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Integrated Crop–Livestock Systems in the U.S. Corn Belt

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ABSTRACT

Agricultural production systems in North America have become increasingly specialized. The lack of diversification has had negative economic, biological, and environmental consequences. One alternative approach to diversify agricultural production is to integrate cash grain cropping with ruminant livestock production. Our objective was to review research applicable to development of diversified crop–livestock systems in the U.S. Corn Belt and discuss research priorities and constraints to adoption of those systems. One form of integration becoming more common in the U.S. Corn Belt occurs through contractual arrangements between spatially separated, specialized crop and livestock production farms. Less common is the spatial and temporal integration of crops and livestock on the same land base, which can occur via rotations of grain crops with perennial pastures, short rotations of grain crops with annual or short-season pastures, and utilization of grain crop residues for livestock grazing. We feel this latter model is truer to the concept of diversification. Based on published research and preliminary results from an integrated crop–livestock system project in Illinois, we suggest that integration of crops and livestock on the same land base offers tremendous potential to diversify farm ecosystems in the U.S. Corn Belt while being economically competitive and more environmentally compatible than prevailing specialized production systems. Although studies have addressed or are applicable to components of crop–livestock systems in humid–cool environments, there remains a need for systems level research and funding opportunities for addressing the complex environment–plant–animal–economic–social interactions associated with integrated crop–livestock systems.

Many changes have occurred in U.S. agriculture since World War II (Dimitri et al., 2005; Karlen et al., 1994b; Rotz et al., 2005). Before the war, agriculture in the USA was diverse and labor intensive with crop and livestock production tightly integrated on small farms. Commodities were sold mostly within local markets and crop fertilization was strongly dependent on nutrients cycled within and among local farms. Since World War II, farm size has increased, the number of farms has declined, agricultural markets have become more international in scope, and producers rely more on off-farm fertilizers, which disrupts within-farm nutrient cycling. Farms have become more specialized, as evidenced by a decrease in the number of commodities produced on farms from an average of five per farm in 1990 to less than two in 2002 (Dimitri et al., 2005).

The move to specialized farming systems has been very apparent in the midwestern U.S. Corn Belt—Ohio, Indiana, Illinois, Iowa, Wisconsin, and Minnesota. Cattle production in the U.S. Corn Belt declined and moved to more concentrated operations in the western USA. Crop and livestock farms became operationally and functionally separate. Those changes are evident from farm statistics after World War II (National Agricultural Statistics Service, 2000). Since 1945, cattle numbers declined by 52% in the U.S. Corn Belt, while hay and oat (*Avena sativa* L.) acreage declined by 60 and 97%, respectively (Fig. 1). Since 1945, corn and soybean acreage increased 29 and 80%, respectively, in the U.S. Corn Belt (Fig. 2). Corn and soybean currently occupy 85% of the planted acreage, while hay occupies 8.6% of the planted acreage in those five midwestern states (National Agricultural Statistics Service, 2006). Grain crops are now extensively produced in simple, short-term crop rotations that involve few crops (Bullock, 1992; Karlen et al., 1994b). Approximately 20% of the corn (*Zea mays* L.) is grown in continuous monoculture, while most of the remaining 80% is grown in 2-yr rotation with soybean [*Glycine max* (L.) Merr.]. Dairy farms in the midwestern USA and southern Canada have been an exception to those trends, where crops and livestock are usually integrated on the same farm. Longer rotations of corn and alfalfa (*Medicago sativa* L.) or other perennial forage species are still common on midwestern dairy farms.

Introduction of chemical fertilizers (especially N) and synthetic pesticides, mechanization (i.e., replacement of draft animals), and crop cultivar development within a limited number of commodities have all been cited as contributors to the reduced use of extended crop rotations in U.S. agriculture (Bullock, 1992; Karlen et al., 1994b). Farmers have benefited from economies of scale and specialization in production and marketing that are possible when concentrating on one or two crops (Bullock, 1992; Dimitri et al., 2005; Karlen et al., 1994b). The commodity specificity and income support characteristics of U.S. farm policy have also affected the pace of those changes in American agriculture (Dimitri et al., 2005). For example, specialization has been favored through the risk–reduction effects of price supports and the planting rigidities imposed by supply controls.

PROBLEMS WITH SPECIALIZED PRODUCTION SYSTEMS

Extensive use of simple, short-term crop rotations and continuous, annual cropping systems has generally been economically successful, resulting in dramatic growth of

