens killed by predators and sampled for experimental purpose. Many of the chickens killed by raptors were decapitated but had little damage to the rest of the body. Between 6 - 19 June, ten chicken carcasses were found in good condition and promptly frozen for dissection. In addition, on 19 July, four chickens were removed from each bird plot and slaughtered. All of the digestive crops were dissected and the contents identified, usually to the taxonomic family level.

Vegetable crop compatibility with weeder geese

To assess the compatibility of several common vegetable crops with weeder geese a feeding trial and an unreplicated garden plot study were conducted in 1995. The crops tested included tomato, pepper, eggplant, broccoli, cauliflower, cucumber, basil, oregano, and string bean. Plants were 4-6 weeks old at the time of the trial.

The palatability of the crops was initially tested on 22 June with a feeding trial using five, 10-week-old geese. Each goose was given several common dandelion leaves before being offered leaves of each crop. After the dandelion leaves were consumed several leaves of a given crop were offered. If any of the leaves were consumed by at least one goose the test for that plant was considered positive for palatability.

On 23 June, nine geese were introduced into an experimental garden plot which consisted of two 28 m by 2.5 m beds, each situated between rows of apple trees. The garden beds and tree rows, which occupied 350 m^2, were surrounded by electric poultry netting. A total of 223 crop plants were present with each crop being represented by 6 to 61 individual plants. All of the plants were 15-45 cm in height except for the pepper plants which were 7 cm high. Tomatoes and eggplant plants were staked and cucumber plants were trellised; all other plants were without artificial support systems. The geese were maintained in the plot for four days. Each day all of the 223 crop plants were examined for feeding and trampling damage by the geese and classified as having no, light, or heavy damage. A classification of 'light' damage was given if the plant appeared able to recover without yield loss; 'heavy' damage was given if yield loss appeared likely. In addition, weed abundance was monitored by counting all of the weed seedlings in six, arbitrarily-selected 1m^2 samples in the garden beds.

RESULTS

Effects on Insect Pests and Weeds

In 1994 apple yields were relatively high for this orchard. Mean fruit weight for "Redfree' trees in the control, chicken, and goose treatments were 31, 36, and 34 kg/tree (68, 79, and 75 lbs/tree) respectively. These differences were not statistically significant (P > 0.10).

Graphical comparisons indicated that the population abundance of plum curculio (Fig. 4-2), apple maggot (Fig. 4-3), and Japanese beetle (Fig. 4-4) were slightly lower in the chicken and goose treatments compared to the control throughout monitoring periods. However, only the proportion of fruit damaged by to plum curculio differed statistically across treatments (P = 0.03) (Fig. 4-5). In the goose treatment 61% of the fruit had plum curculio damage compared to 78% in the control . The difference in plum curculio damage resulted in a significantly higher proportion of pest-free fruit in the goose treatment (P = 0.06) (Fig. 4-5). The control had a mean of 9% pest-free fruit compared to 21% in the goose treatment. The chicken treatment had intermediate levels of plum curculio damage and pest-free fruit. Because geese are almost completely herbivorous, the effect on plum curculio was considered to be indirect and due to habitat modifications caused by the grazing and weed trampling. Damage by codling moth and tarnished plant bug were relatively low in comparison to that of other pests and did not differ among the treatments. (Pheromone disruption for codling moth was used in the entire orchard in 1994.)

Potato yields were substantially higher in the goose treatment compared to the chicken treatment and control (P =0.009) (Fig. 4-6). The mean tuber weight in the goose treatment was 5860 kg /ha (equivalent to 14122 kg/ha [or 12569 lbs/acre] in monoculture). Interestingly, Colorado potato beetle abundance was also highest in the goose treatment (Fig. 4-7). In fact, only the goose treatment displayed clear generational peaks of Colorado potato beetle larvae and adults. This apparent contradiction between pest abundance and yield can be explained with the weed and potato growth data (Fig. 4-8). Potato plants in the goose treatment had a clear advantage over weeds which were maintained at less than 10% groundcover throughout the season by goose grazing. Potato plant growth rates after emergence were substantially greater than those of the chicken treatment and control. At the time of Colorado potato beetle larval emergence (40 days after planting) potato plants in the goose treatment were more than four times larger than those of the other treatments. Research has shown that large potato plant size and low weed abundance have a positive effect on Colorado potato beetle populations (Horton and Capinera, 1987).

Performance of an integrated bird system

Apple yields in 1995 were extremely low due to biennial yield cycling. Mean fruit weights at harvest for the bird treatment and control were 7.6 and 5.5 kg/tree (or 16.7 and 12.1 lbs/acre], respectively, and did not differ statistically ($P > 0.10$). The weight of apple drops as a percentage of total fruit produced averaged 28% for 'Redfree' trees and 18 % for all sampling trees, but did not differ statistically between treatments ($P > 0.10$). As in 1994, plum curculio damage was most common, however, codling moth damage increased dramatically to be the second most common type found (Fig. 4-9). Apple maggot abundance (Fig. 4-10) and damage (Fig. 4-9) were similar between treatments. Plum curculio abundance was not measured during the season, however, damage was significantly lower in the bird treatment compared to the control ($P = 0.07$) (Fig. 4-9). Once again, this resulted in a greater proportion of pest-free fruit ($P = 0.06$). Although Japanese beetle abundance was consistently lower in the bird treatment compared to the control (Fig. 4-11) the proportion of damaged fruit did not differ between the treatments.

Potato yields in this experiment were very low due to a disease infestation (probably early blight, *Alternaria solani*). This was not surprising considering this was the third year that this soil had been planted in potatoes. Colorado potato beetle abundance patterns were similar to those observed in 1994. A clear larval abundance peak occurred in the bird treatment in late June, approximately 50 d after planting (Fig. 4-12). Considerable variation between plots is evident in the large standard errors of the means. Adult abundance was greatest in mid-July and peaked in both treatments approximately 75-80 d after planting (Fig. 4-12).

Weed growth was considerably greater in the control compared to the bird treatment at the time of potato plant emergence (Fig. 4-13). This difference was accounted for by substantial reductions in orchard grass (*Dactylus glomerata*), Kentucky bluegrass (*Poa pratensis*), common chickweed (*Stellaria media*), and common plantain (*Plantago major*) (Table 4-1). This resulted in greater potato growth in the bird treatment, especially during the first several weeks after plant emergence (Fig. 4-13). The first cultivation in the control was apparently done too late to have an effect on potato growth. Although the potato plants in the bird treatment were consistently larger than those of the control for the first 70 d after planting, yield samples taken 92 d after planting showed no statistical differences between the treatments ($P = 0.21$). Mean tuber weights for the bird treatment and control were 1341 and 874 kg/ha (or 1193 and 778 lbs/acre), respectively.

Economic Assessment

The hypothetical comparison of labor and material inputs for insect pest and weed management considered only the geese because no clear crop protection benefits were derived from the chickens (Table 4-2). Based on the densities used in this study it was assumed that a flock of 75 geese could be used to effectively manage a 1 ha (2.47 acre) orchard with intercropped potatoes. A 20% loss to mortality agents including sickness and predators was included. In addition, it was assumed that a paddock (0.25 - 0.5 ha) was available for pasturing the geese during periods of slow weed growth.

Geese would be purchased as 1-day-old goslings, put out into the orchard at 5 weeks old, and kept for a total of 150 days. Daily management of geese on 1 ha would require 0.5 h of labor for feeding, watering, housing, and fencing. It was assumed that the intercropped orchard would be divided into two equally-sized paddocks and that the geese would be rotated between these areas every 1-2 weeks. In this situation 300 m of fencing would be required for a 0.5 ha area. Material costs for housing (coops of wood and wire) and fencing (electric poultry netting) were given a 10-year depreciation which results in $110.00 per year. Additional hand weeding to remove unpalatable weeds would require 11h.

Without geese, nonchemical weed management for this experimental production system would require the use of a rototiller for cultivation in the potatoes and a gasoline-powered weed trimmer for vegetation management in the tree rows. Both of these activities require a substantial input of human labor. Furthermore, at least some weeding with hand tools would be required within the potato rows. Based upon the labor needed for the control it is estimated that 206 h would be required for weed management on 1 ha of intercropped orchard. Fuel and supplies would be slightly greater without geese.

The results of this hypothetical comparison indicate that the input costs for using geese are slightly greater than using human labor (Table 4-2). The largest costs associated with using the geese are the initial purchase of the birds and the necessary feed. Care of the geese required approximately 0.5 hour of labor per day. However, if it is assumed that the geese can be sold at the end of the season for $10 per bird, the total weed management cost for the weeder geese system is less than 55% of the cost of the system based on human labor (Table 4-2).

Free-range chicken feeding habits

Chicken crop dissections indicated that the birds fed upon a wide variety of insects and other invertebrates and that the diet changed considerably over the season. A total of 33 food items were identified, however only 11 of them were found in both samplings (Table 4-3). In June, the most common food items found were ants, muscoid flies, dung beetles, earthworms, ground beetles, grass, and weed seeds. In July, the diet shifted to include fewer predators, parasitoids, and detritivores and more herbivores. The most common food items found at this time were Japanese beetles, shield-backed bugs, flea beetles, shining leaf beetles, muscoid flies, ants, and grass. Japanese beetle was the most common food item found in the July sampling: 75% of the chicken digestive crops contained this pest. Other potential fruit and vegetable pests found in the diet included tarnished plant bugs, flea beetles, leafhoppers, wireworms, and slugs.

Vegetable crop compatibility with weeder geese

The feeding trial indicated that leaves of the two brassica crops were potentially palatable to the geese (Table 4-4). However, only one of the five geese consumed these leaves and this occurred only after several minutes of masticating it with its bill. During the first two days after the geese were introduced into the garden plot relatively little trampling damage was observed. A thunderstorm which occurred on the third day of the trial resulted in erratic and excited movement by the geese throughout the plot and subsequently caused more damage to the plants. The three crops with support systems, tomato, eggplant, and cucumber, and the shrubby herb, oregano, received no observable trampling damage during the trial. The other five crops, pepper, broccoli, cauliflower, basil, and string bean, had 6 - 22% of plants with light or heavy trampling damage by the end of the trial. Only one crop, string bean, showed any feeding damage by the geese and this was only found on a single plant (Table 4-4). During the four-day period mean weed seedling densities were reduced from $116/m^2$ to $40/m^2$, a 65% reduction.

DISCUSSION

The purpose to this study was to evaluate experimentally the effectiveness of domestic chickens and geese as insect pest and weed control agents in an intensively-managed and integrated horticultural production system. The results support some findings of the study by Clark et al. (1995) and clearly demonstrate the potential of geese as weed control agents. In 1994, weeding by geese resulted in substantially higher potato tuber yields compared to the unweeded control. Similar patterns in weed control and potato growth were observed in 1995, however, disease severely affected potato plants and tuber growth in both treatments and no significant differences resulted.

An unexpected finding was the reduction in plum curculio damage which resulted from free-ranging geese. A possible explanation for this finding is that vegetation removal by the geese resulted in a reduction in soil surface humidity, which consequently reduced plum curculio activity (Racette et al., 1992). While the observed differences in damage in 1994 undoubtedly resulted from the effects of geese, the cause of the patterns in 1995 can only be presumed. This is because the geese were removed and chickens introduced during the time period in which plum curculio is typically active. Plum curculio oviposition scars were already apparent on many fruit at the time of chicken introduction. Furthermore, plum curculio was not found in any of the digestive crops of chickens collected during June. Thus, there is no evidence that chicken predation was responsible for the reduction in plum curculio fruit damage.

Another somewhat unexpected effect of the geese on an insect was the increase in Colorado potato beetle abundance. The relatively large potato plants in the weedless environment produced with weeder geese provided an ideal habitat for Colorado potato beetle (Horton and Capinera, 1987; Hare, 1990). Nonetheless, in this study Colorado potato beetle abundance appeared to be relatively unimportant in influencing yields. The lack of effect from this pest was most likely due to its low population densities and late arrival relative to the planting date (Zehnder and Evanylo, 1989).

The hypothetical economic analysis based on the labor and material input data indicates that the use of geese may be an economically feasible weed management option for small-scale operations largely dependent upon labor-intensive weeding methods rather than herbicides and machinery. The costs associated with weed management in organic or low-chemical fruit and vegetable production are generally a sizable portion of overall costs because alternatives to pesticides are more labor intensive (Prokopy, 1991; Pimentel, 1993). Weeder geese might be profitably used in some cases to reduce labor requirements. Even in comparison to chemical control, weeder geese have been found to be economically comparable (Cramer, 1992).

