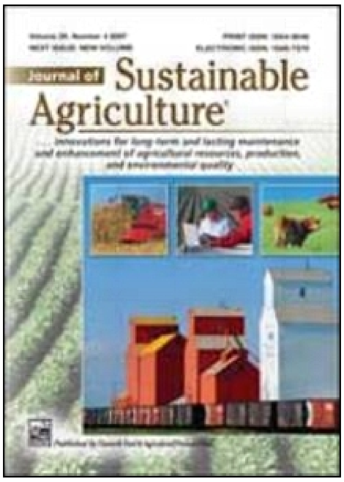

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Integrated Crop/Livestock Agriculture in the United States: A Review

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Integrated Crop/Livestock Agriculture in the United States: A Review

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U.S. agriculture has become increasingly specialized over the last century with attendant benefits to food production and affordability. At the same time, specialized agricultural production has led to concerns for animal welfare, environmental degradation, and loss of biodiversity. An alternative to specialized agriculture is the integration of crops and livestock at the farm scale. Integrated crop/livestock agriculture could improve soil quality, increase yield, produce a diversity of foods, augment pollinator populations, aid pest management, and improve land use efficiency. Crop/livestock agriculture is not without challenges, however, as farmers must confront a history of specialization in agriculture along with loss of animal husbandry knowledge, erosion of genetic diversity, limited meat processing infrastructure, a regulatory framework more suited to specialization, and challenges inherent to animal agriculture.

KEYWORDS *integrated agriculture, crop/livestock, animals, pasture, agroecology*

INTRODUCTION

Driven by economies of scale and enabling technologies such as milking machines and chemical fertilizers, farms have grown increasing specialized over the last century (MacDonald and McBride, 2009). While specialization has resulted in low food prices and increased accessibility of formerly expensive foods such as meat, it has also led to societal and environmental costs such as air pollution from feedlots, contamination of waterways

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with sediment, and problematic concentrations of manure in localized areas (MacDonald and McBride, 2009; Matson et al., 1997). One alternative to specialization is integrated crop/livestock agriculture, the practice of managing crops and animals on a single farm. Studies and reviews have shown that integrated agriculture may enhance crop production and farm economy (Clark, 2004; Hanson and Franzluebbers, 2008; Hendrickson et al., 2008a, 2008b; Lantinga et al., 2004; Russelle et al., 2007; Tanaka et al., 2005). Integrated crop/livestock systems are farms where animals and crops are raised with the goal of utilizing the products of one for the growth of the other. For example, animal waste can be applied to fields for crop nutrient acquisition, forage crops can be cultivated for animal consumption, and livestock can be utilized to manage invertebrate pests of crops. Following Clark's (2004) seminal review on integrated agriculture, this paper describes the history of the separation of crops and livestock[1] in the agricultural landscape of the United States and discusses the challenges and benefits of integration, reviewing studies published subsequent to Clark's paper. This paper also provides a typology of integrated farms and discusses issues relevant to integrated agriculture, such as policy, land use efficiency, and animal genetics.

THE DETAILS OF INTEGRATION

Animals

Most studies of integrated agriculture describe cattle as the integrated species (Table 1). Historical management practices, however, indicate that many other species could be included as the livestock component for integrated agricultural production. These include but are not restricted to turkey, chicken, duck, swine, cattle, rabbit, sheep, goats, horses, ostriches, llamas,

TABLE 1 Studies of Integrated Agriculture Showing a Trend of Cattle as Primary Animal Type Studied