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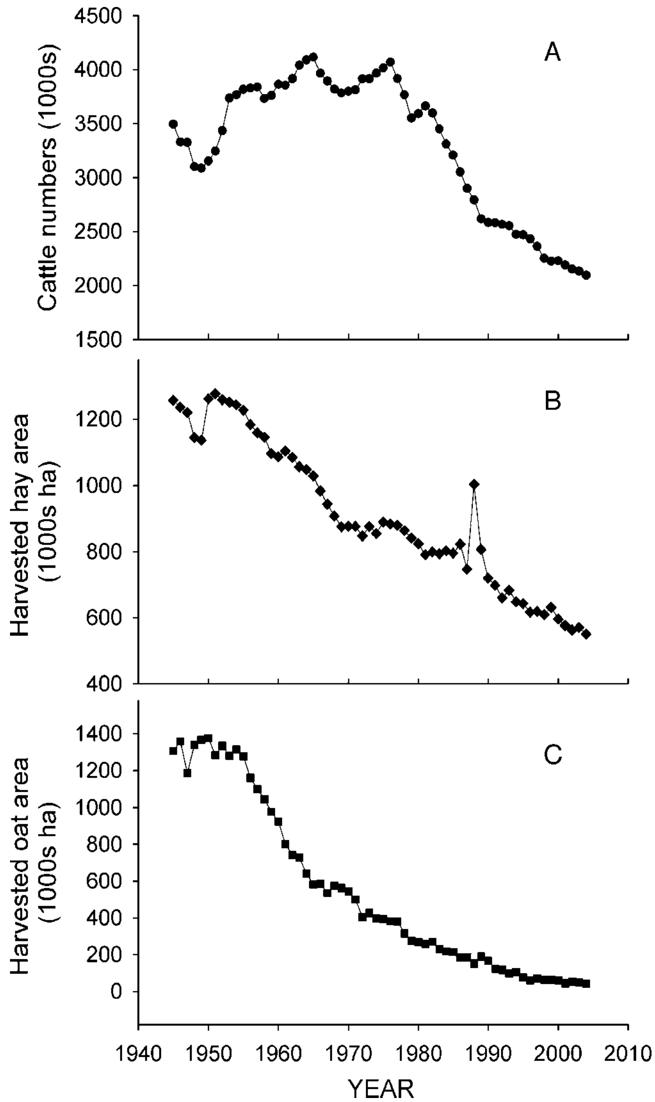

Fig. 1. (A) Mean cattle numbers, and land area of (B) harvested hay and (C) oat since 1945 in the midwestern U.S. Corn Belt. Statistics were taken from the states of Ohio, Indiana, Illinois, Iowa, Minnesota, and Wisconsin (National Agricultural Statistics Service, 2000).

output from U.S. farms. On the other hand, it has led to some negative consequences, especially with regard to environmental effects, including: reduction of crop diversity (Brummer, 1998); loss of soil organic matter (Tiessen et al., 1982); degradation of soil physical characteristics and increased soil erosion (Bullock, 1992; Karlen et al., 1994b; Pimental et al., 1995); increased sedimentation of reservoirs (Karlen et al., 1994b), increased eutrophication of surface and marine waters (McIssac et al., 2001); increased surface and groundwater contamination (Ritter, 1990; Spalding and Exner, 1993; Karlen et al., 1994b), worsening of insect and disease problems such as the western corn root worm (*Diabrotica virgifera virgifera* LeConte) (Levine and Sadeghi, 1991), soybean cyst nematode (*Heterodera glycines* Ichinohe) (Porter et al., 2001), and gray leaf spot in corn (*Cercospora zeae-maydis* Tehon & Daniels) (Lipps et al., 1996); development of herbicide-resistant weeds (Derksen et al., 2002; Stachler and Loux, 2003;

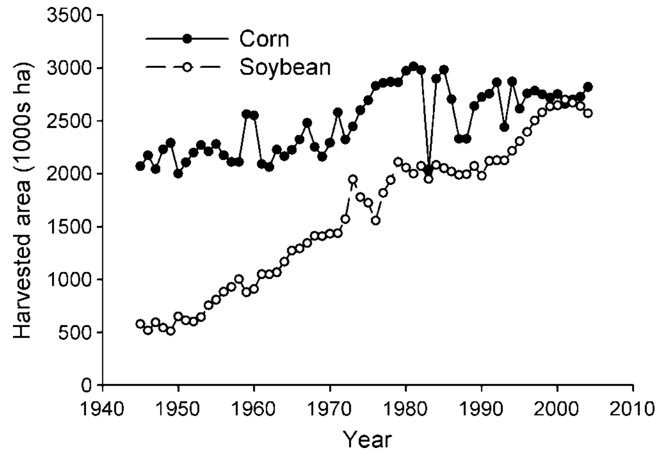

Fig. 2. Mean land area of harvested corn and soybean since 1945 in the midwestern U.S. Corn Belt. Statistics were taken from the states of Ohio, Indiana, Illinois, Iowa, Minnesota and Wisconsin (National Agricultural Statistics Service, 2000).

Trainer et al., 2005); and increased contribution to greenhouse gas emissions (Lal et al., 1999). The decoupling of livestock and crop operations has led to nutrient imbalances both at feedlots (too much) and on grain farms (too little) (Chang and Entz, 1996). Although many of the negative factors mentioned above are site specific, they have consequences that reach across local, regional, and global scales.

Current agricultural systems utilizing monocultures and short rotations require more external inputs (Karlen et al., 1994b), and the question has been raised whether the substitution of capital, energy, and synthetic chemicals for diverse crop rotations can sustain stable and productive agricultural systems (Bullock, 1992; Brummer, 1998; Randall, 2003). As described above, evidence is accumulating that over-reliance on simple crop rotations may have long-term implications that threaten economic and biological sustainability of agriculture in the U.S. Corn Belt region. Diversification of farming operations could be a viable approach to alleviate many of the problems being documented in our current agricultural production systems (Brummer, 1998). One method for diversifying agricultural systems is through integration of crops and livestock within the same farm enterprise.

BENEFITS OF CROP–LIVESTOCK INTEGRATION

Randall (2003) cited four positive factors associated with livestock being integrated into cropping enterprises: (i) crops produced on the farm can be used to feed the livestock, thus minimizing the importing of outside feed stuffs in livestock production; (ii) livestock manure can serve as the primary source of nutrients for crop production, thereby cycling nutrients from the crops through the animals and back out onto the land; (iii) livestock can serve as the sink for agricultural byproducts; and (iv) ruminant livestock encourage the establishment of perennial grass and legume forages as a primary feedstuff.