The estimate of 75 geese/ha (30 geese/acre) for this agroecosystem is substantially greater than other estimates which range from 8 (Johnson,1960; Bachmann, 1993) to 45 (Ware, 1995) geese/ha. Clearly, required weeder geese densities will depend upon the crop species, climate conditions, supplemental weeding methods, and management strategies. This estimate is based upon the requirements during potato plant emergence from the soil, which tends to coincide with a period of rapid weed growth in the spring. Furthermore, it was assumed that no supplemental hand weeding would be conducted during this time. Although weeder geese density requirements decline later in the growing season, it is the period of most rapid weed growth that determined this estimate.

An assumption of this simplistic economic analysis is that the geese can be easily marketed at the end of the growing season. However, the opportunities for marketing geese are considerably less than for other fowl, such as chickens or turkeys. Therefore, an alternative to the sale and re-purchase of geese each year is that a portion of the birds be kept for breeding and flock re-establishment. In this situation the user would incur greater costs in maintaining the birds because they would need supplemental feed to over winter.

The garden trial indicated that weeder geese can be compatible with crops other than apple and potato. The most important factor determining compatibility was the presence of a support system. Those crops which were staked or trellised, tomato, eggplant, and cucumber, and the low-growing, shrubby herb, oregano, were left undamaged during the trial. If artificial support systems could be used other vegetable crops may also be compatible with weeder geese. However the need for stakes or trellises in crops otherwise not requiring them will add to the costs of production and may make the use of weeder geese less economical. Furthermore, many young crop plants are likely to be at least as palatable as young weeds. This means that the compatibility of weeder geese is dependent upon the absolute age of the crop and the relative age compared to the surrounding weeds. More field evaluation is necessary to understand the relationship between these variables.

The possibility of weeder geese selecting for unpalatable weeds in agroecosystems was discussed by Wurtz (1995). In her study of weeder geese in spruce seedling plots the abundance of unpalatable weeds increased by 25 times after two years. Although such a pattern was not detected in this study our observations during weeding operations in late June, 1995, indicated that curly dock and daisy fleabane dominated in areas weeded by geese. These two species were clearly unpalatable and therefore selected for with the removal of palatable species. These observations support Wurtz's assertion that the use of geese be integrated with other weed management methods to prevent selection for unpalatable weeds.

Chickens provided no clear crop protection benefits in 1994 or 1995. Although reductions in the abundance of some insect pests were observed in both years no differences in pest damage or crop yield resulted. Indirect sampling of plum curculio in June 1994 indicated a small reduction in activity, however, no significant differences in fruit damage were found. Similar abundance patterns were observed for apple maggot in 1994, yet no differences in fruit damage were found.

In 1994 and 1995 Japanese beetle abundance was consistently lower in the treatments with chickens compared to the control except for the last sampling date in 1994 (5 August). Furthermore, in the analysis of chicken digestive crops Japanese beetle was the most common food item found in mid-July. Nevertheless, no differences in apple fruit damage by this pest were found. There are several possible explanations for these results. The relatively small size of the plots in comparison to the general mobility of this insect may have allowed it to rapidly colonize available trees during the few weeks in between chicken removal and apple harvest. Furthermore, fruit which was heavily damaged by Japanese beetle tended to drop from the trees prior to harvest; this may have caused some underestimation of damage in the control. Finally, it is likely that damage from wasps was counted as that of Japanese beetle in some cases. Both of these insects chew into the fruit and when such damage could not be differentiated it was assumed to be due to Japanese beetle. This would have inflated estimates of Japanese beetle damage in all treatments, assuming wasp damage was not affected by treatments. Although chickens showed no clear benefits in this study the results suggest they still may be potentially useful as part of an integrated approach for Japanese beetle management. It is possible that higher chicken densities in conjunction with the use of lures to draw the beetles within range of the birds, could be used to control this pest without pesticides in apple or other susceptible crops. Other options may include using mobile, floorless chicken cages, sometimes called chicken tractors, to remove or reduce apple drops on the orchard floor.

Although chickens have been observed to feed on Colorado potato beetle in the field (see chapter 3) there was no clear evidence of this based upon the observed population dynamics patterns or digestive crop analysis in this study. In 1994, Colorado potato beetle abundance patterns in the chicken treatment mirrored those of the control primarily because of similar weed and potato growth patterns. Because of the effects of weeds on Colorado potato beetle abundance an adequate assessment of chicken predation was not possible in this experiment. In 1995, weed growth between the two treatments differed considerably, especially in the early part of the season (Fig. 4-13), confounding Colorado potato beetle abundance and again preventing an assessment of chicken predation.

Interestingly, Colorado potato beetle survival between the peaks in larval and adult abundance was substantially less in the treatment with chickens compared to the control in 1995. While the mean proportion of larvae surviving to the adult stage was 73% in the control it was only 7% in the treatment with chickens. Although greater mortality may be expected in a denser population, this large difference in survival suggests the possibility of an effect by chickens. Although the results of the digestive crop analysis offer no evidence of predation on Colorado potato beetle, the scratching and pecking which typifies chicken foraging activity may have been enough to cause some level of mortality, especially during the larval stage. Hough-Goldstein et al. (1993) found Colorado potato beetles to be unpalatable to broiler chicks but noted a high mortality rate in pecked larvae. There are differences in foraging and feeding behaviors between chicken breeds and individual chickens within breeds (M. S. Clark, personal observation; Hough-Goldstein et al., 1993). Further research is needed on this intra- and inter-breed variability as it relates to the potential use of chickens as biocontrol agents of Colorado potato beetle.

The results of this study indicate that geese can be effective and economical weed control agents in some agricultural production systems. Agroecosystems in which weed management is largely dependent on human labor might integrate weeder geese to reduce labor requirements. Habitat factors, such as tree cover, vegetation height, plant species composition, and water availability, will influence the performance of weeder geese and therefore should be considered when designing management systems. The overall goal of this research was to evaluate a non-chemical management strategy (free-ranging domestic birds) to further the development of agroecosystem design. Although the yields in this experimental system are low by conventional standards they are fairly typical of organic systems (Reinken, 1986; Stanhill, 1990; Pimentel, 1993). I should reiterate that organic or nonchemical agricultural methods cannot be widely adopted without substantial changes in public perceptions and values and the re-organization of food systems toward more localized production and consumption (Merwin and Pritts, 1993; Pimentel et al., 1993; van Ravenswaay, 1994). Nonetheless, the results of this research demonstrate the biological feasibility of a food production system without agrochemicals.

Table 4-1. The abundance of common weed species based on percent groundcover estimates (mean + SEM) taken on 30 May, 1995. The asterisks indicate significant reductions in plant species abundance in the bird treatment compared to the control based on Student's t-test (**= 0.05 ≥ p > 0.01; ***= p ≤ 0.01).

		Percent Groundcover		
Common Name	Species Name	Control	Bird	
Orchard Grass	*Dactylis glomerata*	19.0 + 1.2	1.3 + 0.3	***
Kentucky Bluegrass	*Poa pratensis*	16.7 + 2.2	6.7 + 1.2	**
Common Dandelion	*Taraxacum officinale*	7.0 + 5.0	0	
Common Chickweed	*Stellaria media*	6.7 + 2.0	0.3 + 0.3	**
Common Plantain	*Plantago major*	5.7 + 1.5	0	**
Daisy Fleabane	*Erigeron annuus*	4.0 + 1.2	2.7 + 2.7	
Curly Dock	*Rumex crispus*	2.3 + 0.9	4.7 + 1.3	
Canada Thistle	*Cirsium arvense*	1.0 + 1.0	0	
Winter Cress	*Barbarea vulgaris*	0.7 + 0.7	1.3 + 1.2	

Table 4-2. A comparison of labor and material input costs ($U.S.) for nonchemical weed management with and without weeder geese in a hypothetical 1 ha apple orchard with intercropped potatoes.

	Costs ($US)	
Inputs	Weeder Geese	Human labor
Geese (95 @ $5 per bird)	475	-
Feed ($72 per month for 5 months)	360	-
Care of Geese(75 h @ $6 per h)	450	-
Housing and Fencing (10-year depreciation)	110	-
Weeding and Cultivation ($6 per h)	67	1235
Rototiller (10-year depreciation)	-	100
Weed trimmer (5-year depreciation)	40	40
Fuel and Supplies	20	55
Total Input Costs	1522	1430
Outputs		
Geese (75 @ $10 per bird)	750	-
Balance		
Total Costs (Inputs - Outputs)	772	1430

Table 4-3. The diet components of free-range chickens in the experimental system based on the presence / absence of items in digestive crop dissections from two sampling periods; 6-19 June (N=10) and 19 July (N=12).

	Food Items		% Crops with Item	
Functional group	Common name	Scientific name	6-19 June	19 July
Herbivore	Japanese beetle	*Popillia japonica*	0	75
	tarnished plant bug	*Lygus lineolaris*	0	25
	shield-backed bug	Scutelleridae	0	50
	flea beetle	Alticinae	0	33
	shining leaf beetle	Criocerinae	20	42
	wireworm	Elateridae	0	8
	click beetle	Elateridae	0	17
	caterpillar	Lepidoptera	10	25
	leafhopper	Cicindellidae	20	25
	cicada	Cicadidae	0	8
Predator	ground beetle	Carabidae	30	0
	hover fly larvae	Syrphidae	20	0
	hister beetle	Histeridae	10	8
	soldier beetle	Cantharidae	10	0
	rove beetle	Staphylinidae	10	17
	assassin bug	Reduviidae	0	8
	wolf spider	Lycosidae	0	17
	crab spider	Thomisidae	0	8
Parasitoid	braconid wasp	Braconidae	20	0
	ichneumon wasp	Ichneumonidae	10	17
Detritivore	earthworm	Lumbricidae	30	0
	slug	Limacidae	10	0
	dung beetle	Scarabaeidae	30	8
	muscoid fly	Diptera, Muscoidea	40	33
	sap beetle	Nitidulidae	10	0
	earwig	Forficulidae	0	8
Other animals	ant	Formicidae	50	58
	hover fly	Syrphidae	0	17
	moth pupae	Lepidoptera	0	8
	caddisfly	Trichoptera	0	8
	cuckoo wasp	Chrysididae	0	8
Plant	grass	Poaceae	30	67
	weed seeds	undetermined	30	17

Table 4-4. The results of a feeding trial, which tested the potential palatability of vegetable crops (N=5 geese), and an unreplicated garden trial which assessed feeding and trampling damage caused by weeder geese during a four-day period.

crop[a]	feeding trial[b]	garden trial				
		# plants	% with feeding damage		% with trampling damage	
			light	heavy	light	heavy
tomato	-	61	0	0	0	0
pepper	-	23	0	0	13	0
eggplant	-	18	0	0	0	0
broccoli	+	30	0	0	10	0
cauliflower	+	23	0	0	13	4
cucumber	-	6	0	0	0	0
basil	-	18	0	0	6	0
oregano	-	7	0	0	0	0
string bean	-	37	0	3	14	8

[a] tomato and eggplant plants were staked; cucumber plants were trellised; all other crop plants had no support system

[b] + indicates that at least one goose fed upon the leaves offered; - indicates that none of the five geese fed upon the leaves offered.

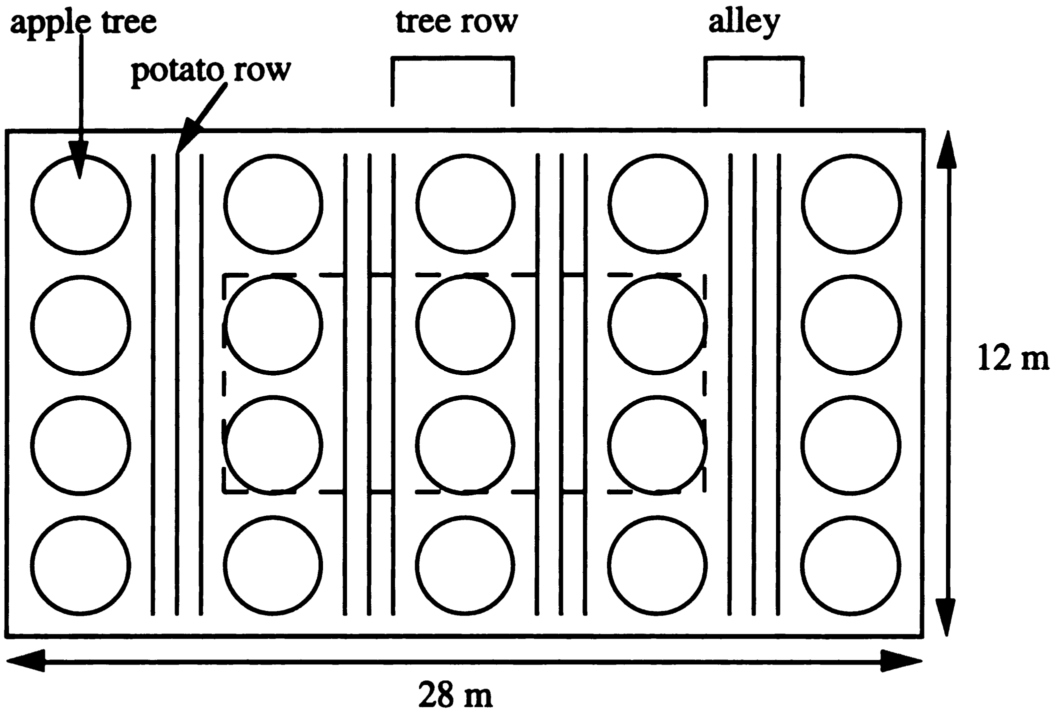

Figure 4-1. Layout of a single plot showing important features. Four of the six apple trees within the dotted box in the center of each plot were designated as sampling trees for all insect pest monitoring.

