Evolution of Integrated Crop-Livestock Production Systems

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Key points

1. Many factors contribute to changes in the crop-livestock systems, but no logical end-point in the evolution process exists.
2. While benefits of integrated crop-livestock systems over specialised crop and livestock systems are well documented, there has been a move to specialised crop and livestock production.
3. Sustainability issues (manure nutrient concentration, soil quality maintenance, salinity, herbicide resistance, economic instability) have created a renewed interest in integrated crop-livestock systems.
4. Farmer adaptability is as an important link in the evolution between 'states of integration'.

Keywords: forage and pasture crops, ley farming

Introduction

Integrated crop-ruminant livestock (mixed) farming systems exist in many different forms around the world. Pasture leys are common in humid and temperate zones. Conserved forages play a significant role in temperate zones where they are grown in rotation with grain crops. This paper describes some unique benefits of integrated systems compared to specialised systems, and discusses current and future trends in crop-livestock integration.

Benefits of crop-livestock integration over specialisation

Farming systems that integrate ruminant livestock and crops tend to be more sustainable because they provide opportunities for rotation diversity and perenniality, nutrient recycling and greater energy efficiency.

Crop rotation diversity

The benefits of forage legumes in rotation have been known for centuries. Sir John Lawes reported soil structural benefits of ley phases in the 1880's (Clarke & Poincelot, 1996). Benefits of forages for soil health (soil structure, nutrient status), salinity control, pest management, improved crop yield, and higher overall whole farm profitability are well recognized (Entz *et al*., 2002).

Hay and pasture leys reduce weed and disease problems and increase productivity of the following grain crops. In Canada, for example, *Medicago sativa* L. (Lucerne) hay crops provide excellent control of several problem weeds including *Avena fatua* L. (wild oat) and

Cirsium arvense L. (Canada thistle) (Ominski *et al*., 1999). In a survey of 250 western Canadian farmers, 83% of respondents indicated weed control benefits from forage leys 3 years after forage crop termination, while 71% of respondents indicated higher grain yields following forage than in annual crop rotations (Entz *et al*., 1995). Using 30 years of rotation trial data from Saskatchewan, Canada, Zentner and co-workers (in Campbell *et al*., 1990) demonstrated that integrated crop-forage rotations had a lower cost of production than annual grain production systems, and forage crops provided more income stability to grain farming than government crop insurance programs. In south Australia, pasture-grain systems provide relatively stable income even in drought years where grains result in large financial losses. When comprehensive economic analysis is carried out, grain does not look nearly as attractive as a simple (and misleading) gross margin would suggest.

Perenniality in the cropping system

A striking example of what can happen when perenniality is removed from the landscape is dryland salinity. In southern Australia, *M. sativa* is being used to restore the hydrological balance and reduce the deep drainage that eventually results in dryland salinity (Angus *et al*., 2001; Latta *et al*., 2001). This restoration is based on the deep rooting system of *M. sativa* and its ability to provide transpiration leaf area for the entire year. Annual crops are unable to provide the necessary ‘perenniality’ to better match plant water use to available rainfall.

Rising nitrate concentration in ground water has been partly attributed to the shift away from sod-based rotations. Deep-rooted perennials such as *M. sativa* (Campbell *et al*., 1994) and grasses (Entz *et al*., 2001a) are able to retrieve deep-leached nitrates better than annual crops, thereby reducing the nitrate contamination risk. The deep root systems of forages also enable carbon to be placed deep into the soil profile. Gentile *et al*. (2004), using a 38-year old crop rotation study in Uruguay, showed that mixed farming systems (4 year pasture, 4 year grain crops) had significantly higher levels of subsoil C than crop only systems. Annual systems, even under grazing, return less organic matter back to soil than perennial pastures (Mapfumo *et al*., 2000).

Nutrient cycling

Integrated crop-livestock systems allow opportunities for locally controlled nutrient recycling. Nutrient cycling occurs by: 1) adding soil-N by legumes; 2) excreta from grazing animals; 3) manure from confined fed animals; and 4) nutrient transfer specifically associated with livestock movement (i.e., nighttime corralling).