Pasture and row crop integration has received limited attention by researchers in the U.S. Corn Belt region; however, research in other regions of North America has demonstrated many benefits of diversified crop–livestock systems where forage crops are incorporated into grain crop rotations. Greater productivity of diversified crop–livestock systems can be attributed to improvements in soil structure, soil fertility, weed control, disruption of insect and disease cycles, and availability of high-quality feed for livestock on pasture (Bullock, 1992; Humphreys, 1994; McKenzie et al., 1999). In the northern Great Plains of North America, diversifying cropping systems with forages helps increase grain crop yields, reduce weed pressure, and improve soil quality (Entz et al., 2002). In the Texas High Plains, many soil microbial variables such as microbial biomass C and N, enzyme activities, and protozoa populations, were higher in an integrated cotton (*Gossypium hirsutum* L.) and grazing beef steer (*Bos taurus*) system than in cotton monoculture (Acosta-Martinez et al., 2004). The integrated cattle–cotton system with 54% of the land in permanent C4 grass pasture also used 23% less irrigation water, 40% less fertilizer N, fewer other chemical inputs, and was 90% more profitable than the cotton monoculture (Allen et al., 2005).

Diversified crop–livestock systems have also shown promise in other regions of the world. Investigators in Argentina found that pasture integrated within various grain crop rotations significantly increased soil organic matter levels compared with grain cropping alone (Studdert and Echeverria, 2000). Compared with continuous cropping systems, crop–pasture rotations in Uruguay were more economically and climatically buffered due to their higher diversity, and were more environmentally sustainable since fuel and agrochemical usage was 50% lower (García-Préchac et al., 2004). Soil organic C content was maintained or increased from the original levels in the crop–pasture system. Integrated pasture-cropping systems in southern Australia resulted in higher cereal crop yield and livestock carrying capacity, greater soil protection, and more consistent farm profitability compared with less diversified systems (Puckridge and French, 1983). In southern Brazil, research and experiences on commercial farms have demonstrated that integrated crop–livestock grazing systems can improve net returns eightfold over the traditional extensive stocker grazing systems and 1.5-fold over soybean grain production systems (Sulc et al., 2005). Grazing winter cover crops did not reduce subsequent grain yield of soybean and corn when animal stocking was managed so as to maintain forage dry matter on offer at a minimum of 5% of the animal live weight present (Mello and Assmann, 2002; Moraes et al., 2003). Steers with high genetic potential had average daily gains exceeding 1.2 kg d^{-1} on winter cover crop pasture and 0.8 kg d^{-1} on perennial summer pasture, resulting in live weight production of 650 kg ha^{-1} during the winter season (annual pastures rotated with summer grain crops) and 1600 kg ha^{-1} on permanent summer pastures (210 d) in integrated crop–livestock systems in southern Brazil (Sulc et al., 2005).

The literature provides ample evidence that well-managed integrated crop–livestock systems can provide overall positive effects on soil functioning, profitability, and natural resource use. We suggest that integrated crop–livestock systems should be encouraged in the U.S. Corn Belt region, and we hypothesize such systems will be economically competitive and less environmentally harmful than the short-term grain crop rotations currently in use. Moreover, crop–livestock farming systems are amenable to production of differentiated products (e.g., organic or natural labels), which can provide additional marketing opportunities beyond the conventional commodity markets that are so common with traditional grain or confinement livestock operations.

OBJECTIVES

In this paper we will focus on the midwestern U.S. Corn Belt region as we address the following objectives: (i) review research conducted in the Midwest and surrounding regions related to potential methods for integrating crop and ruminant livestock grazing systems; (ii) discuss research priorities needed to provide a sound basis for productive, profitable, and environmentally sound integrated crop–livestock systems, and highlight constraints to their adoption; and (iii) describe an ongoing experiment that serves as an example of research addressing important aspects in the development of a diversified crop–livestock system for the U.S. Corn Belt region.

METHODS OF CROP–LIVESTOCK INTEGRATION IN THE U.S. CORN BELT

There are numerous methods and degrees to which grain and ruminant livestock production can be integrated. From a practical point of view, crop–livestock integration can occur at two basic scales: (i) spatially separated crop and livestock farms that are integrated via contracts and partnerships (i.e., among-farm integration), and (ii) spatial and temporal integration of crops and ruminant livestock on the same land base (i.e., within-farm integration of enterprises). The basic characteristics and challenges associated with those two scales of integration are discussed in an associated article in this issue (Russelle et al., 2007).

Among-farm integration in the U.S. Corn Belt has occurred primarily via contractual relationships involving manure from large confinement livestock operations that is applied on neighboring crop farms. Efforts are underway to develop planning approaches to facilitate manure management among farms. New and expanding confinement dairy operations in the U.S. Corn Belt are utilizing this model, with the dairy producer specializing on managing the dairy cow operation while contracting with neighboring crop farms for manure application and production of the forages for the dairy (Hadley et al., 2002). Among-farm integration has promise for contributing to biological and economic diversity on a regional scale within the U.S. Corn Belt; however, it will require establishment of collaborative and mutually beneficial relationships among many producers.

Within-farm integration is characterized by livestock and grain crops present on the same farm where the primary activity on the land changes temporally and spatially via rotations, intercropping, and relay cropping of grain crops and forages. The complexity of the soil–plant–animal interface in such systems is dynamic and presents management challenges, especially when the forages are grazed directly by livestock rather than mechanically harvested and fed to confined animals. We have chosen to focus the remainder of this paper on within-farm integration of grain crops and grazing livestock because there is a need to address the complexity of those systems and we believe they represent significant potential for achieving a range of biological and economic synergies. Our goal is to provide insights from published research conducted in the U.S. Corn Belt and surrounding regions that will guide the development of integrated crop–livestock systems that are practical and sustainable for the U.S. Corn Belt.