Crops	Livestock	State	Source
Cotton	Cattle	Texas	(Acosta-Martinez et al., 2004; Allen et al., 2005)
Feed crops	Cattle	North Dakota	(Anderson and Schatz, 2003)
Sweet corn, field peas, watermelon	Cattle	Alabama	(Balkcom et al., 2010)
Cotton	Cattle	Georgia	(Hill et al., 2004)
Corn	Cattle	Illinois	(Maughan et al., 2009)
Feed crops	Cattle	Wisconsin	(Posner et al., 1995)
Grain	Cattle	Illinois	(Sulc and Tracy, 2007)
Grain	Cattle	North Dakota	(Tanaka et al., 2005)
Taro	Ducks	Hawaii	(Ako and Tamaru, 2007)
Apples, potatoes	Poultry	Michigan	(Clark and Gage, 1996)
Mixed vegetables	Sheep and poultry	Massachusetts	(Lowy, 2009)

bison, and elk. Selection of animal type depends on the desired goals of the growers. For example, poultry are often selected for weed/pest control (Ako and Tamaru, 2007; Clark and Gage, 1996; Tanaka et al., 2008); ruminants can convert forage to fertilizing manure (Weller and Bowling, 2007); and bison, elk, or goats may be desired for specialty markets.

Typology of Integrated Farms

Russelle et al. (2007) describe the difference between integration at regional and farm scales. In *regional integration,* specialized livestock operations and crop-only farms co-exist and form relationships to exchange goods such as manure and crop residue. At the regional level there is much less actual integration on each individual farm. This paper is concerned with the *farm scale,* or within-farm crop/livestock integration. The following typology delineates farms based on the temporal and spatial combination of animals and crops. In all types, animals feed on pasture plants, harvested and dried forage, crop residue, purchased feed, or a combination.

1. *Spatially separated.* In this type of integrated agriculture, animals are maintained in a separate part of the farm such as a permanent pasture, corral, or barn. Permanent pasture is located on a part of the farm that is never cropped, and supplemental feed and forage crops can be grown on other areas of the farm. If animals are housed in a corral or barn, manure can easily be gathered for field application to crop and forage fields, or it can be composted. See, for example, Powell et al. (2002) and Ghebremichael et al. (2009).
2. *Rotational.* Animals and crops occupy the same field but at different times. In this scenario, a field is alternately dedicated to crop production and annual or perennial forage. In rotational systems, excreta are deposited by the animal and incorporated into the soil via animal activity such as pecking or trampling, invertebrate movement, rainfall, or preplanting tillage. See, for example, Balkcom et al. (2010) and Maughan et al. (2009).
3. *Fully combined.* Animals graze underneath or in between crops. This type of integrated agriculture is common for orchards or vineyards with crops too tall or unpalatable for animal foraging. Fully combined systems may also exist where animals are integrated post-harvest to feed on crop residue or pre-fruiting to feed on pests. See, for example, Clark and Gage (1996) and Ako and Tamaru (2007).

THE DIS-INTEGRATION OF AGRICULTURE

Integrated agriculture is not a new phenomenon. Before the advent of industrial agriculture, agroecosystem function in farming systems was based on complexity and diversity, where the integration of crops and livestock was the norm (Russelle et al., 2007). Livestock were an integral part of crop farms in the U.S. and were used for production of food and fiber, powering farm machinery, and soil fertilization. However, over the past century, food systems have tended towards industrialization and specialization, creating a food system predicated on economies of scale, specialization, and cheap labor (Clark, 2004; FitzSimmons, 1986; Sulc and Tracy, 2007). Dis-integration of crops and livestock was spurred by a convergence of policy and technology changes that directed agriculture towards specialization (Franzluebbers, 2007; Sulc and Tracy, 2007), as well as the growing availability of cheap fossil fuels (Sulc and Tracy, 2007). The first driver of crop/livestock separation was likely the improvement of tractor design in the 1920s, when growers began to select tractors over animal-pulled plows, decreasing the need for work animals on the farm (Hendrickson et al., 2008a). In the following decade the U.S. government passed the first Agricultural Adjustment Act of 1933, intended to stimulate rural economies following the Great Depression (Bowers et al., 1984). The act created price support for certain designated commodities: milk, cattle, swine, wheat, cotton, corn, rice, rye, flax, barley, sorghum, peanuts, and tobacco (Bowers et al., 1984). This policy may have promoted specialization by mitigating risks for those particular commodities. During the same time period, synthetic fertilizers were growing in popularity and accessibility. Growers who specialized in crop production could switch from animal manure to petroleum-based soil fertilization (Clark, 2004).