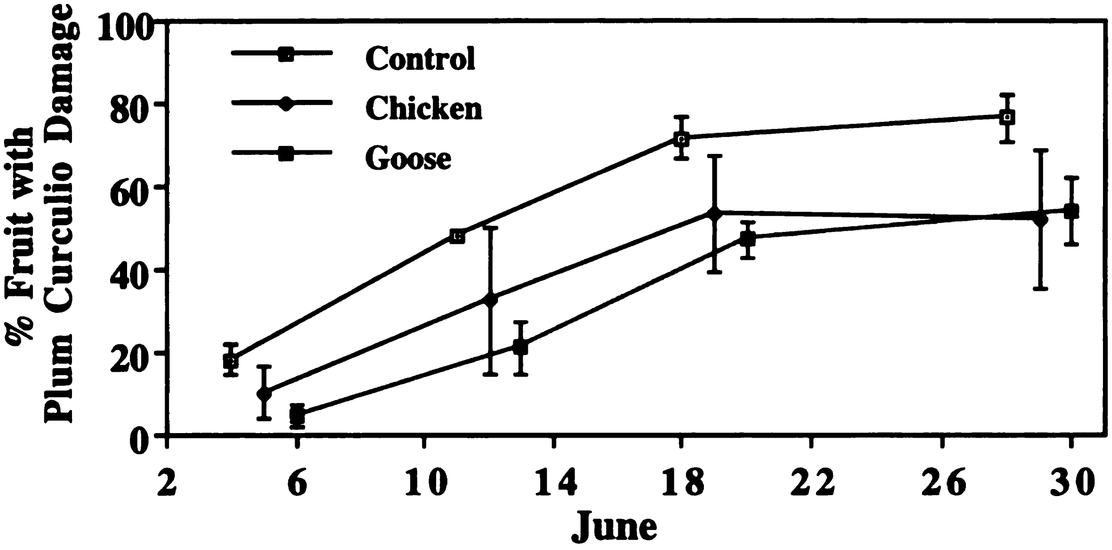

Figure 4-2. Percentage of apples damaged by plum curculio based on visual monitoring during June, 1994 (mean + SEM).

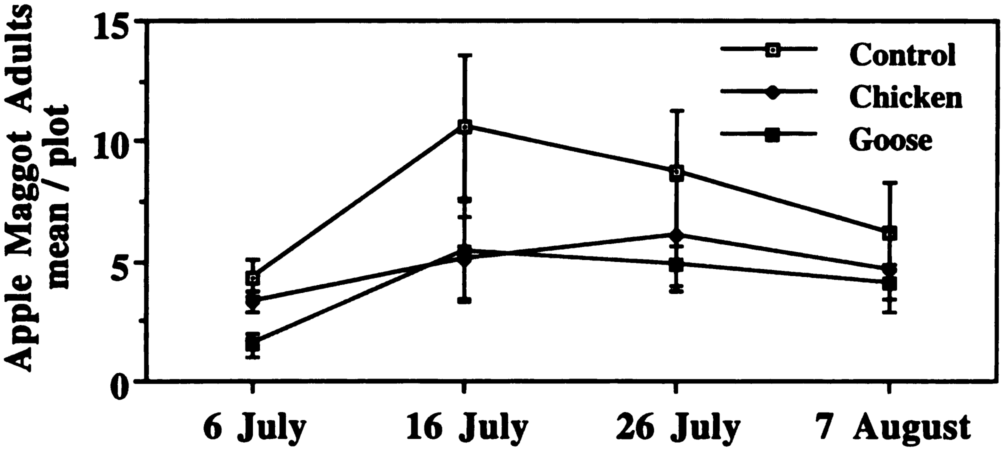

Figure 4-3. Apple maggot abundance based on the number of adults caught on four red spheres per plot in 1994 (mean + SEM).

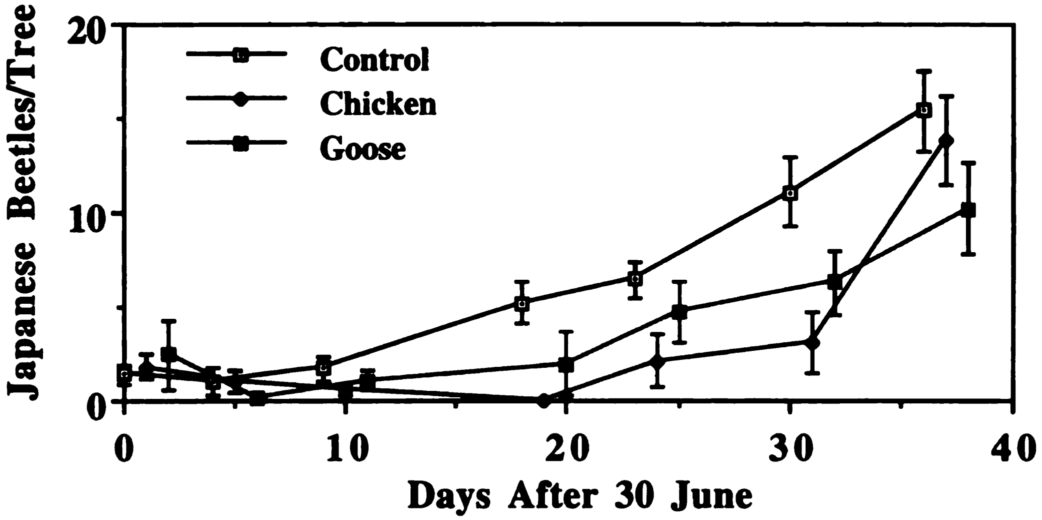

Figure 4-4. Japanese beetle abundance based upon direct counts on the sampling trees in 1994 (mean + SEM).

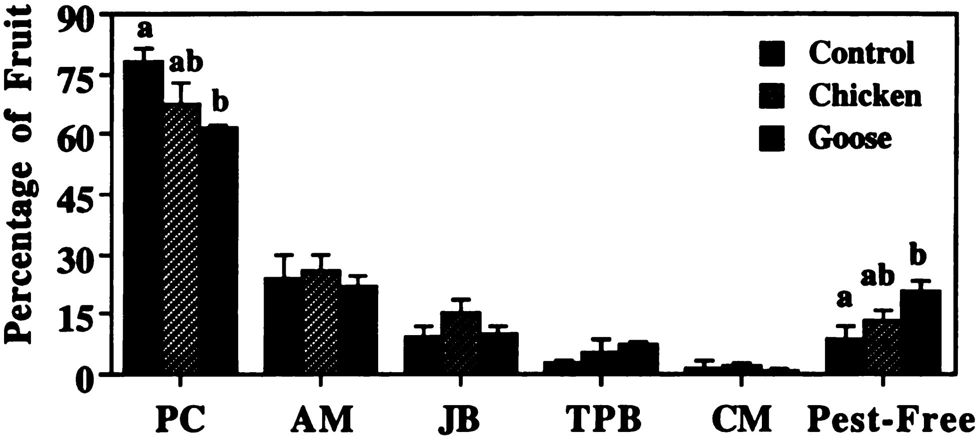

Figure 4-5. The percentage of harvested fruit damaged by insects (PC=plum curculio, AM=apple maggot, JB=Japanese beetle, TPB=tarnished plant bug, CM=codling moth) and undamaged (Pest-Free) in 1994 (mean + SEM). Different letters indicate significant differences ($p \leq 0.06$).

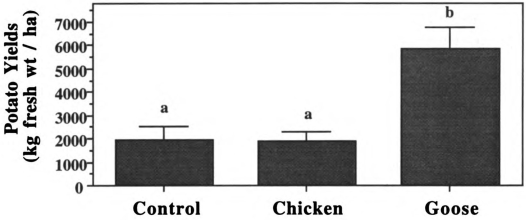

Figure 4-6. Potato tuber yields (kg / ha) based on sampling 6m of row in 1994 (mean + SEM). Different letters indicate significant differences ($p \leq 0.01$).

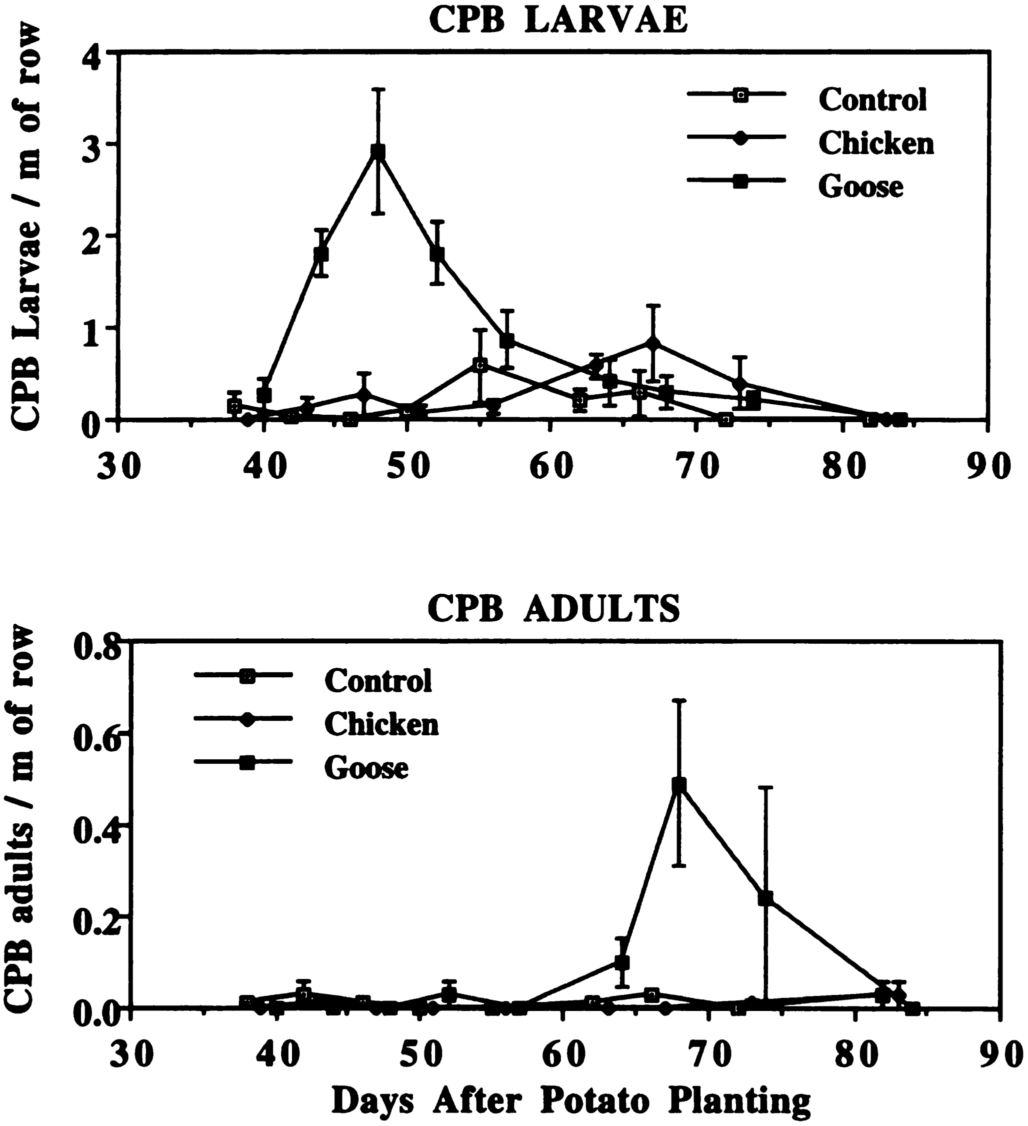

Figure 4-7. Colorado potato beetle (CPB) larvae and adult population dynamics in the control, chicken, and goose treatments in 1994 (mean + SEM).