Crop–livestock systems that are spatially and temporally integrated can occur in the U.S. Corn Belt through various combinations of the following: (i) rotations of grain crops with perennial pastures; (ii) short rotations of grain crops with annual or short-season pastures; and (iii) utilization of grain crop residues for livestock grazing.

Rotations of Perennial Pastures and Grain Crops

Integration of perennial pasture and grain crops could involve long rotations in which beneficial effects on grain crop performance and soils are often expressed. Benefits of long rotations that include forage and pasture crops include: increased grain crop yield; reduced input costs through disruption of insect, weed, and disease cycles; reduced soil erosion; improvements in soil physical properties; increased soil organic matter; improved water and nutrient efficiencies; reduced risk of environmental damage by nitrate leaching, and improved wildlife habitat (Bullock, 1992; Karlen et al., 1994b; Reeves, 1994, 1997; Russelle et al., 2007). In northern Iowa and southwestern Wisconsin, extended crop rotations that included at least 3 yr of forage crops ranked high in soil quality indicators, with total organic C being the most sensitive indicator (Karlen et al., 2006). Simpler rotations and monocultures of grain crops had lower soil quality indices, with soil C being the most sensitive indicator of soil quality. Continuous corn had the lowest soil quality indicators and lowest 20-yr average returns (excluding annual government support payments). In the northeastern USA, including a short-term sod crop such as red clover (*Trifolium pratense* L.) into grain cropping systems resulted in positive effects on cash crop yield and profitability under different tillage and chemical management systems (Katsvairo et al., 2003; Katsvairo and Cox, 2000a, 2000b; Singer and Cox, 1998). In New Jersey, investigators concluded that incorporating alfalfa into crop rotations can significantly increase returns to land and management, provided a viable forage market exists (Singer et al., 2003).

One often cited benefit for incorporating forage legumes into crop rotations is the significant amount of available N added to the farm through dinitrogen fixation (Peoples et al., 1995; Russelle and Birr, 2004). This reduces the fertilizer N requirements for subsequent nonlegume crops (Mohr et al., 1999). Others have argued that much of the yield benefit that has been credited to N contribution from legumes actually is due to other factors (Bullock, 1992). The important point is that grain crops usually demonstrate a positive response when planted after perennial forage legumes in extended crop rotations.

The biological N fixation or N replacement value resulting from inclusion of perennial legumes in grain crop rotations has significance to the balance of energy in bioenergy production. Currently, many crops grown for bioenergy have a high N fertilizer requirement (e.g., corn for ethanol production). Rotations containing perennial forage legumes or pasture swards in an integrated crop–livestock system would provide a means to reduce the need for N fertilizer in the production of the bioenergy crop, enhancing the energy balance of the bioenergy production system as a whole (Karlen et al., 1994b). For example, several studies have documented there is little, if any, response to additional N in corn following alfalfa (Bundy and Andraski, 1993; Morris et al., 1991; Schmitt and Randall, 1994).

Workers in Wisconsin have recently been conducting a systems level approach for evaluating the hypothesis that increasing cropping system diversity will reduce negative environmental impacts of farming while lowering input levels, increasing productivity, and maintaining or increasing profitability (Posner et al., 1995). Six cropping systems varying in levels of crop diversity and inputs are being evaluated, three of which integrate forage species with grain crops. Based on results from the first 10 yr of the project, they ranked the systems for profitability, productivity, and environmental compatibility (Griffith and Posner, 2006). Environmental compatibility was evaluated via a series of soil and water quality measurements. The no-till corn–soybean system had the best yields and highest gross margins. The low-purchased-input rotation that included a small grain and legume cover crop with corn and soybean was the best system from an environmental standpoint, but the corn and soybean crops were 14% less productive making that system 9% less profitable than the no-till corn–soybean system. The forage-based rotations were at least as profitable (more profitable at one location, equal at the other location), produced high yields with fewer inputs, and were more environmentally benign than the cash grain systems. Among the forage systems, the rotational grazing pasture system was the most environmentally benevolent system. The intensive alfalfa rotation (corn followed by 3 yr of alfalfa with high-purchased inputs) was the most productive but the least environmentally benign of the forage-based systems. The low-purchased-input forage system (corn–oat/alfalfa–alfalfa rotation) equaled the intensive alfalfa system in profitability, but had better environmental performance. The continuous corn system had high input costs, erratic and only fair corn yield, lower and more erratic economic performance, and resulted in high environmental costs. The no-till corn–

soybean system had the lowest labor requirement, which was 20% lower than the continuous corn system. In contrast, the low-purchased-input rotation that incorporated a small grain and legume cover crop with the corn–soybean system required 64% more labor than the no-till corn–soybean system. In terms of the ratio of energy output to energy input, the forage based systems ranked highest, and the most diverse systems were the most energy efficient.