It is well established that pastures, especially legume-based pastures, return a high proportion of nutrients back to the land (70 to 90%) (Entz *et al*., (2002). Within grazing systems, the degree of nutrient recycling depends on pasture composition and grazing intensity, with more intensive grazing increasing nutrient recycling to the soil system (Mapfumo *et al*., 2000). Removing forage from the land (i.e., hay and silage) removes nutrients and reduces rotational benefits of the pasture ley. For example, in a long-term (1920 to 1990) rotation study in NSW, Australia, Norton *et al*. (1995) reported that a change in *Trifolium pratense* (red clover) harvest management from grazing to haying contributed to a marked decline in yields of the following crops, whereas in the grazed *T. pratense* pastures, rotational crop yields were maintained. However, a long history of legume dominant pastures has resulted in many acidic soils in some of the most productive (medium-high rainfall) soils (McCown, 1996). Regular liming is the recommended practice to maintain a desirable soil pH. The problem becomes difficult to manage when the acidity progresses into the subsoil where liming is less effective.

Nutrient recycling opportunities are especially limited when conserved forage is transported and fed a long distance from its production site. Such separation of forage and livestock can reduce soil quality at forage production sites and accumulate manure nutrients at the livestock production site.

Energy efficiency

Integrated crop-livestock systems have the potential to be more energy efficient than either specialised crop or specialised livestock production (Clarke & Poincelot, 1996). Even when ruminant livestock gain a high proportion of their nutrition from human digestible sources (e.g. grains), their basal diet is typically comprised of forage (unusable to humans) giving ruminants an advantage over pigs and chickens (Loomis & Connor, 1992).

A number of studies have confirmed that integrated systems use less energy per ha (Clarke & Poincelot, 1996) and have higher energy efficiency than either specialised crop or livestock systems. In Germany, increasing off-farm feed purchases and decreasing reliance on grazing increased energy use in dairy production (from 5.9 GJ/ha to 19.1 GJ/ha) and decreased energy use efficiency (2.7 vs. 1.2 GJ/t of milk produced) (Haas *et al*., 2001). In Canada, integrated systems were found to have 10% higher energy use efficiency than specialised crop systems (Hoeppner, 2001).

Examples of crop-livestock integration around the world

Previous workers have suggested that changes in the degree of crop-livestock integration are a function of population and economic processes (Steinfeld, 1998). In this paper, different crop-livestock systems from different regions of the world are discussed in the context of the crop-livestock integration model presented by Powell *et al*. (2004).

West Africa

In semi-arid West Africa, vast increases in human population and urbanization have increased the need for crop and animal products. Traditional cropping systems based on shifting cultivation, and livestock systems based on transhumance and communal grazing are rapidly transforming to more sedentary, intensive mixed farming enterprises. *Pennisetum glaucum* (Pearl millet), *Sorghum bicolour* (sorghum) and *Zea mays* (maize) are the principal cereals, *Digitaria exilis* (fonio) is important in some areas, and *Oryza sativa* (rice) is cultivated in delta areas and along river and stream borders. The legumes *Vigna unguiculata* (cowpea) and *Arachis hypogea* (groundnut) are both subsistence and cash crops. Cattle, sheep and goats provide food for households, cash income, and are a means of storing capital and of buffering food shortages in years of poor crop production. Most agricultural products are used for subsistence purposes. Low rural incomes and the high cost of inorganic fertilisers and feed supplements prevent the widespread use of these external nutrient sources. Problems common to these agricultural systems include insufficient high quality forages, encroachment of cropping on communal grazing lands, reduced fallow periods (and declining soil fertility), lack of access to fertiliser and feed supplements, labour shortages during the cropping season, and inadequate market opportunities (Steinfield *et al.,* 1997; Powell *et al*., 2004).

In semi-arid West Africa, specialised and independent crop and livestock production systems are more attractive than mixed systems when population pressures are low (Figure 1). Cropland productivity is maintained through fallowing, which is preferred to land application of manure because it requires less labour. As population pressures rise, the demand for cropland increases, and because fallows occupy too high a proportion of the land, farmers look for alternatives to maintain soil fertility. Many farmers manage livestock to graze and capture nutrients from natural pastures and transfer them to cropland in the form of manure. Daytime grazing and nighttime corralling of livestock on cropland between cropping periods, returns faeces and urine to soils, and results in much higher grain yields than the application of manure alone (Powell *et al*., 1998). For interesting examples of such systems visit (Anon., 2005). Thus, the integration of livestock into West African crop production systems is driven by the need to increase soil fertility, which in turn is driven by population pressure. Unfortunately, even this system does not currently supply sufficient nutrients, as there is insufficient manure to sustain crop production over the long term (Fernandez-Rivera *et al*., 1995). Manure output varies with feed availability and quality, decreasing during the dry and early wet season as grazing resources diminish.