CHALLENGES OF INTEGRATING LIVESTOCK INTO CROP AGRICULTURE

Growers seeking to re-integrate in present times face this history of specialization along with a suite of challenges such as 1) confronting a loss of animal husbandry knowledge; 2) regulations designed for specialized agroecosystems; 3) erosion of animal genetic diversity; and 4) limited meat processing infrastructure for small-scale production.

Lost Knowledge

Integration of crops and livestock fell out of wide practice after the 1920s, and it has become a lost art to many farmers. Crop farmers often do not have training in animal husbandry, and integrated agriculture requires proficiency with both crops and livestock (Clark, 2004; Russelle et al., 2007). In particular, younger farmers often do not have experience, training, or a background of working with animals. In California, for example, the average age of a rancher is 59 (Brunson and Huntsinger, 2008). Would-be integrated farmers with a crop background may be challenged by animal care and health, selection of feed and forage, butchering and processing supply chains, preparation of products such as cheese and yogurt, handling items such as eggs to prevent pathogen contamination, and other regulations specific to animals. These are all skills and areas of knowledge that must be acquired by potential integrated farmers in addition to the years of apprenticing or coursework already committed to learning vegetable and/or fruit cultivation practices. Small-scale organic crop farmers, in particular, are often already managing complex rotational mixed annual systems, and adding animals can be a logistical deterrent.

Regulations

Food systems policy and regulation in the United States have co-evolved with specialization. As such, agriculture-related policy and regulations are at times at odds with the realities of integrated agriculture. The California Leafy Green Marketing Agreement (LGMA) illustrates this issue. In 2006, an outbreak of *E. coli 0157:H7* occurred in bagged spinach originating in California. The LGMA was an industry response to the outbreak and proposed a series of management practices intended to mitigate *E. coli 0157:H* in leafy greens. Although the source of the pathogen was impossible to determine, livestock and wild animals were targeted as potential hosts, and actions were taken against the mixing of animals and crops under the LGMA (Beretti and Stuart, 2008). These comprehensive management guidelines suggested, among other practices, vegetation removal to reduce animal encroachment, fencing around leafy greens fields, and separation of livestock and crops (LGMA, 2010). The LGMA required that the 100 food handling intermediaries who were signatories to the agreement and represent 99% of leafy green production in California only purchase from growers who adhered to the suggested management practices (Beretti and Stuart, 2008). Other authors have written at length about conservation issues caused by the LGMA such as removal of hedgerows and contamination of waterways (Beretti and Stuart, 2008; Stuart, 2010). These regulations also posed a challenge to integrated agriculture due a requirement that one year must lapse between raw manure application and planting of leafy greens (LGMA, 2010). Regulations such as these make it difficult for growers to integrate in any way other than keeping crops and animals spatially separated. Participation in the LGMA is voluntary, and many integrated farmers in California are not participants, although this restricts the range of buyers to whom they can sell leafy greens.