Research on use of living mulches in crop production (Hartwig and Ammon, 2002) may have some applicability to integrated crop–livestock systems, because many of the species evaluated as living mulches also can be utilized to produce forage. One option would be to produce a grain crop for 1 yr in a partially suppressed perennial pasture sod (i.e., living mulch), after which the sod is allowed to recover and produce forage the following year. That practice may be especially applicable to producers with well-managed grazing systems, because they are often reluctant to destroy a productive perennial pasture sod in exchange for the rotational benefits it would provide to a grain crop grown in succession. Research in the north-central USA, however, demonstrates that living mulch and interseeded systems typically depress corn yield due to competition for water, light, and nutrients (Eberlein et al., 1992; Echtenkamp and Moomaw, 1989; Kurtz et al., 1952; Pendleton et al., 1957). More recently, investigators in Wisconsin reported promising results in a kura clover (*Trifolium ambiguum* M. Bieb.) living mulch system (Zemenchik et al., 2000). An established perennial sod of kura clover was suppressed with herbicides before planting corn with little or no reduction in whole-plant or grain yield of the corn. The authors stated that a kura clover–living mulch system could be largely self-sufficient for N, but more research is needed to evaluate corn yield response to sidedressed N treatments. Herbicide-resistant corn technology improved the consistency in managing kura clover as a living mulch for corn production (Affeldt et al., 2004). The suppressed kura clover sod recovered to full forage production within 12 mo after the corn crop was grown. Winter small grains and Italian ryegrass (*Lolium multiflorum* Lam.) can be interseeded into kura clover stands to increase early spring and total season forage production the following year (Contreras-Govea and Albrecht, 2005), and would serve to alleviate the risk of bloat for livestock grazing on kura clover pastures. Kura clover has demonstrated significant potential as a pasture legume crop in the northern U.S. Corn Belt (Contreras-Govea and Albrecht, 2005; Mouriño et al., 2003; Sheaffer et al., 1992), and appears worthy of further investigation as a component of an integrated crop–livestock grazing system, especially in view of the resistance among producers to plow down perennial pasture sods to obtain rotational benefits to a monocotyledonous grain crop.

Although benefits of perennial forages grown in rotation with grain crops have been documented, the studies conducted in the midwestern U.S. Corn Belt have usually utilized mechanical harvesting rather than livestock grazing of the forages. Information is lacking on how livestock grazing would impact soil properties and grain crop performance and profitability of systems that utilize long rotations of grain crops and pastures in the U.S. Corn Belt environment.

Integrating Short-Season Pastures into Grain Rotations

There are many options for growing short-season annual forages for use as pasture within grain crop rotations: (i) warm-season annual grasses or cool-season annual species can be planted in mid- to late July after a small grain harvest; (ii) cool-season annual species can be planted in early to mid-September after soybean or corn silage harvest; and (iii) warm- and cool-season annual species can be planted sequentially to provide forage throughout most of an entire growing season, then rotated back to grain production the following year. All of these options provide significant opportunities for integrating grain crop production and livestock grazing on the same land base in the U.S. Corn Belt region.

There is considerable interest among pasture-based livestock producers in using short-season forages to reduce winter feed costs of livestock. Approximately one-half of the annual production cost in a typical beef cow operation is associated with feeding during the winter period (Schoonmaker et al., 2003). In an integrated crop–livestock system, permanent pasture can provide grazing from spring to fall, while annual forages can be grown between grain crops to provide grazing from autumn through early winter and again in early spring, periods when production from perennial pastures is low. Integrating late fall to early spring grazing on cropland to extend the grazing season would reduce hay needed to feed livestock, thus reducing costs and increasing profitability.

Cool-season cover crops have been identified as important components of diversified crop rotations (Snapp et al., 2005). Benefits of cover crops include soil erosion protection (Dabney, 1998; Kaspar et al., 2001), decreased nutrient losses through leaching and runoff (Magdoff, 1991; Ruffo et al., 2004; Staver and Brinsfield, 1998), greater C sequestration (Reicosky and Forcella, 1998; Sa et al., 2003), increased weed suppression (Buhler et al., 1998; Fisk et al., 2001) and critical habitat for wildlife (Dabney, 1998; Entz et al., 2002). Although cover crops have been extensively studied in the context of supplying N to the following corn crop, they often fail to be an economical alternative to N fertilizer (Mallory et al., 1998). Obtaining animal production from cover crops has the potential to dramatically improve their economic viability within cropping systems.

There are few published reports on studies conducted in the midwestern U.S. Corn Belt on use of short-season cover crops as sources of forage in late autumn through early spring, and even fewer reports on utilizing such forages in livestock grazing operations. It is not clear how grazing might affect the positive aspects of cover crop use as documented in diversified crop rotations, especially with regard to soil physical and chemical properties. It also is unclear whether utilization of cover crops by grazing livestock will produce additive effects within integrated farming systems that may lead to greater system productivity and profit. The potential to utilize cover crops for forage within the U.S. Corn Belt region is variable. For example, lack of adequate light, growing degree days, and water can severely limit the reliability of cover crops in northern and western portions of the U.S. Corn Belt (Strock et al., 2004). Clearly, much work is needed to identify how cover crops could be utilized by grazing animals in an integrated system to enhance agricultural productivity and environmental sustainability in the U.S. Corn Belt.

Winter cereal species are obvious candidates for producing high-quality forage during late autumn and early spring in rotation with summer grain crops. Research in Michigan demonstrated that winter wheat and winter rye (*Secale cereale* L.) were effective as double-crop forage in corn–soybean cropping systems when the winter annual forage crop preceded soybean in the rotation (Thelen and Leep, 2002). Investigators in Ohio (McCormick et al., 2006; Samples and Sulc, 2000) and Wisconsin (Maloney et al., 1999) demonstrated that cereal grain species can be selected to provide forage primarily in late fall, early spring, or in both the fall and spring. Research in Nebraska demonstrated that winter rye was the most winter hardy and versatile of several cover crop species evaluated for forage production and grazing in an integrated crop–livestock system (Lesoing et al., 1997). Rye no-till drilled following corn silage production resulted in more uniform stands than broadcast seeding into standing soybean. The rye provided winter cover and 4 to 5 Mg ha^{-1} of dry matter production, which was sufficient to carry 2.7 cows ha^{-1} for 30 d during spring grazing. Even when grazed, cover crops often provided greater soil cover than grain crop residues.