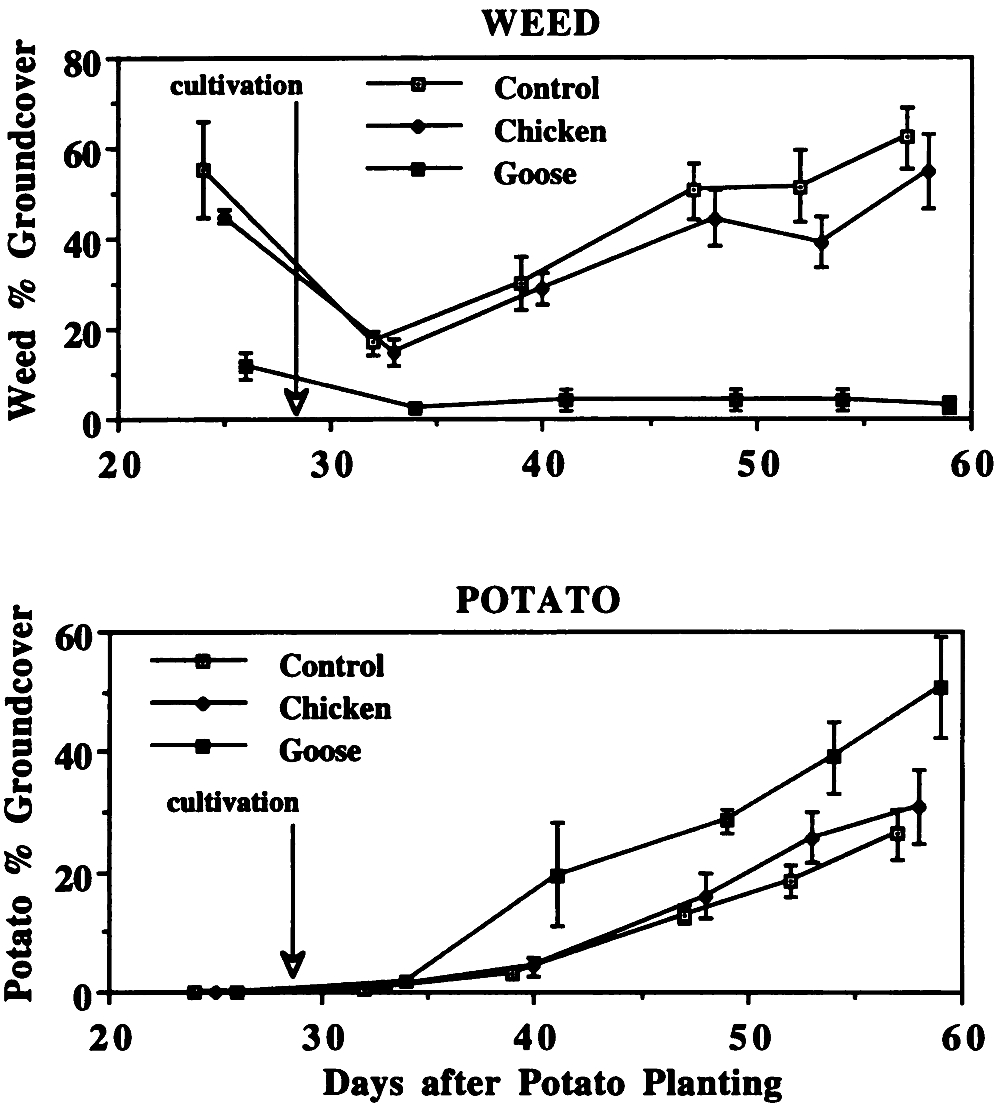

Figure 4-8. Percent groundcover of weeds and potatoes in the control, chicken, and goose treatments in 1994 (mean + SEM).

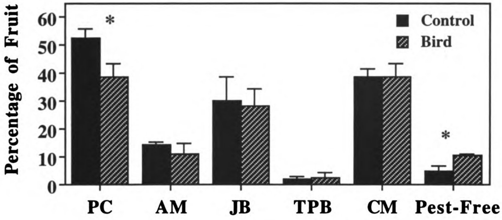

Figure 4-9. The percentage of harvested fruit damaged by insects (PC=plum curculio, AM=apple maggot, JB=Japanese beetle, TPB=tarnished plant bug, CM=codling moth) and undamaged (Pest-Free) in 1995 (mean + SEM). Asterisks indicate significant differences ($p \leq 0.07$).

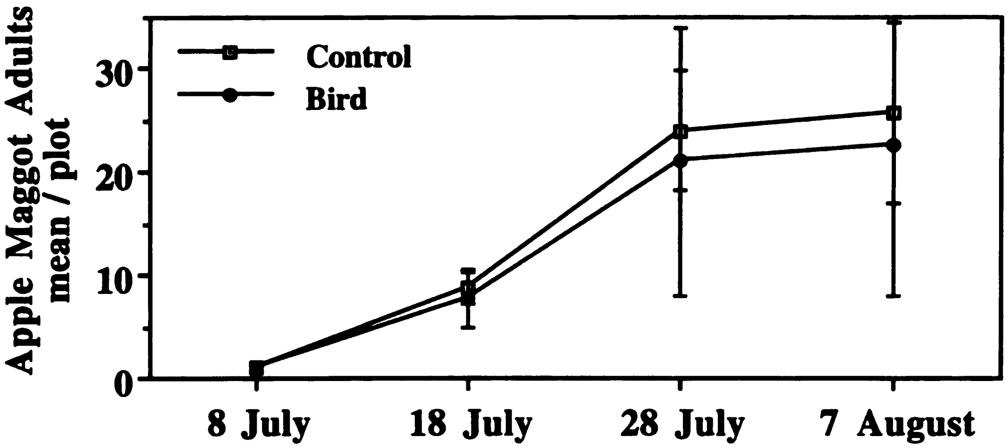

Figure 4-10. Apple maggot abundance based on the number of adults caught on four red spheres per plot in 1995 (mean + SEM).

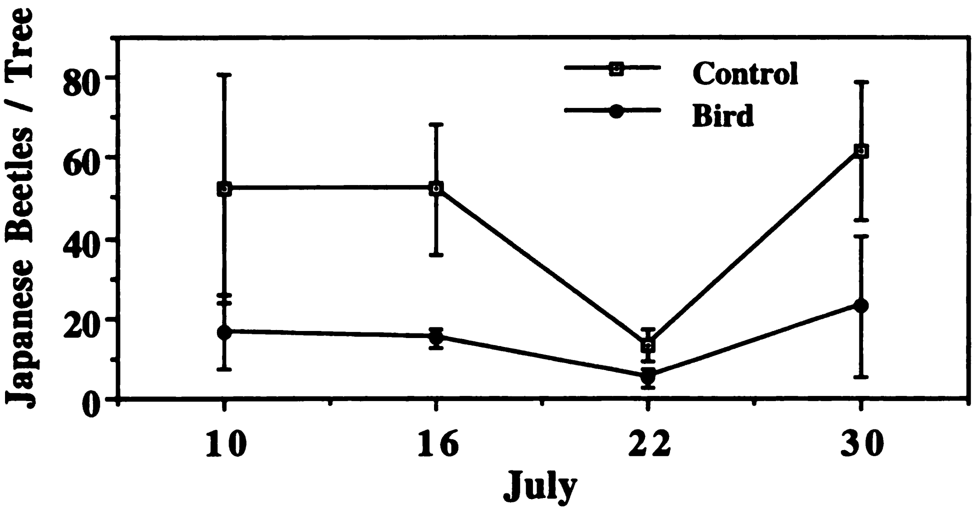

Figure 4-11. Japanese beetle abundance based upon direct counts on the sampling trees in 1994 (mean + SEM).

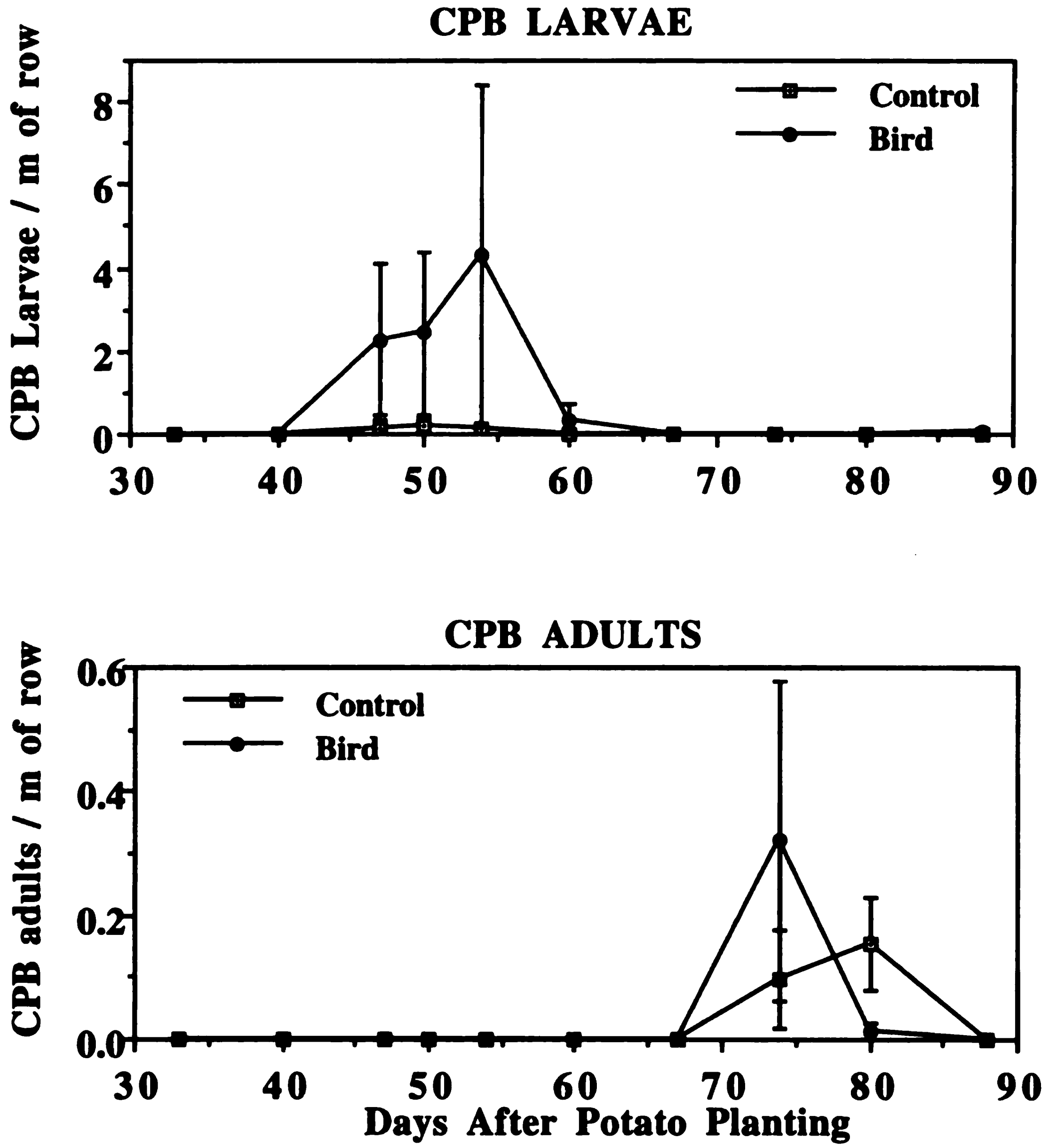

Figure 4-12. Colorado potato beetle (CPB) larvae and adult population dynamics in the control and bird treatment in 1995 (mean + SEM).