Pasture-hardy Animal Breeds

In integrated agroecosystems, animals are generally reared on pasture with the possible exception of *spatially separated* systems. Access to breeds of animals that are suitable for pasture is key to integrated agriculture. Breeding programs for industrial agriculture have drastically affected the genetic make-up of farm animals since the advent of confined animal feeding operations because livestock are selected for efficiency and productivity rather than hardiness (Mendelsohn, 2003). As an example, in the last 30 years, meat poultry fattening duration has been shortened on average from 50 to 34 days (Ristic et al., 2004). In the U.S., increasing industrialization of the livestock industry correlates with a decreasing number of livestock species (Dubeuf and Boyazoglu, 2009). Although conservation of livestock breeds is the topic of many studies, the multiple effects of this loss in diversity are not entirely understood (Cardellino and Boyazoglu, 2009). It is known that breeding animals solely for productivity can weaken their health. For example, poultry breeding innovations have created broilers with impressive weight gain capabilities but an attendant decrease in resistance to pathogens, decrease in reproduction, and muscular degeneration (Nardone and Valfre, 1999). Holstein-Friesian dairy cows that have been bred for high milk yield have lower survival and body weight than traditional breeds of dairy cows in pasture-based systems. (Dillon et al., 2003).

Although less resistant and resilient breeds may threaten the livelihoods of livestock managers, it is common practice to rear less hardy animals. This paradox has been created by the complex economic, political, and socio-cultural structures of the food system. From an economic standpoint, homogenization can be partially explained by grain subsidies and affordable technology (Mendelsohn, 2003). Grain subsidies have artificially reduced the price of grain such that it is more profitable to feed animals on grain in an industrial system than to graze animals on pasture. Pasture is likely to be more heterogeneous than feedlots due to the semi-wild nature of grasslands, whereas industrial feeding operations tend to converge on one mode of production with few "wild" or stochastic characteristics. Confined animal operations tend to be less variable than pasture-based systems because certain environmental factors, such as wind, sun exposure, and precipitation, can be mitigated. As such, a need is created in industrial systems for one phenotype, while in pasture systems it may be more advantageous to seek heritage livestock breeds, although there is a lack of research on this subject (Fanatico et al., 2005). When animals that have been bred for industrial agriculture are managed on pasture, they may be more susceptible to disease and environmental stress than animals that have been bred for pasture-based systems, meaning that access to pasture-appropriate animal varieties can be a prerequisite to successful integrated farming.

Small-scale Meat Processing Infrastructure

Diverse farms are not as vertically integrated with processing facilities as are the production centers of industrial livestock agriculture (Hinrichs and

Welsh, 2003). Without a relationship to slaughter and processing facilities, integrated farms face challenges to animal product finishing. Processing a small quantity of animal products can pose a serious hindrance to would-be integrated growers due to a paucity of small-scale processing facilities in the U.S. (Gwin, 2009; USDA, 2010). The lack of small-scale facilities has been traced to an unwieldy regulatory framework for butchering and processing (Osrtom, 2009), vertical and horizontal integration within the industry (Nguyen and Ollinger, 2006), labor-intensive smaller operations (Ollinger et al., 2004), and cost of byproduct disposal (Holz-Clause, 2004). Many of the costs associated with a meat processing facility fall evenly across scale, making real costs higher for small-scale plants. Producers cite the lack of infrastructure for small-scale processing as a major deterrent when considering entering the alternative meat market (Gwin, 2009). Overcoming this barrier recently became a priority for the United States Department of Agriculture who sponsored a study to identify regions of the U.S. where a high number of small-scale meat producers corresponded with a low number of processing facilities (USDA, 2010). With demand for small-scale meat production on the rise and a supportive federal agenda, many of the above-described barriers may change in the next decade.

BENEFITS OF INTEGRATING LIVESTOCK INTO CROP AGRICULTURE

Despite the challenges to re-integrating animals into agriculture in the U.S., in recent years there has been a resurgent interest in integrated crop/livestock farming from researchers and the popular media (Pollan, 2006; Tanaka et al., 2008). Integrated crop/livestock agriculture is recognized for its capacity to 1) fertilize soil with an on-farm input, livestock manure; 2) encourage and allow growers to maintain semi-permanent pasture fields, which can improve soil quality; 3) increase crop yield; 4) enhance on-farm biodiversity and related ecosystem services such as pollination, and weed/pest management; 5) enhance economic gains to growers; and 6) confer social benefits to growers and communities.