Other species with forage production potential for cool months include annual ryegrass (*Lolium multiflorum* Lam.) and *Brassica* spp. (Kallenbach et al., 2003; Penrose et al., 1996; Reid et al., 1994). In Ohio and Illinois, producers are experimenting with various small grains and *Brassica* species planted in early to mid-August after winter wheat grain harvest, aerially seeded over corn and soybean grain fields in mid-August, or planted after corn silage harvest in early September. Livestock are then grazed on the short-season pastures in late fall to early spring to reduce high feed costs associated with utilizing mechanically harvested or purchased feeds.

Producers in the U.S. Corn Belt often express concern with the potential for soil compaction caused by cattle grazing winter cover crops. In Nebraska, when cover crops were grazed during wet conditions, soil compaction occurred in tracked areas, resulting in 10-fold reductions in water infiltration rates compared with areas that were not grazed (Lesoing et al., 1997). This could lead to greater runoff and erosion from tracked areas during intense rainfall events. In a dry year, subsequent corn grain yields were reduced as much as 63% after cover crops due to reduced soil water availability. Studies in the southern Great Plains (Krenzer et al., 1989; Winter and Unger, 2001) and South Carolina (Worrell et al., 1992) demonstrated that animal trampling can alter soil physical properties and reduce root growth and yield of subsequent grain crops. Many factors influence degree of soil compaction by animal trampling, including weight of animals, grazing management, animal density, sward cover of the soil, and forage species present. Soil moisture is especially important in determining severity of compaction (McCormack, 1987). There is a need to identify grazing management practices for the U.S. Corn Belt region that will minimize the negative effects of animal trampling on cropland. For example, Winter and Unger (2001) demonstrated in the southern Great Plains that when winter wheat residues were maintained at 3500 kg ha^{-1} after grazing, subsequent grain sorghum [*Sorghum bicolor* (L.) Moench] yields in a no-tillage crop rotation were similar to those in the nongrazed treatment.

Grazing Grain Crop Residues

Grazing livestock on crop residues after the grain has been harvested represents one of the simplest and most economical methods for producers in the U.S. Corn Belt to integrate livestock into grain crop rotations. Crop residues represent a vast feed resource available to ruminant livestock producers in the U.S. Corn Belt that can effectively reduce feed costs (Lawrence and Strohbehn, 1999). This practice has become an integral part of many cattle operations in the western U.S. Corn Belt, but is less common in the eastern U.S. Corn Belt. Numerous research studies conducted in Iowa and Nebraska have led to management guidelines for utilizing crop residues in livestock production systems (e.g., Anderson et al., 2005; Erickson et al., 2001; Hitz and Russell, 1998; Jordan et al., 1997b; Klopfenstein et al., 1987; Russell et al., 1993; Ward, 1978). Corn residues can provide four to five animal unit months of grazing per hectare, provided weather conditions are favorable. Grazing, rather than mechanically harvesting, is usually the most economical method of utilizing corn stover in beef cow systems (Klopfenstein et al., 1987). Grazing crop residues reduces soil surface cover by only 5 to 25% (Clark et al., 2004; Lesoing et al., 1996).

Animal traffic can cause soil compaction near the surface and increase soil surface roughness; however, grazing can be managed to prevent significant detrimental effects on subsequent grain crop yields (Clark et al., 2004; Jordan et al., 1997a; Lesoing et al., 1997). The investigators made note that effects of grazing crop residues on subsequent grain yield will be minimal if grazing is restricted to periods when soils are dry or frozen, or if the soil is tilled before crop planting. In the Iowa study, as the proportion of time soil temperature was below 0°C during the grazing period increased, soybean yield increased (r^2 = 0.72). Dry or frozen soil conditions are more likely in the western than in the eastern U.S. Corn Belt. Soils in the eastern U.S. Corn Belt are often not frozen and are moist from precipitation in the period from late autumn to spring. Thus, additional work is needed to develop management systems for winter grazing on cropland in the eastern U.S. Corn Belt where the potential for soil compaction from cattle trampling is high.

CONSTRAINTS TO ADOPTION AND RESEARCH NEEDS

There are many constraints to adoption of integrated crop–livestock systems in the U.S. Corn Belt region, but we suggest the following as being especially important to consider: (i) the tradition of single enterprise farming that has become the norm for the current generation of farmers; (ii) ease of management and government support programs that favor large-scale grain cropping systems over more complex, diversified production systems; (iii) higher managerial and labor input required for diversified, complex production systems; (iv) a lack of appreciation and understanding among many producers for system-level performance, i.e., performance of the individual components of a production system is valued more than overall system performance; and (v) limited incentives for greater diversity and environmental conservation in production systems.

Those of us who work primarily in the physical and biological sciences (e.g., plant and soil scientists, agronomists) often fail to appreciate the importance of social factors affecting adoption of technology. There are many reasons producers may adopt or fail to adopt integrated crop–livestock systems that have nothing to do with science-based technology. We agree with Entz et al. (2005) that there is a need to develop an understanding of the decision-making process used by crop and livestock producers. Karlen et al. (1994a) proposed that development of farmer–researcher partnerships and use of reductionist, as well as system methods, can be used together to guide development of more efficient and sustainable farming practices. Such an approach is worthy of consideration in developing integrated crop–livestock systems.