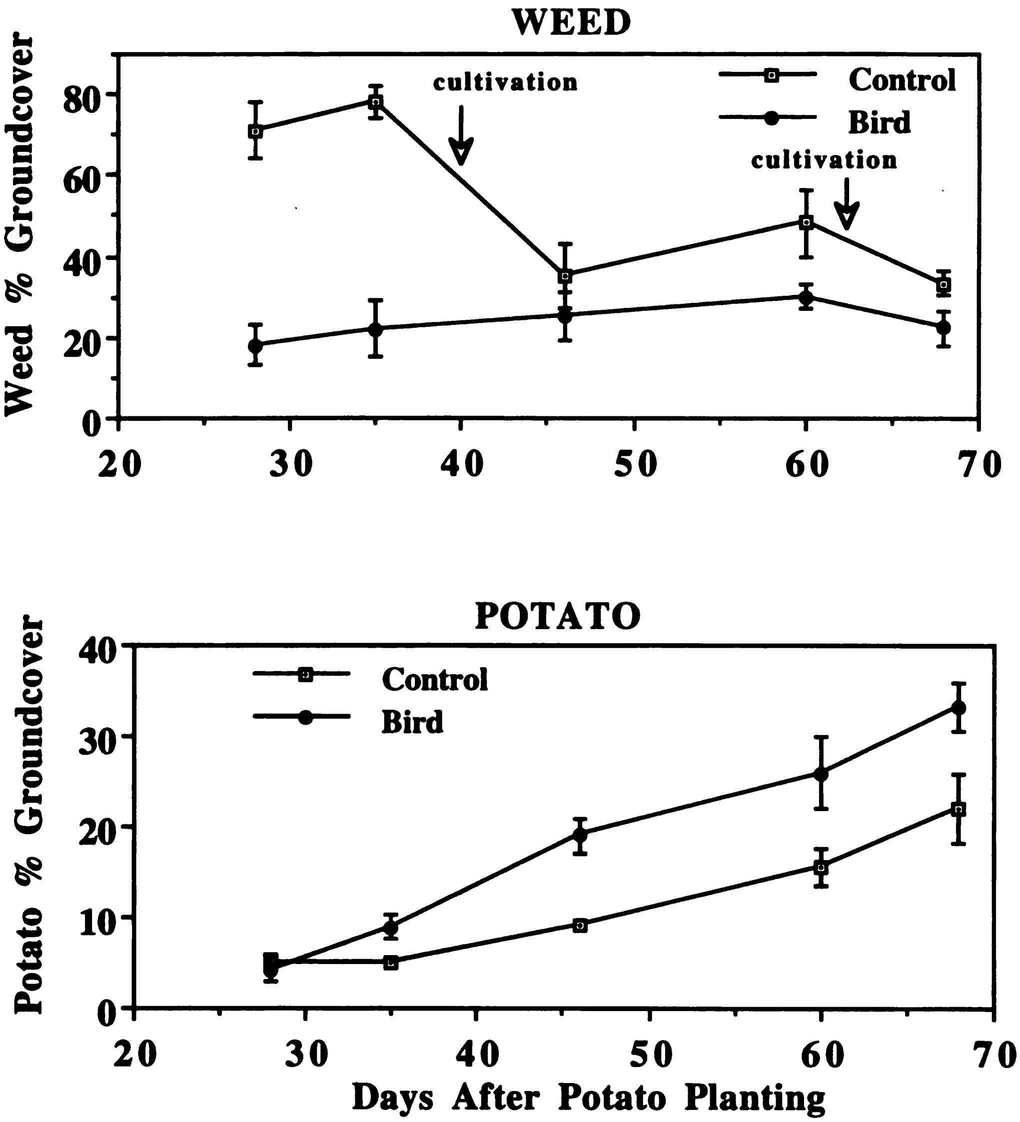

Figure 4-13. Percent groundcover of weeds and potatoes in the Control and Bird treatment (mean + SEM).

CHAPTER 5

THE EFFECTS OF FREE-RANGE DOMESTIC BIRDS ON THE ABUNDANCE OF BENEFICIAL SOIL MACROINVERTEBRATES

INTRODUCTION

Integrating animals into cropping systems can result in a variety of benefits including nutrient cycling, resource conservation, natural or biological pest management, and economic stability. This research reported so far has focused on the potential of the birds as insect pest and weed biological control agents. However, chickens have been found to feed upon a wide variety of macroinvertebrates from the soil surface including ground beetles (Carabidae), rove beetles (Staphylinidae), spiders (Araneae), and earthworms (Lumbricidae). Geese, by contrast, are herbivores and do not directly affect soil macroinvertebrates. Nevertheless, the removal of vegetation and mild soil compaction which results from their foraging activities can dramatically alter the soil surface environment. Furthermore, the manure produced by both of these bird species could potentially alter food webs and thereby be manifested in changes in macroinvertebrate abundance.

There are risks associated with introducing new or exotic species into ecosystems for biological control, or any other purpose, because it is generally not possible to predict all direct and indirect consequences of such introductions (Howarth, 1992). Although domesticated animals present relatively little threat because of their manageability, they can have significant ecological effects. The impact of overgrazing cattle on soil resources is one well known example (Pimentel et al., 1995).

The purpose of this study was to evaluate the effects of free-range chickens and geese on two groups of beneficial soil macroinvertebrates: epigeic predators and earthworms. The experimental agroecosystem used for the study was a nonchemical apple orchard with intercropped potatoes. Research has demonstrated or suggested that both of these macroinvertbrate groups play important roles in these crops. For example, ground beetles have been found to be predators of some apple pests, including apple maggot (Allen and Hagley, 1990) and codling moth (Hagley and Allen, 1988; Riddick and Mills, 1994), and the potato pest, Colorado potato beetle (Hough-Goldstein et al., 1993; Brust, 1994). Spiders can be natural control agents of a variety of horticultural insect pests (Riechert and Bishop, 1990). The role of earthworms in maintaining soil fertility and improving soil structure has been widely demonstrated in agroecosystems (Berry, 1994; Edwards et al., 1995; and references therein). Furthermore, earthworms can indirectly reduce plant diseases in orchards by breaking down leaf litter (Raw, 1962; Kennel, 1990). The results of two objectives are reported: 1) to evaluate the short-term effects of free-range chickens and geese and intercropping on the activity patterns of epigeic predators in an apple orchard, and; 2) to measure the effects of free-range domestic bird production on earthworm abundance and compare these to the observed landscape-level patterns.

MATERIALS AND METHODS

The Study Site

This study was conducted in an experimental apple orchard and surrounding area at the Kellogg Biological Station of Michigan State University. The orchard was planted in 1983 with the disease-resistant varieties 'Redfree', 'Priscilla', and 'Liberty' and arranged in three blocks of 0.5 to 0.7 ha which represent high (430 trees/ha), medium (225 trees/ha), and low (110 trees/ha) tree planting densities. All of the research reported in this paper was conducted in the high density block and adjacent agricultural fields (Fig. 5-1). The entire orchard has been managed without the use of pesticides since its establishment.

Effects on Epigeic Predators

In 1993, twelve plots were randomly established in the block for three treatments with four replications. Plots were 16.8 m X 9.9 m and consisted of three rows of three apple trees and two inter-row alleys (Fig. 5-2). The trees in two of the rows were 'Redfree' and the third were 'Priscilla.' The tree spacings were 3.3 m and the row spacings were 6.5 m. Prior to potato planting the orchard alleys were cultivated with a chisel plow and disk. The alleys were planted by hand in potatoes ('Red Pontiac') on 18 May with 30-cm plant spacings and 75-cm row spacings. This allowed three rows of potatoes to be planted within each alley such that the outside potato rows were not directly beneath the canopy of the apple trees. In one randomly-selected alley of each plot the potato plants were mulched to a depth of 15 cm with recently cut rye (*Secale cereale* var.'Wheeler') which was collected from a field adjacent to the orchard, creating mulched and unmulched subtreatments. The potatoes were hand weeded on 11 June and hand weeded and hilled on 17 June.

The three main treatments included 1) placing 15 chickens per plot (chicken treatment); 2) placing 11 geese per plot (goose treatment); and 3) a control with no birds (control). Plots with chickens or geese were surrounded with 1.5 m-high plastic fencing with 6 cm mesh. On 2 July, the birds, at 6 weeks old and with an approximately equal number of males and females, were introduced into the designated plots. The birds were kept in coops (1.2 m X 1.2 m) located on the perimeter of earch plot at night and released to free range from approximately 7:00 am until 9:00 pm (EST). The birds were provided with water and small amounts of grain-based feed twice daily. On 17 July, 3 geese were removed from each plot of the goose treatment, setting the population at 8 per plot. The birds were maintained in the plots until 6 August.

Ground-dwelling predators were sampled in each plot with three pitfall traps from 2 July until 29 July. One trap was positioned in the center of each of the alleys with potatoes and one trap was placed in the center of the middle apple row (Fig. 5-2). A trap consisted of 250 ml plastic cup with a 7-cm diameter opening, placed into the ground so that the top was flush with the soil surface. It was filled with approximately 100 ml of soapy water as a killing agent. A plastic rain cover (12 cm X 12 cm) was held 5 cm above the cup with galvanized nails. The traps were emptied weekly and the contents taken to a field laboratory for specimen identification. The data for the 27-d trapping period were pooled for each trap and comparisons made with a two-way analysis of variance with the main treatments (chicken, goose, and control) and subtreatments (apple row, mulched potatoes, and unmulched potatoes) as the two factors, each with three levels. When significant differerences were found among the main treatments ($P \leq 0.10$) means were separated using Tukey's multiple range test.

Effects on Earthworms

Earthworms were sampled in the orchard and nearby fields from 28 to 30, July, 1995 (Fig. 5-1). A sample consisted of 20 cm^2 cube of soil which was hand-sorted for earthworms in the field. Pairs of samples were taken from eight areas of the orchard. In each area one sample was from the apple tree row and the other from the alley. Five of the eight areas had been used for ranging chickens and geese from 1993 to 1995 at densities of 150-700 birds/ha for 1-3 months each summer. The other three areas had been free of birds and were used as controls. Two samples were taken in fields near the orchard which included an old field (never tilled), two corn fields, and an alfalfa field (Fig. 5-1, Table 5-1). Nearly all earthworms collected were immature; thus no species identifications were attempted. In addition, three, 5-cm deep, soil probe samples were taken at each sample site, mixed, and a subsample removed. These were analyzed by the Michigan State University Soil and Plant Nutrient Laboratory for nutrient, texture, and organic matter characteristics.

Earthworm abundance, nutrients, texture, and organic matter were compared between the areas with and without birds and between tree rows and alleys of the orchard with two-way analysis of variance. The relationships between earthworm abundance and soil chemical and physical properties and geographic location (linear distance from the old field) were evaluated with Pearson correlation and regression analyses. For these analyses each pair of orchard samples (tree row and alley) was pooled for a total of eight orchard samples and each pair of samples from the nearby fields was pooled to form a single sample from each of the four fields.

RESULTS

Effects on Epigeic Predators

Approximately 1100 epigeic predators were collected in pitfall traps during the 27-d period with four taxa repesenting over 99% of all specimens (Fig. 5-3). The abundance of all four taxa showed similar patterns with respect to the subtreatment effect: the traps in the tree rows collected more predators than those in the intercropped alleys (Fig. 5-4). These differences were statistically significant for Staphylinidae, Opiliones, and Araneae, but not for Carabidae. No difference in predator abundance between mulched and unmulched alleys was observed.

Effects due to the birds were found for Opiliones and Araneae (Fig. 5-4). In both cases, predator abundance was reduced by the presence of chickens and geese. Staphylinidae and Carabidae showed no differences in abundance that could be attributed to the birds.

Effects on Earthworms

No differences were found between orchard areas with and without birds for earthworms, clay, silt, sand, organic matter, nitrates, phosphorus, potassium, calcium, magnesium, or cation exchange capacity. Furthermore, no difference in earthworm abundance was found between the tree rows and alleys. However, when samples from the orchard and surrounding fields were analysed for correlations, earthworm abundance was found to have significant positive relationships with percent clay, percent organic matter, and cation exchange capacity and significant negative relationships with percent sand and distance from old field (Table 5-2).

As expected, cation exchange capacity was correlated with organic matter and percent clay. Percent clay was relatively constant, ranging from 17 to 23% for all samples except those from the old field and alfalfa field. The old field had the highest clay content, 33%, while the alfalfa field had the lowest, 9%. Percent sand displayed the opposite pattern; the old field had the lowest value, 24%, while the alfalfa field had the highest, 71%. The strongest relationships (i.e. those with the highest correlation coefficients and p values) with earthworm abundance were with organic matter and distance from the old field (Table 5-2, Fig. 5-5). A multiple regression model with these variables accounted for most of the variation in earthworm abundance ($r^2=0.96$; $p<.0001$). The old field had the highest organic matter content and earthworm abundance. The two corn fields and the alfalfa field had the lowest organic matter contents, yet corn field #2 had the second highest earthworm abundance. This apparent contradiction was explained with distance from the old field (Fig. 5-5). This rather narrow corn field was located between the old field and orchard, two stable habitats with high organic matter. Thus, movement into the corn field from these locations would account for the high earthworm abundance found there.

DISCUSSION

The overall effects of domestic birds on beneficial soil macroinvertebrates in this study were found to be absent or relatively unimportant. The practice of intercropping in the orchard had a greater overall effect on the activity patterns of predatory macroinvertebrates than did the presence of chickens or geese. However, the presence of the birds did result in fewer spiders and harvestmen in the pitfall traps.

In general, ground-dwelling predators are most active at night (Brust et al., 1986); however, most of the spiders collected were lycosids, a family with many diurnally active species. Furthermore, the most common harvestman, *Phalangium opilio* L. is commonly found on the soil surface or on plants in the day. In contrast, most carabids and staphylinids seek shelter under the soil surface or debris in the day, where they are less likely to be eaten by foraging chickens or disturbed by foraging geese.