Animals, Manure, and Soil Quality Management

Integrating animals into crop production may provide a cost-effective on-farm source of soil fertility in the form of animal manure. Animals recycle nutrients contained in forage and feed and make them available in their excreta, thus becoming part of the on-farm nutrient cycle. Relative quantities of nitrogen, phosphorus, and potassium vary considerably among species, depending on the foraging preferences of the animal as well as the supplemental feed the grower chooses to provide (Watson et al., 2005). Animal excreta can be applied in many ways in integrated systems, via deposition during free-range grazing or through application of raw or composted manure collected from animal corrals and barns. Excreta from rotationally managed animals is deposited directly into pasture fields that are later planted with crops or have perennial species growing in them. Rotational systems have the potential to contribute significantly to soil nutrition and to plant health without the detrimental pollution from nutrient leaching that can occur from applying manure to a field because excreta are deposited more gradually than when manure is applied by the farmer (Berry et al., 2003; Clark, 2004). However, land application of manure can also cause environmental contamination. For example, phosphorus runoff from manured fields can exacerbate eutrophication of nearby waterways (Sharpley and Moyer, 2000), suggesting that growers should manage manure applications to meet the growth needs of crops but use caution not to oversupply nutrients such as phosphorus or nitrogen.

When properly managed, animal manure can provide the soil organic matter, macronutrient, and trace mineral needs of the soil microbial community and crops being grown (Russelle et al., 2007) and potentially decrease the need for external inputs of purchased fertilizer. Several studies have found positive changes to soil quality under integrated management (Table 2). A five-year study of an integrated beef cattle and cotton system in Texas found higher organic carbon, soil aggregate stability, soil microbial biomass carbon, soil microbial biomass nitrogen, and soil enzyme activity in integrated forage/cotton plots than continuous cotton plots (Acosta-Martinez et al., 2004). Another study found higher total nitrogen, total organic carbon, and water aggregate stability in cattle forage/corn integrated plots than in continuous corn plots. Finally, in a cooperative farmer/extension study conducted in Massachusetts, meat chickens and sheep were integrated into pasture planted on fallow crop fields (Lowy, 2009). Soil tests conducted

TABLE 2 Soil Quality Research Studies Comparing Integrated Systems with Crop Monocultures

Agroecosystems	Indicators studied. Positive change indicated by (+), negative change by (−), and neutral results by (0)	Source
Integrated beef cattle and cotton five-year study	Total nitrogen (0), organic carbon (+), soil aggregate stability (+), soil microbial biomass carbon (+), soil microbial biomass N (+), soil enzyme activity (+)	(Acosta-Martinez et al., 2004)
Cattle grazing winter cover crop followed by corn	Total nitrogen (+), total organic carbon (+), water aggregate stability (+), soil penetration resistance (−)	(Maughan et al., 2009)
Sheep and broilers grazing for five months during spring-fall growing season	Nitrogen (+), Phosphorus (+), Potassium (+), Calcium (+), Magnesium (+), CEC (+), Organic Matter (+)	(Lowy, 2009)

after five months showed higher levels of nitrogen, phosphorus, potassium, calcium, magnesium, cation exchange capacity, and organic matter in the treatment (grazed pasture) vs. the control (ungrazed pasture) (Lowy, 2009).

Caution must be used when interpreting these studies, however, as an increase in phosphorus is only a benefit when levels are not likely to contribute to environmental pollution. These same studies also found neutral benefits to total nitrogen (Acosta-Martinez et al., 2004) and negative impacts to soil penetration resistance (Maughan et al., 2009). Integrated agriculture is not a panacea for soil degradation, and management must be tailored to manage for the known impacts of livestock such as labile nitrogen or high phosphorus levels, which can lead to pollution (Sharpley and Moyer, 2000) and imbalanced soil fertility (Watson et al., 2005). In the case of soil penetration resistance, other studies have found negative impacts by cattle to soil compaction (Balkcom et al., 2010; Maughan et al., 2009). This is, however, a problem that can be corrected with crop-specific tillage (Balkcom et al., 2010), again emphasizing that integrated agriculture instigates changes in the soil ecosystem as compared to continuous cropping. These changes are only positive when coupled with locally appropriate management.