Advancement of research on diversified integrated crop–livestock systems in the U.S. Corn Belt region and across North America is being constrained by the lack of research teams capable of adequately addressing the complex environment–plant–animal–economic–social interactions that occur within fully integrated crop–livestock systems. The lack of public funding for sustained programs of sufficient size and depth to realistically conduct whole systems research is a significant constraint. These are the same constraints cited by Burns (2006) related to grazing research in the humid eastern USA. Multidisciplinary teams supported by the USDA in cooperation with land grant universities will be critical to advancements in our understanding of integrated crop–livestock systems and how to manage them for the good of society.

Much additional research is needed to build a better understanding of how to develop and manage integrated crop–livestock systems for the midwestern U.S. Corn Belt region that will meet production, economic, and environmental priorities. We suggest the following areas for investigation: (i) optimal combinations of perennial and annual pastures to meet the nutritional needs of livestock throughout the year and development of improved forage germplasm for integrated systems; (ii) grazing management of cropland pastures to optimize livestock performance and subsequent grain production under conservation tillage practices; (iii) mechanisms affecting nutrient cycling in integrated systems, and development of management practices that improve nutrient use efficiency within the whole production system; (iv) monitoring and management systems to minimize the environmental impact of integrated systems, especially related to soil properties and water quality; (v) financial analyses to evaluate profitability and stability of integrated crop–livestock production systems over time; (vi) use of modeling and field validation studies to investigate multiple factors affecting functioning and environmental impact of integrated crop–livestock systems, including production, economic, and environmental factors; and (vii) studies on the social issues affecting adoption of integrated crop–livestock systems.

Use of modeling and field validation studies seems especially appropriate in addressing the complexity of integrated crop–livestock systems. Whole-system studies should be useful for validating conclusions drawn from modeling. Such studies can also serve to engage producers, which will help accelerate the transfer of technology to commercial application. Whole-farm simulation models have been used to evaluate incorporation of small grain and soybean crops on Pennsylvania dairy farms, but experimental or on-farm validation trials of those results are lacking (Rotz et al., 2001, 2002). Combining experimental farm data with whole-farm simulations has been used successfully in studying nutrient flows in grassland agriculture, and appears to be a powerful and cost-effective approach for evaluating, refining, and transferring production management systems to commercial production (Rotz et al., 2005).

We agree with Kay (1990) that a major goal of agricultural research will be to identify and promote cropping systems that sustain soil productivity and minimize deterioration of the environment. Long-term studies have shown that continuous cropping results in decline of soil organic C; however, conservation tillage coupled with intensive cropping systems, and rotations which include pasture or ley periods, can ameliorate this decline in soil organic C (Reeves, 1997). Forages are a significant component of systems that integrate cash grain operations with ruminant livestock grazing. Thus, there is tremendous potential to promote soil quality and conservation, water quality, and water use efficiency while also reducing costs via the synergism of forages with conservation tillage practices within integrated crop–livestock systems. Preliminary data in the southeastern USA demonstrated that no-tillage management preserved the long-term accumulation of organic matter from a perennial pasture when the land was converted to an integrated crop–livestock grazing system (Franzluebbers and Stuedemann, 2004). Cattle grazing of the cover crops in those systems had no negative effects on subsequent grain crop yield. Integrated crop–livestock systems under no-tillage practices are being successfully developed in southern South America (García-Préchac et al., 2004; Mello and Assmann, 2002). A few studies have been conducted on the impact of grazing under different tillage systems within the midwestern USA and surrounding regions, such as the work conducted in Nebraska (Lesoing et al., 1996), Iowa (Clark et al., 2004) and Virginia (Morris et al., 1998); however, more research is needed on developing integrated crop–livestock systems under conservation tillage practices, especially in the eastern and northern U.S. Corn Belt.

AN INTEGRATED CROP–LIVESTOCK SYSTEM EXPERIMENT

Based on some of the issues presented in the preceding literature review, an integrated farming systems experiment was initiated in 2002 at the University of Illinois, Dudley Smith Farm, near Pana, IL. A goal of this project was to help fill knowledge gaps and demonstrate an integrated crop–livestock system as a viable alternative to the corn and soybean cash grain production system prevalent in the region. Although preliminary results are available, we will focus primarily on describing the experimental procedures used to achieve the desired objectives. We do this to provide an example of the systems-level research necessary to provide a basis for developing sustainable integrated crop–livestock production.

The overall objective of this project is to evaluate the ecology and economics of a farming system that integrates cattle with grain crop production on the same land unit. The project is scheduled to continue through 2012. For statistical purposes, the integrated farming system is replicated three times across a 90-ha land unit. The farming system consists of four treatments (Fig. 3):

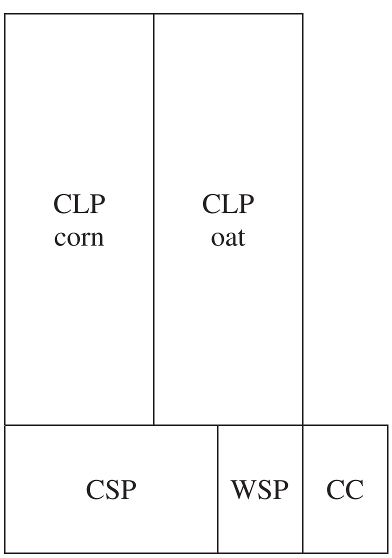

Fig. 3. Schematic diagram of an integrated farming system used at the Dudley Smith Farm in Illinois. The farming system is replicated three times across the land unit and consists of four treatments: CLP, cropland pasture grazed in winter and planted with corn or oat in summer (19 ha); CSP, perennial cool-season grass pasture (6 ha); WSP, perennial warm-season grass pasture (2 ha); and CC, continuous corn (2 ha).