The presence of the birds over the 3-yr period had no detectable effect on earthworm abundance. Moreover, the soil chemical and physical analyses showed no differences between the areas with and without birds. Earthworm abundance was clearly correlated with soil organic matter, a relationship which has been widely shown in other studies (Hendrix et al., 1992; Edwards et al., 1995 and references therein). Soil organic matter provides a food source for earthworms and when it is lost, due to agricultural practices or erosion, earthworm abundance declines. By contrast, when organic matter is added to soil, such as in manure applications, earthworm abundance increases. The fact that the birds had no effect on organic matter indicates that earthworms should not have been influenced positively by their presence. However, there was also no evidence of negative influence due to chicken predation or vegetation alterations. Although the chickens were observed to feed on earthworms (see chapters 3 and 4)), their effect on earthworm populations, at least at these stocking densities, appears to be absent or relatively minor.

The relationship between earthworm abundance and distance from the old field was an interesting and surprising finding. It suggests an explanation for why corn field #2, a field with relatively little organic matter, had such high earthworm abundance. It is probable that there is a substantial amount of surface activity by the earthworms and that there is a net movement out of areas with higher densities into areas with lower densities (Mather and Christensen, 1988). This corn field, which is annually tilled, apparently benefits by its close proximity to undisturbed land with high earthworm densities. This combined with its small size, makes it easily colonizable.

In summary, free-ranging chickens and geese resulted in some reduction in spider and harvestman activity. The mechanism for this reduction may have been direct predation by chickens or habitat disturbance and alteration by both bird species. Chickens have been found to feed on the two common carabid species in this landscape, *Pterostichus melanarius* (Illiger) and *Cyclotrachelus sodalis* (LeConte), which represented 93% of all carabids collected during the sampling period. However, no reductions in the abundance of carabids or staphylinids were detected. A plausible explanation for this lack of effect is that these predators are generally active at night when the birds were in coops (chickens are inactive at night regardless of whether they are in a coop or not). Furthermore, the presence of the birds did not result in any detectable changes in soil organic matter or any other chemical or physical variable measured. Thus, no positive effects on earthworm abundance would be expected. At the same time, no negative effects on earthworm abundance were found.

Table 5-1. Management histories of the agricultural habitats sampled for earthworm abundance estimates.

Habitat	Recent cropping history	Pesticides	Tillage
Apple Orchard	intercropped with potatoes 1993-1995	none	minimum (in alleys)
Old Field	never cropped, mowed once per year	none	none
Corn Field #1	rotated with wheat	herbicides	conventional
Corn Field #2	rotated with wheat, rye, and oats	herbicides	conventional
Alfalfa	re-planted in 1994	none	conventional (1994)

Table 5-2. Pearson correlations between earthworm abundance and soil texture, organic matter, nutrient levels, cation exchange capacity, and distance from an old field.

Variable	correlation coefficient (r)	P value
% clay	0.67	0.018
% silt	0.40	0.197
% sand	-0.55	0.065
% organic matter	0.78	0.003
nitrate (ppm)	0.09	0.772
phosphorus (kg/ha)	-0.37	0.242
potassium (kg/ha)	0.13	0.698
calcium (kg/ha)	0.40	0.199
magnesium (kg/ha)	-0.29	0.359
cation exchange capacity (me/100g)	0.71	0.009
distance from old field (m)	-0.77	0.003

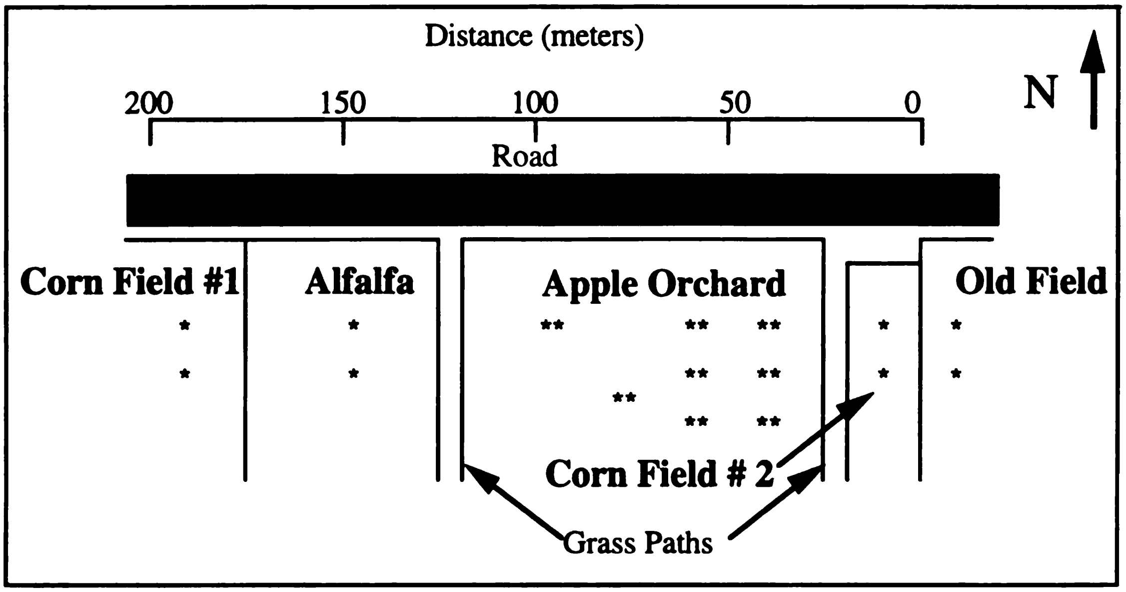

Figure 5-1. Landscape map showing the experimental apple orchard and surrounding fields and the earthworm sampling locations (*).

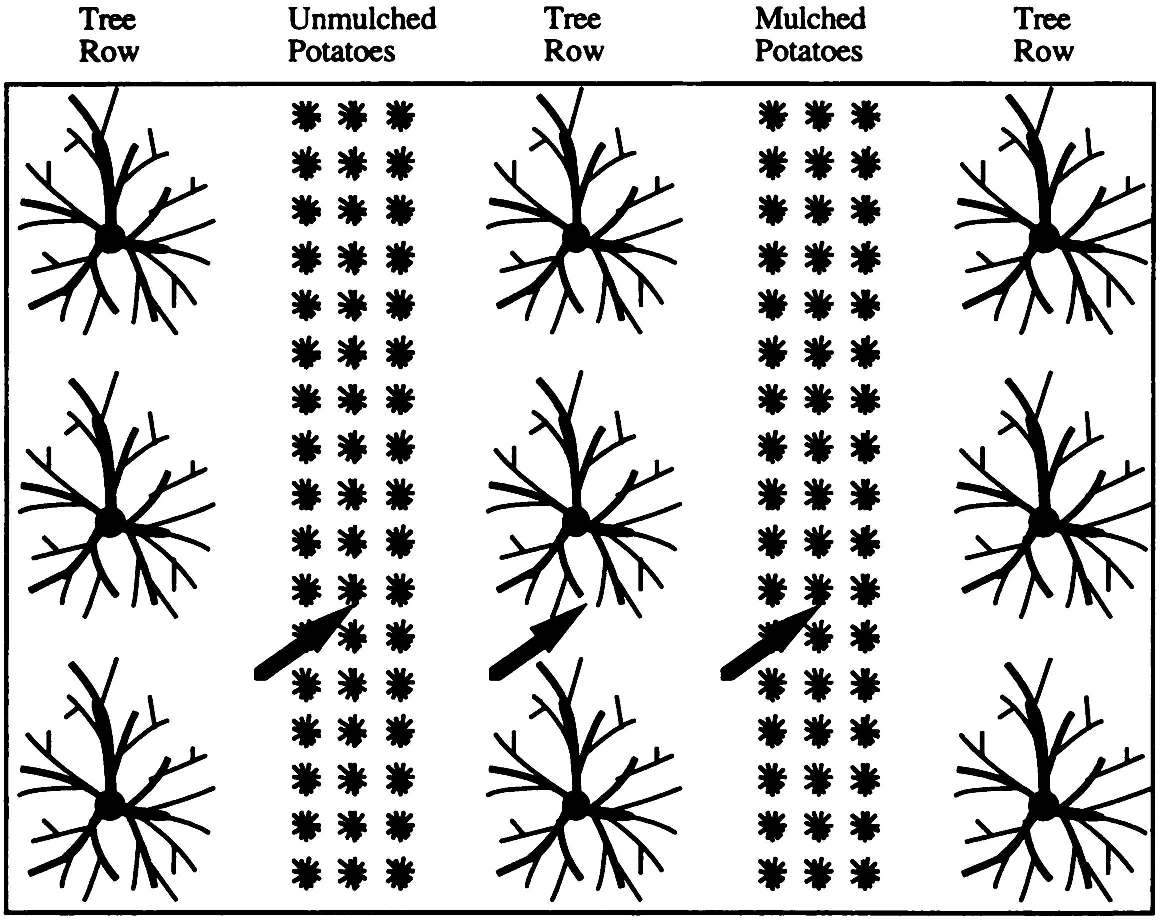

Figure 5-2. Plot diagram showing the general layout and the locations of the pitfall traps (shown with arrows). Plots measured 16.8m X 9.9m and included three rows of three trees and two inter-row alleys which were intercropped with potatoes (mulched and unmulched).

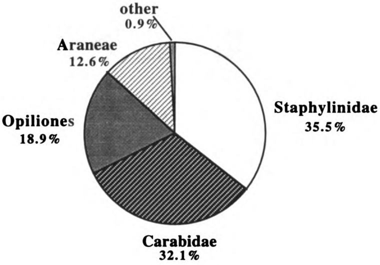

Figure 5-3. The relative abundance of predator taxa collected in pitfall traps in the orchard from 2 July until 29 July, 1993.

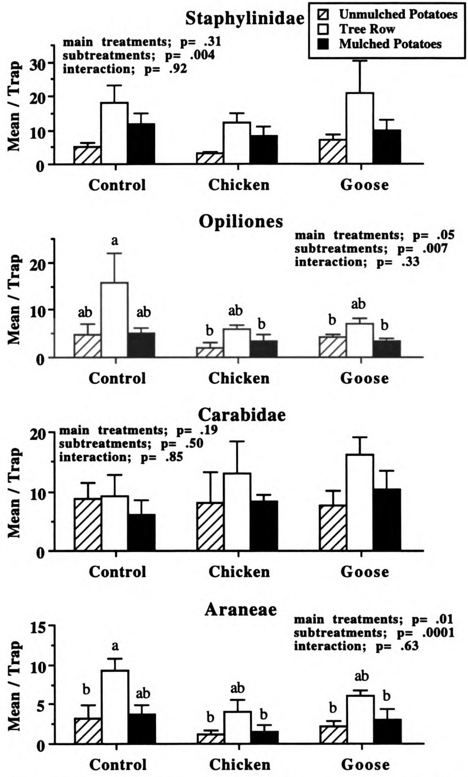

Figure 5-4. Mean abundance (± SEM) of predatory arthropods collected in pitfall traps in main treatments (control, chicken, and goose) and subtreatments (unmulched potatoes,

mulched potatoes, and tree row). Different letters indicate significant differences according to Tukey's multiple range test ($p \leq 0.10$).