Using Pasture to Enhance Soil Quality

In addition to manure, pasture itself can enhance soil quality in integrated systems due to the deep and abundant root systems of pasture plant species and the ecological functions of plants such as nitrogen fixers (Clark, 2004). Maintaining a field with a pasture mix of grass and legume species is functionally similar to but may be less expensive than cultivating a cover crop because the sale of meat and animal byproducts may allow the field to pay for itself or generate a profit (Clark, 2004). Pasture is often planted with deep-rooting Poaceae grass species (e.g., *Dactylis spp., Lolium spp., Secale spp., and Sorghum spp.)* and nitrogen-fixing Fabaceae species (e.g., *Lotus spp., Medicago spp., Trifolium spp., and Vicia spp.*). These same plant families form the cornerstone of most cover crop plantings. Seeded pasture can contribute to soil quality through nitrogen fixation, increased soil organic matter and carbon storage, providing both ecosystem services and improving agricultural soil (Clark, 2004 and see Table 2). For example, one study of an integrated corn-pasture system in Illinois found higher total nitrogen, total carbon, and water aggregate stability than in the system continuously cropped with corn (Maughan et al., 2009). Additionally, pasture is tilled less frequently than crop fields, and studies have found that reduced tillage greatly improves physical soil quality (Cannell and Hawes, 1994). With animals on pasture producing marketable products, integrated agriculture becomes an economically viable way to maintain a multi-year low-till cover crop (Clark, 2004).

Yield

Soil quality enhancement in integrated systems is also associated with increased yield in some studies. A 4-year 2009 study conducted in Illinois assessed yield and soil quality under a cattle/corn (*Zea mays* L.) integrated system in comparison to a system continuously cropped with corn (Maughan et al., 2009). The study found significantly higher corn yield in the system where cattle grazed a winter cover crop subsequently planted with corn than in the continuously cropped system (11.5 Mg ha^{-1} vs. 10.8 Mg ha^{-1}). Likewise, 67% of respondents in a 253-participant survey from Manitoba and Saskatchewan, Canada reported greater yields in crops following forage rotations (Entz et al., 1995).

Biodiversity

Integrated farms have been shown to have higher species richness than crop- only or animal-only farms (Funes-Monzote, 2008). This is due, of course, to the simple fact that integrating animals adds at least one more species to a specialized farm. Other less obvious increases to biodiversity are created by the addition of pasture to a crop farm, which can augment insect and wild animal populations (Brunson and Huntsinger, 2008; Langer, 2001). Pasture is more like wild habitat than frequently tilled arable cropland, and organisms that cannot survive in intensively cultivated fields often thrive in pasture. Bees native to the U.S., in particular, are found in higher abundance in agricultural landscapes that include pasture than in areas of tilled crop agriculture alone (Morandin et al., 2007). Native bees can replace honeybees in some crop systems or increase honeybee efficiency in others (Greenleaf and Kremen, 2006; Winfree et al., 2007), but they have more complicated requirements than honeybees, which are commonly raised in a portable hive boxes. In order to thrive, native bees need three things: consistent floral forage, nesting sites, and safe haven from pesticides. Pasture has the potential to offer all of these and allow native bee colonization, depending on management. Animals change the pasture in which they graze via trampling and consuming vegetation. Vegetation consumption releases forbs from the direct and indirect effects of invasive plant growth and thatch production, allowing forbs to grow and flower improving pollen and nectar foraging possibilities (Hayes, 2002). Trampling opens up bare space and compacts the soil. With proper management, bare spaces can become nesting sites for ground-nesting native pollinators if livestock are excluded from those zones subsequent to grazing them to prevent further trampling (Carvell, 2002). Finally, pasture is a pesticide-free environment in which bees can exist (Sjodin et al., 2008).