(i) cropland pasture that has grain crops in summer and then is grazed in winter, (ii) a continuous corn rotation for comparison with cropland pasture, (iii) perennial cool-season grass pastures, and (iv) perennial warm-season grass pastures.

In summer, cropland pasture is planted with equal areas (19 ha each) of corn and oat that are harvested as cash grain crops. Instead of soybean, we use spring oat in the farming system because that crop can be harvested in July, which provides ample time for establishment of winter annual cover crop pasture. Adjacent to the croplands, beef cattle graze perennial cool-season pastures during the growing season at a stocking rate of 2.5 cows ha^{-1} (Fig. 3). Perennial warm-season grass pastures are used to extend the rotation in midsummer and give some additional rest to cool-season pastures. When perennial pastures become unproductive in November, cattle are moved to cropland pasture where they graze cover crop mixtures and corn residues (Fig. 3). The cover crop mixtures are planted in July following oat harvest and consist of oat, cereal rye and *Brassica* spp. Corn residues become available for grazing after the late-September to early October grain harvest. Pregnant beef cows graze each cropland area from November to March with calving occurring in February and March. Stocking rate is 1 cow ha^{-1} on winter cropland pasture. Cattle have equal access to corn residues and cover crops in each strip as well as a water source. We use a strip grazing method for winter grazing by moving forward a single strand of portable electric fence 25 m every 5 to 10 d depending on forage availability. Cattle are fed hay and grain as needed if they run out of forage on cropland pastures.

Various agronomic variables are being evaluated within the farming system, including crop yield, soil organic matter accumulation and soil C fluxes, soil compaction from cattle trampling, changes in weed abundance, insect diversity, and cattle performance. Some of our findings since 2002 are summarized briefly in Table 1. We also have been collecting data on costs and revenues in the farming system and local community reactions to this type of agriculture. Overall, the farming system has been working well although we have had some difficulties—especially with forage waste on cropland pastures. Most winters in central Illinois have multiple freeze/thaw events. When soils thaw, cattle easily trample and bury cover crop forage and corn residues. This trampling necessitates moving cattle to new forage faster than desired. More intensive management, like moving cattle to alterative forage sources, may be required to deal with this forage waste issue. We have many years of data collection ahead to assess the farming system and test different management alternatives. The long-term nature of this project is essential to produce definitive information that can be used to improve the sustainability of this type of integrated crop–livestock system.

FINAL THOUGHTS

Integrating grain and ruminant livestock production on the same land base offers tremendous potential to

Table 1. Summary of results from integrated crop–livestock system research in Illinois.

Items evaluated	Results
Winter forage supply from corn residue plus rye + oat + turnip (*Brassica rapa* L. subsp. *Rapa*) mixture grown on cropland	adequate from November to January, may last longer under favorable weather; supplemental feed needed in late winter, especially for pregnant cows
Soil compaction and soil organic matter	cattle trampling on cropland caused some soil compaction, but had minimal effects on soil properties and no detrimental effect on crop yield; soil organic matter increased significantly within 5 yr of conversion from corn–soybean rotation suggesting rapid building of soil organic matter in the integrated system
Weed biomass in system	winter grazing on crop fields suppresses weed biomass through trampling and grazing; however, presence of cover crops is just as effective in reducing weed biomass
Nutrient cycling	cattle on winter cropland concentrate nutrients near water sources through manure deposition; thus, animal excreta may not improve overall soil fertility due to uneven redistribution of nutrients
Economic return	cattle operation in integrated system is competitive with other cattle systems used in Illinois, but there is room for improvement; total feed costs in 2004 were \$158 cow^{-1}, compared with the Illinois state average >\$200 cow^{-1}; additional inputs spent on grazing have reduced overall feed expenditures

diversify farm ecosystems while increasing production efficiency in the U.S. Corn Belt. An increasing number of livestock producers in the region are beginning to take small steps toward integrating grain and ruminant livestock production; however, many questions remain regarding how best to develop and manage those systems. Unfortunately, there is limited research documenting the benefits, pitfalls, and management of integrated crop–livestock systems in the U.S. Corn Belt. A critical need exists for funding and development of multidisciplinary teams dedicated to systems-level research on integrated crop–livestock production. There also is a need for education and training of agricultural advisors and producers on how to develop and manage integrated crop–livestock systems. We feel that establishment of farmer–researcher partnerships have the potential to enhance development and adoption of efficient, profitable, and environmentally sound management practices for integrated crop–livestock systems.

The adoption of integrated crop–livestock systems will likely occur slowly in the U.S. Corn Belt as long as government programs for agriculture are not changed to encourage the use of more diversified systems that favor environmental preservation. We find it interesting there is significant research investment in and adoption of integrated crop–livestock systems in countries where government price supports for agriculture are limited or nonexistent (e.g., Brazil, New Zealand). We suggest that scientists, advisors, and producers in those countries recognize the economic and biological synergies possible through integration of crops and livestock, which help increase efficiency and sustainability of their production systems. Adoption of integrated crop–livestock systems is improving the ability of individual farmers in those countries to remain solvent, ultimately enabling them to compete in global agricultural markets. We conclude that integrated crop–livestock systems have the potential to be profitable and can enhance production efficiency and environmental quality in the U.S. Corn Belt; however, for this to become reality we will have to invest in research and training for establishment of management systems adapted to our environment and sociological context.

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