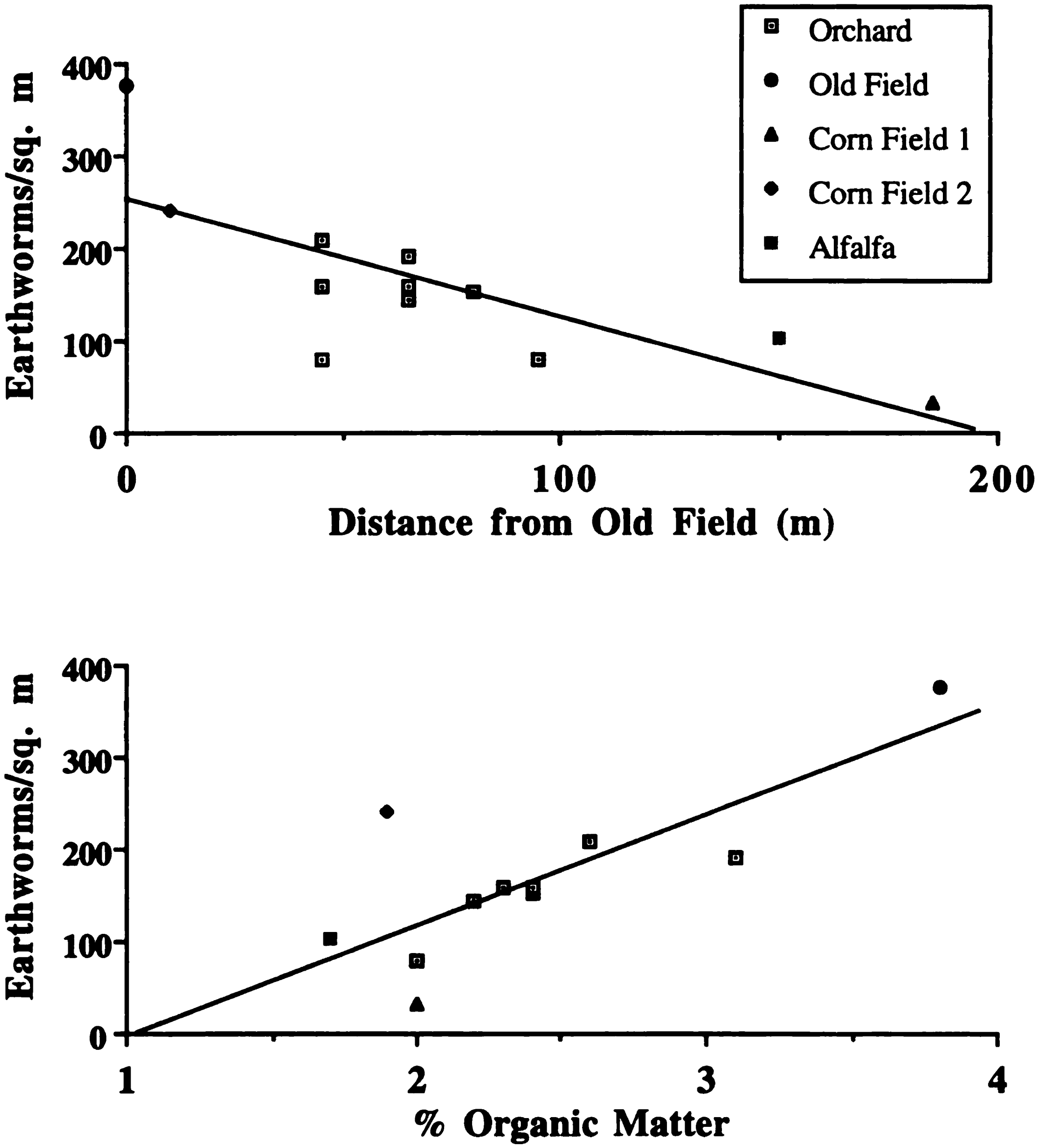

Figure 5-5. The relationship between earthworm abundance (number/m^2) and distance from old field and percent organic matter, based upon samples taken from the apple orchard and nearby fields. Earthworm abundance was negatively correlated with distance from old field ($r=-0.77$, $p=0.003$) and positively correlated with organic matter ($r=0.78$, $p=0.003$).

CHAPTER 6

FARMER PERCEPTIONS OF FREE-RANGE DOMESTIC BIRDS AS BIOLOGICAL CONTROL AGENTS ON SMALL FARMS

INTRODUCTION

In recent years the use of domestic birds as insect pest and weed biological control agents has received increased attention by both farmers and researchers. Although some published historical information on the use of domestic birds for biological control does exist, it is mostly anecdotal and lacks detail on management practices and measurements of the birds' effectiveness (Quaintance and Jenne, 1912; Hoare, 1928; Mayton et al., 1945; Johnson, 1960). Thus, it has not adequately served the purposes of farmers or researchers seeking to learn more on the use of birds as alternatives to pesticides.

Recently published case studies, on-farm trials, and research experiments have reported on the use of geese for weed control in fruits, vegetables, and nursery plantings (Cramer, 1992; Bachman, 1993; Ware, 1995; Wurtz, 1995), ducks for housefly control in dairy operations (Glofcheskie and Surgeoner, 1990; 1993), and chickens for insect and weed control in potato and apple systems (Hough-Goldstein et al., 1993). Nevertheless, there are still questions regarding the potential for widespread applicability of domestic birds as biological control agents on farms.

In order to address these questions, cooperation between farmers and researchers is clearly needed. Discussion on the appropriate roles of farmers, researchers, and land-grant universities in generating agricultural knowledge and technologies has been an important but controversial topic in the sustainable agriculture movement (see for example: *American Journal of Alternative Agriculture*, 1990, volume 5(4); *Agriculture and Human Values*, 1994, volume 11(2&3). Although it has been stated that when farmers do not accept technologies it is simply because they are either unable or unwilling to do so (Nowak, 1992), the reasons for such inability or unwillingness are varied and complex. Some have claimed that the experiences, values, perceptions, and goals of researchers and farmers have diverged over the years to such an extent that fruitful communication between these groups is difficult and rare. Such a view is expressed by Soule and Piper (1992, p. 51) who stated that "Farming has moved from a cultural art, handed down from generation to generation, to an industry taught as a profession by expert specialists who may never have farmed a day in their lives." Regardless of whether this view is correct, it seems reasonable to assume that if sustainable technologies are to be developed for use on farms, farmer involvement in research and researcher experience is crucial (Gerber, 1992; Ikerd, 1993).

This chapter reports the results of an effort to gather information from small farmers, through the use of structured interviews, on the applicability of using domestic birds as biological control agents for insect pests and weeds. The purpose is to build upon the controlled studies of the previous chapters to gain a greater understanding of the potential roles of domestic birds on small farms and help direct future research efforts.

MATERIALS AND METHODS

Six farmers were selected for interviews based upon their experience with raising free-range domestic birds. The farmers were identified through their expressed interest in research conducted at Kellogg Biological Station in southwestern Michigan, to evaluate the potential of domestic chickens and geese as biological control agents. Five of the six farmers were from southern Michigan, while the sixth was from Ontario (Table 6-1). All of the farmers were practicing certified organic, nonchemical, or low-chemical farming methods and used some means of direct marketing to sell their products. While all of the farms were relatively small, there was considerable diversity in the farm enterprises which included fruits, vegetables, herbs, poultry, and larger livestock. Only two of the six farmers made a full-time income from their farm. The other four stated that their farms provided only supplemental income although some worked the equivalent hours of a full-time job on the farm.

The interview questions were based upon interests and concerns stimulated by observations during research or from discussions with farmers, either at their farms or at the experimental site. The purposes of the interviews were to identify why farmers had free-range domestic birds on their farms; to find out what, if any, biological control benefits they thought the birds provided; and to determine what aspects of bird management they considered to be excessively difficult or problematic (Table 6-2). Five of the six interviews were conducted in person; the sixth (Tony McQuail) was mailed. The interview questions were designed to be objectively analyzed while also allowing growers to describe their unique situations, attitudes, and problems. Thus, the growers were asked to answer nine of the 11 questions with one of five choices, then to elaborate on the answer in their own words. The choices provided a range of answers between "yes" and "no" (yes, probably, maybe/not sure, probably not, *and* no).

For analysis, the multiple choice answers were ranked from 0 to 4 with "no" corresponding to 0 and "yes" to 4 (see bottom of Table 6-2). Means and standard errors of the means were calculated based on the rankings from the six interviews (N=6) for most of the questions. Questions related to geese were not answered by one farmer (Tony McQuail) because he had no experience with them. Thus, those statistics are based upon five interviews (N=5). The interview responses were interpreted based upon these descriptive statistics and on the more elaborate answers provided by each of the farmers.

RESULTS AND DISCUSSION

The farmers were in general agreement that domestic birds, including chickens, geese, and ducks, played important roles on their farms (Fig. 6-1). This was not particularly surprising considering these farmers were selected based of their interest in raising and using domestic birds. However, a wide variety of reasons were given for keeping birds on the farm, including weed management, insect pest management, egg production, food and waste recycling, aesthetics, meat production, income, manure fertilizer, and general enjoyment.

Most of the farmers felt certain that chickens helped in controlling insect pests around their farm. However, only two farmers mentioned specific pests which they had observed the chickens to eat. These included scarab beetle larvae and Colorado potato beetles. Identification of chicken diets through observation is difficult (see chapters 3 and 4) and it is therefore not surprising that the farmers mentioned few specific incidents of pest control by chickens. One farmer did mention the differences in chicken breeds, noting that birds bred for meat production were poor insect predators.

There was considerably less agreement on how effective chickens were as weed control agents, as indicated by the "maybe/not sure" mean rating and the larger standard error (Fig. 6-1, question 4). While three of the growers stated that chickens had potential as weed control agents, the other three were quite doubtful of that prospect. Two reasons were provided to justify the negative responses. First, in comparison to geese, chickens have very little impact on vegetation, particularly when free-ranged at low densities. Second, chickens can do more damage than good by pecking and feeding upon crop plants as well as weeds. In contrast, one of the farmers who responded positively to this question maintained relatively high chicken densities within a small block of fruit trees (several birds per tree) and was quite satisfied with the resulting weed control.

All of the farmers considered geese to be effective weed control agents (Fig. 6-1, question 5), however not all felt that geese were compatible with their operation. Two of the five respondents thought geese, or at least some breeds, were too aggressive to keep on the farm (Fig. 6-1, question 8). One farmer noted that while the geese were good-natured as immatures, they became too aggressive as adults, particularly around children. Other farmers also expressed some concern about geese around young children.

Most of the farmers had experienced at least some problem with bird loss to predators. Two of the growers felt that predator problems on their farms were minimal because of a high level of human activity on the farm and in the landscape around the farm. Those farmers with the most pressure from predators mentioned putting the birds into coops during the night to protect them from dogs, opposums, and raccoons. However, even with such management losses still occurred occasionally. Geese were considered to be less vulnerable than chickens although one grower did mention loosing geese to wandering dogs.

Although all of the farmers stated that they would definitely or probably continue to raise domestic birds on their farm (Fig. 6-1, question 10), there was less agreement on the potential profitability of small-scale production systems. Three of the six growers were actively marketing poultry and considered their enterprises to be relatively successful. One the growers was keeping a chicken flock for egg production and was planning to direct market in the future, though he doubted that it could be profitable based on the high cost of feed and the labor required in maintaining the birds during the winter. Similarly, another farmer, who attempted to use geese in an orchard for vegetation management, stated that labor requirements were too greater because the birds had to be moved frequently to prevent them from damaging the groundcover and digging holes.

Overall, the interviews indicated that these farmers kept domestic birds on their farm for a variety of reasons and although insect pest and weed biological control were commonly considered benefits, the birds were not managed primarily for these purposes. Rather, insect pest and weed control were considered more as fringe benefits than as primary reasons for having the birds. Most of the farmers expressed some interest in finding more efficient and more effective means of managing the birds for biological control. In addition, they were interested in knowing; 1) which crops were compatible with the birds,; 2) which pests the birds were most effective in controlling; 3) which breeds of birds were the best performers; and 4) how many birds would be needed per unit area of crop production for controlling weeds and insect pests. Future research directed at these questions would likely yield the most useful information for addressing small farmer interests and concerns related to the on-farm use of domestic birds as biological control agents.

Table 6-1. General descriptions of the farmers interviewed in this study.

Farmer / Location	Farm Size	Description of Operation
Quinn & Shelly Cumberworth Dimondale, Michigan	16 ha	part-time, nonchemical, poultry, pork, beef, potatoes, and squash
Markus Held Mason, Michigan	1 ha	part-time, low-chemical, apple orchard
Jane Bush Charlotte, Michigan	7 ha	full-time, certified organic, apple orchard, herbs
Bruce Schultz Kalamazoo, Michigan	2 ha	part-time, certified organic, fruit and vegetable
Pauline Lee Williamston, Michigan	1ha	part-time, fruit and vegetable
Tony McQuail Lucknow, Ontario	26 ha	full-time apples, sheep, poultry

Table 6-2. Questions used in interviews with farmers on role of domestic birds on small farms as biological control agents.

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1) Do you feel that free-range domestic birds have a role on your farm?*

2) What is/are the role(s)?

3) Do you think that free-range chickens have potential as insect pest biological control agents?*

4) Do you think that free-range chickens have potential as weed biological control agents?*

5) Do you think that free-range geese have potential as weed biological control agents?*

6) Do you feel that predators are a serious problem for free-ranging birds on your farm?*

7) Do you feel that the labor required in free-ranging domestic birds is too much?*

8) Do you think that geese are too aggressive to use as weeders?*

9) Do you think that raising free-range domestic birds on a small scale can be a profitable enterprise?*

10) Will you (continue to) raise free-range domestic birds on your farm?*

11) Why? Why not?

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*the following multiple choice responses were used with the corresponding ranks: no, (0); probably not (1); maybe/not sure, (2); probably, (3); yes, (4).

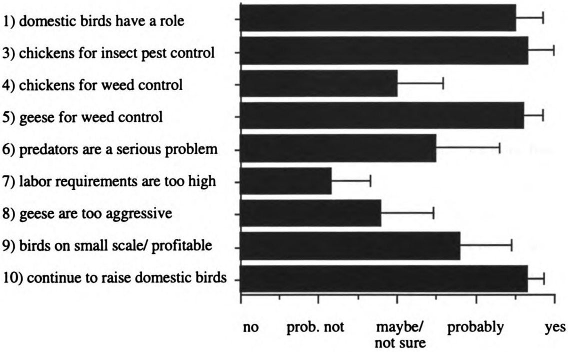

Figure 6-1. Mean (+SEM) responses by farmers to interview questions 1 and 3 -10. The original questions are summarized into statements (see entire questions in Table 1) and the statistics were calculated based on ranks (see text).