Weed Management

Integrated systems can be used to manage weed and pest populations both by the direct effects of livestock feeding habits and by the indirect effects of pasture on weed and pest populations. Poultry, for example, eat weeds in both seed and herb form and can be used either before crops are planted to clean a field or during crop growth as herb grazers. In a study on free-range poultry in diversified apple/potato agroecosystems, geese were found to directly reduce weed abundance, which in turn correlated to significantly higher potato yield (Clark and Gage, 1996).

In addition to the direct effects of livestock foraging on weed abundances in integrated systems, weeds are suppressed indirectly through the effect of crops planted for foraging. Several studies conducted in Canada in the 1990s found that forage plants were as effective as chemical herbicides for control of wild oat (*Avena fatua* L.) weeds (Schoofs and Entz, 2000). Forage species included winter triticale (*Triticosecale*), spring triticale, spring/winter triticale intercrop, alfalfa hay (*Medicago sativa* L.), sorghum-sudangrass (*Sorghum bicolor* [L.] *Moench x Sorghum sudanese [Piper]*), fall rye (*Secale cereale* L.) grain crop, and a sweet clover (*Melilotis officinalis* L.)/winter triticale double crop. Forage crops can decrease weed populations through occupation of bare ground, allelopathic interactions, and competition. A large-scale study conducted in 1995 surveyed 253 farmers in Manitoba and Saskatchewan known to integrate forages with their crop rotations (Entz et al., 1995). Eighty-three percent of the survey participants reported fewer weeds following the forage rotation. Weeds controlled were wild oat (*Avena fatua* L.), Canada thistle (*Cirsium arvensis* L.), wild mustard (*Sinapis arvensis* L.), and green foxtail (*Setaria viridis* (L.) *Beauv.*), all notably noxious weeds in that region of Canada. In this way, integrated agriculture can decrease the need for purchased herbicides.

Pest Management

In terms of arthropod and mollusk pest control, some livestock, such as poultry feed directly on pest species while others, such as cattle, can modify pest habitat enough to mitigate populations. Animal-instigated pest management can allow farmers to decrease the need for external inputs of pesticides or other pest-control measures. A 6-year extension research study in Hawaii assessed control of the apple snail (*Pomacea canaliculata)*, a devastating pest of the staple taro (*Colocasia esculenta).* Use of carnivorous ducks as apple snail predators reduced snail populations to manageable sizes (Ako and Tamaru, 2007). In another study, free-range chickens were found to significantly reduce Japanese beetle populations through predation (Clark and Gage, 1996). Another series of studies from the inter-mountain West found that cattle grazing could be managed to indirectly reduce pest grasshopper outbreaks (O'Neill et al., 2010; O'Neill et al., 2003). Cattle compete with grasshoppers for food and alter vegetation, soil, and microclimate making conditions inhospitable to grasshoppers (O'Neill et al., 2003). Like weed management, pasture planted for livestock forage can indirectly control pest populations. A study from Denmark found that a clover/grass field functioned as a reservoir for parasitoid predators (*Aphidius* spp. and *Praon* spp.) of cereal aphids (*Sitobion avenae* (F.)) in adjacent crop fields (Langer, 2001).