CHAPTER 7

SUMMARY & CONCLUSIONS

The overall objective of this research was to evaluate the potential for using free-range chickens and geese as biological control agents for insect pests and weeds. In 1993, the compatibility of the birds was assessed in a nonchemical apple orchard with intercropped potatoes, located at the Kellogg Biological Station, Hickory Corners, MI. The compatibility assessment was based primarily on visual observations of the birds' behavior. This included their diurnal activity patterns, their tendency to disperse from the coop and water source, and most importantly, their feeding habits.

Based upon structured observations, chickens were found to be omnivorous, feeding on insect pests, beneficial insects, weeds, and in some instances, the crops. They were found to feed on two important insect pests, Japanese beetle and Colorado potato beetle, however there was noticable inter-bird variability in the willingness to feed on the latter pest. Although chickens fed upon vegetation, their effects on weed biomass were small in comparison to the geese. The tendency of the chickens to feed on unearthed potato tubers was generally not a problem during this study because the potatoes were hilled, providing protection from the scatching and pecking which typify chicken foraging. However in later studies in which the potatoes were not hilled, chicken damage to the tubers was a common occurrence. One other problem during this study was the loss of chickens to predators. Loss to predators is probably the most obvious drawback to free-ranging chickens. Because the birds were put into coops at night, the most serious losses to predators were due to hawks, which hunt in the day.

The geese were found to be solely herbivorous. They were observed to feed less often than the chickens but consumed large amounts of vegetation while foraging. The most preferred plants included common dandelion, common plantain, and grasses, but a variety of other species were also consumed. Geese required large quantities of water and spent more time than chickens close to the coop and water source. Geese occasionally fed upon unearthed potato tubers but did not feed on potato or apple foliage. Weed biomass comparisons clearly demonstrated that geese had potential as weed control agents. Furthermore, the geese, which grew faster and larger than the chickens, were less susceptible to hawk predation.

The compatibility study suggested that chickens might have an effect on at least two pests (Japanese beetle and Colorado potato beetle), and possibly others, which spend part of their life cycle on or near the soil surface. By contrast, the geese showed clear promise as weed control agents. Therefore, in 1994 and 1995, the effectiveness of free-range chickens and geese as biological control agents of insect pests and weeds was studied. The ultimate goal was to determine if the presence of free-range chickens or geese provided any crop protection benefits. The effects of the birds on the abundance of four insect pests (plum curculio, apple maggot, Japanese beetle, and Colorado potato beetle), weed growth, potato growth and yield, and apple damage and yield were measured. The direct and indirect ecological effects of the birds, as determined in this study, and the compatibility study, are presented in Figure 7-1.

The feeding activities of the geese resulted in clear reductions in weed growth which led to increased potato plant growth. In 1994, potato tuber yields in plots weeded by geese were substantially higher than those of control plots. However, in 1995, no increase in potato yields were found due to a disease infestation which affected all treatments. Interestingly, weeding by the geese also resulted in greater Colorado potato beetle abundance. Presumably, the presence of large potato plants in a relatively weed-free environment encouraged the colonization and survival of this pest species. Other published research supports this explanation.

A surprising, but consistent, finding was the reduction in plum curculio damage due to the presence of geese. In 1994 and 1995, the percentage of fruit with plum curculio damage in plots with geese was less than in control plots. This resulted in a corresponding increase in the percentage of undamaged or pest-free fruit. The compatability study suggested that the effects of the geese in reducing weeds could result in higher apple fruit yields, however, harvest weights in the plots with geese were not statistically greater than those of the controls in 1994 or 1995.

The results of the compatibility study indicated that the chickens could have some effect on weed growth but that densities would have to be increased substantially to achieve adequate control. The chickens showed more potential, however, as insect control agents. Insect pest abundance patterns in 1994 and 1995 indicated that the chickens had an effect on Japanese beetle. Furthermore, analyses of chicken gut contents showed that Japanese beetle was a common prey. However, fruit damage assessments showed no differences between the plots with chickens and those without. There are several possible explanations for these contradictory findings: 1) the small plot size allowed for rapid colonization during the period of time between chicken removal from the plots and apple harvest; 2) severely damaged fruit tended to drop from trees resulting in an underestimation of damage in the plots without chickens; and/or 3) wasp damage was mistaken for Japanese beetle damage, causing an overestimation of Japanese beetle damage in some plots.

In 1994, plum curculio damage in the plots with chickens was intermediate between the control and goose treatment but did not differ statistically from either of them. If chickens did feed on plum curculio it was probably a relatively rare occurrence and chickens could not be counted on to provide control for this pest. Unfortunately, the effect of chickens on Colorado potato beetle could not be adequately assessed in this study because of the confounding effects of weeds on the abundance of this pest. Further research is needed in this area, particularly to address the effects of intra- and inter-breed variability on the tendency of chickens to feed on this pest.

The effects of free-range chickens and geese on beneficial soil invertebrates was assessed with two studies. In 1993, the effects on epigeic predators, including ground beetles, rove beetles, spiders, and harvestmen, were measured in a pitfall trapping study. Neither bird species was found to have an effect on the activity of ground beetles or rove beetles, however, the presence of chickens and geese resulted in a reduction in spider and harvestmen activity. Although the mechanism for these predator reductions were not determined, these finding suggest that diurnally-active predators were negatively influenced by the birds while nocturnally-active predators were not. Presumably, the predator reductions in the chicken plots were due to predation because chickens were found to feed on a variety of beneficial arthropods including ground beetles, rove beetles, and spiders. The effect of geese was apparently indirect, likely resulting from the reduction in vegetation or from habitat disturbance. Although the presence of the birds did result in a reduction in predator activity, their influences were relatively minor in comparison to the effects of intercropping potatoes, which resulted in greater reductions in epigeic predator activity.

In 1995, soil sampling in areas with and without birds showed no differences in earthworm abundance. Soil analyses showed that earthworm abundance was most highly correlated with soil organic matter and the distance from an untilled, old field located 25m east of the orchard. After three summers of free-ranging chickens and geese there were no detectable increases in soil organic matter. Therefore, increases in earthworm abundance should not have been expected. However, the results also suggest that the activities of the birds, particularly chicken predation, did not have an important negative influence on earthworm abundance, at least at the stocking densities used in this study.

In 1995, six small farmers, with experience in free-ranging domestic birds, were interviewed to gain some insight into the feasibility of using domestic birds for biological control and to provide direction for future research. Nearly all of the farmers believed that chickens and geese had potential as insect pest and weed biological control agents, however, none kept birds solely or primarily for that purpose. Most of the farmers expressed interest in finding efficient and effective management systems for small scale bird management which would reduce losses to predators, purchased feed inputs, and labor requirements. Suggested future research included: assessing the compatibility of different crops with chickens and geese, determining which insect pests can be managed with chickens or other domestic fowl, comparing the effectiveness of different bird species and breeds for biological control, and estimating bird stocking rates for particular management needs.

Overall, the findings of this study indicate that there are possibilities for integrating domestic birds into ecologically-based agricultural systems for biological pest management. The geese, in particular, demonstrated clear potential as weed control agents. Although not suited for all types of systems, geese show the greatest potential in diversified horticultural operations, especially when agrochemicals, such as herbicides, are not used. Production systems comprised of perennial shrubs and trees are most compatible with geese because they provide shade for the birds and are relatively immune to feeding and trampling damage. However, annual vegetables and herbs can also be compatible with weeder geese, but may require additional care, such as trellising or staking, to prevent damage. The indirect effects of geese on insect pests may be positive, negative, or absent. Further research is needed to evaluate how disturbance by foraging geese affects insect pests and their damage.

One factor which may limit the use of weeder geese is the perception that they are too aggressive. Although the threat by domestic geese is commonly overstated, farmers and gardeners who are unfamiliar with these birds may be intimidated by their defensive displays. Education and experience with geese may be needed to counter this perception.

This study provides relatively little support for integrating free-range chickens into agroecosystems for insect pest or weed control. Although chickens did consume insects and weeds in this study, their impact did not result in any real detectible crop protection benefits. The results did suggest that chickens may have some potential in controlling Japanese beetles, especially if used in conjunction with lures. However, achieving any measurable level of insect pest or weed control with free-range chickens would require much higher stocking rates than were used in this study. Another factor which can limit the applicability of free-range chickens in pest management is loss to predators. Although coops and electric fencing can provide some protection, losses can still be high in rural areas with little human presence. In situations in which high stocking rates can be achieved and predator pressure is minimal, free-range chickens may have some potential to play a role in biological pest management.

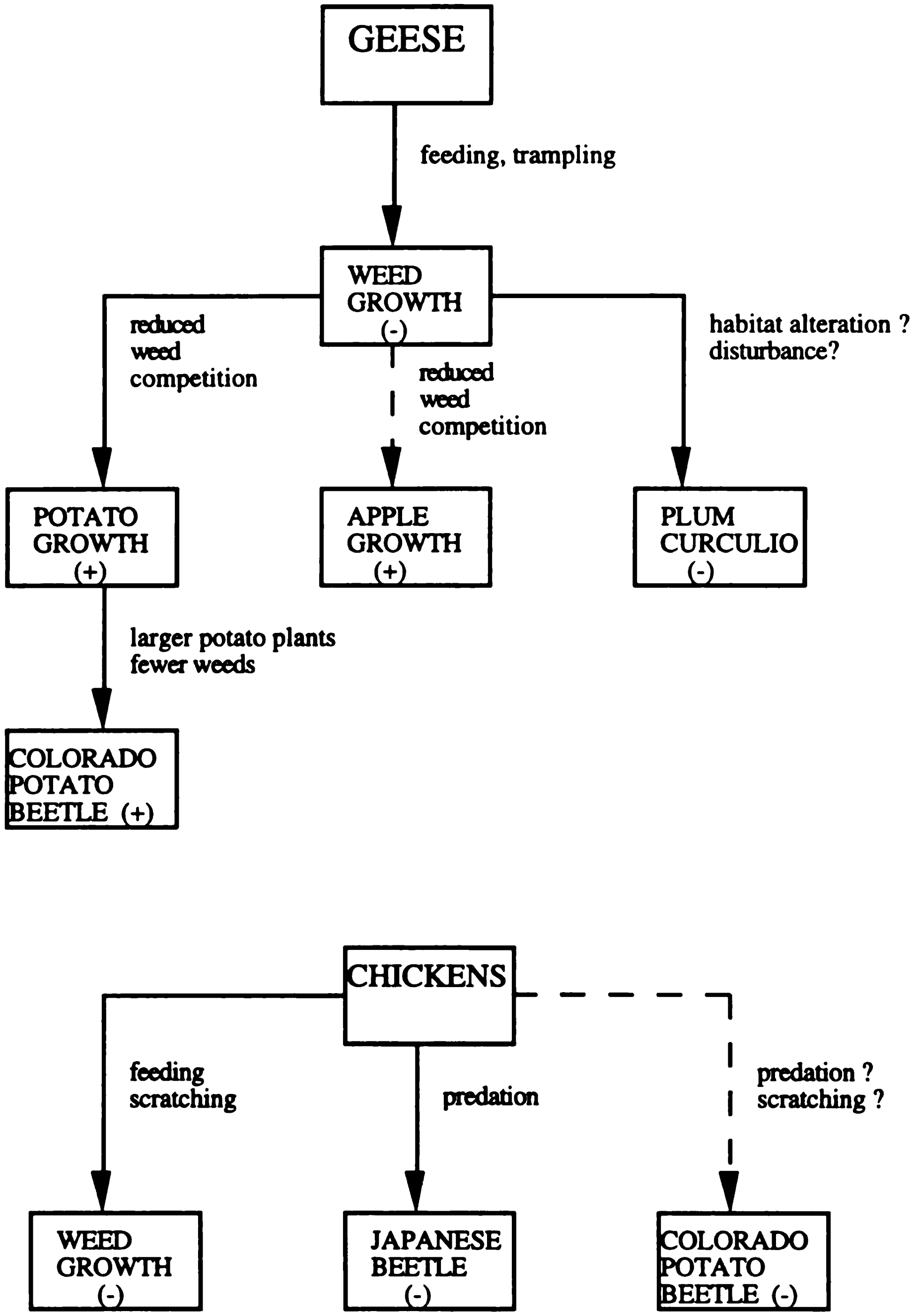

Figure 7-1. Diagram summarizing the detected (solid arrows) and suggested (dashed arrows) ecological effects of geese and chickens in the experimental agroecosystem. The effects are indicated as positive (+) or negative (-) for each of the measured variables.

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