Land Use Efficiency and Profitability

Land use efficiency is the practice of layering enterprises or crop types to generate more food or income than a field otherwise would if managed for a single enterprise or a single crop (Gliessman, 2007). Integration of animals into a farm can increase land-use efficiency beyond that of crop-only farms. Animals may facilitate crop growth through manure deposition, weed control, and reduced pest numbers as described above. The pasture portion of the farm may support beneficial insect populations that pollinate crops and increase yield. The crop portion of the farm may be used to provide feed for the animals through the conversion of the portion of crop residue un-useable for humans into food products (meat, milk, cheese, eggs). One study from Cuba found that integrated dairy/crop farms had a higher land use efficiency than non-integrated farms, meaning that overall food production from the same amount of land was higher on the integrated farms (Funes-Monzote, 2008). A study conducted in Georgia integrated cattle during winter months to graze cover crop in fields planted with peanuts and/or cotton during the growing season (Franzluebbers, 2007; Hill et al., 2004). Crop yields were not significantly improved by the approximately 2.5 months of grazing (10 head/4 ac), but land use efficiency was significantly improved by this practice because cattle and peanut/cotton enterprises were layered, resulting in a greater gross income than the ungrazed plots. Other studies have found integrated systems to be more profitable than crop-only systems. A study conducted in North Dakota, for example, found net worth could be increased by $8,000 for crop-only farms converting to integrated beef cattle/crop management (Anderson and Schatz, 2003). A study from Texas found that savings from reduced irrigation and reduced fertilizer application in an integrated cattle/cotton systems increased profitability to nine times above the corn-only monoculture (Allen et al., 2005). Table 3 lists studies where integrating animals into a crop farm increased total farm profitability. This increase in abundance and diversity of food production may also confer increased resiliency to farmers and ranchers who have more options for market and a greater options in the case of either crop or livestock failure.

TABLE 3 Increased Profits from Livestock in Integrated Agroecosystems

Agroecosystem	Profits from animals (excludes profits from crops)	Source
Cattle grazing winter ryegrass cover crop	\$170–\$560/ha	(Bransby, 1999)
Cattle grazing winter ryegrass cover crop	\$227–323/ha	(Hill et al., 2004)
Sheep and broilers grazing for five months during spring-fall growing season	\$2,077/ha	(Lowy, 2009)
Cattle grazing winter ryegrass or oat cover crop	\$200/ha	(Siri-Prieto et al., 2007)

Social Benefits

Studies of integrated agriculture have found they can confer social benefits to growers and communities. Lowy, the grower participant in the cooperative farmer/extension study described in the 'Animals, manure, and soil quality' section of this paper, reported that community support for local animal production was noticeable during the study (Lowy, 2009). Another study found that in order for diverse integrated farms to succeed in Minnesota, social relationships between consumer and producer would necessarily need to be developed, thus generating community social capital (Boody et al., 2005). Communities can also benefit from increased crop/livestock agriculture because integrated farms have the capacity to produce more food calories than crop-only farms. A study from Cuba found that integrated dairy/crop farms could produce a milk yield per unit of forage land area of up to 2.4 Mg ha^{-1} yr^{-1} as compared to 0.7 Mg ha^{-1}yr^{-1} on specialized dairy farms (Funes-Monzote et al., 2009). Improving land use efficiency on farms to produce more calories from less land aids both food security goals and local food economy initiatives, such as 'eat local,' campaigns because more food calories can be produced close to a given locale.

CONCLUSIONS

A review of research, policy, and theory related to integrated agriculture shows that re-integrating animals back into agriculture may improve soil quality, decrease reliance on external inputs, contribute to pest management, augment conservation of critically important wild biodiversity, strengthen farm economies, and confer food security benefits to communities. Integrated agriculture does, however, face barriers and challenges predicated on a century of industrial specialization and regulations designed within the context of specialization. The use of livestock also introduces many of the known challenges of farming with animals such as nutrient balancing for soil fertility, environmental contamination caused by manure runoff, and soil compaction caused by animal trampling. For integrated agriculture operations to be successful in the United States, these and other issues, such as training programs for beginning animal farmers, breeding initiatives for pasture-hardy animals, and small-scale meat processing facilities must all receive attention and support.

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NOTE

1. The term "livestock" is used in this paper to refer to all domesticated animals raised for agricultural production purposes (i.e., poultry, cattle, sheep, etc. but not dogs, cats, and other pets).

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