The potential for large-scale increases in forage production from natural or improved pastures appears to be limited. In many locations, most high producing pastures have been cultivated. Crop residues will likely continue to be a principal source of feed, especially during the dry season. Sustainable increases in livestock production will depend therefore on sustainable increases in crop productivity (Powell *et al*., 2004). Improvements in crop production can be achieved by intensifying management, for example, incorporating high yielding forage and grain legumes into the cropping system, and through crop and land management techniques that provide feed, and leave sufficient crop residues for soil conservation. Using forage legume fallows, instead of utilising the natural regeneration of indigenous plant species is desirable, but constrained by tenure security and labour (McIntire *et al*., 1992), fencing, and legume persistence when grown in association with grasses (Powell *et al*., 2004). Substantial gains in crop and livestock production can also be made through increased judicious use of fertiliser and diet supplements, crop genetic improvement and a wider integration of animal power instead of human power, and legumes into the farming systems.

The Loess plateau of western China

On the Loess Plateau of Gansu, western China, local farming systems have evolved due to population pressure and soil sustainability issues. Soil erosion is a major constraint in the region, and mixed farms have replaced livestock grazing on sloping and terraced land. On the better flat land, intensive cropping has replaced mixed crop-livestock systems. Integration of crops and livestock in western China occur on both a local (on-farm) and area-wide basis (Figure 1).

Benefits of integrated crop-livestock systems over specialised production are well recognized in west China. Animals supply manures for soil fertility, draught power for tillage, and are important to generate cash flow, as opposed to grain production, which is largely consumed for subsistence. Recent Government policies are aimed at increasing animal production. Other policies are aimed at replacing sloping cultivated cropland with either trees or perennial forages (cut & carry) to reduce erosion.

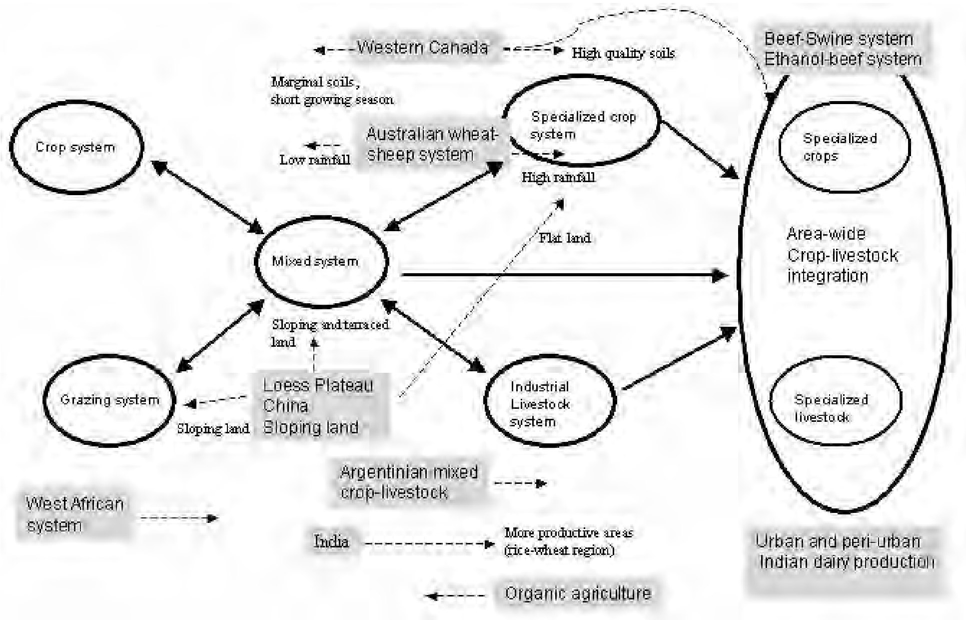

Figure 1 A 'state and transition' model describing the evolution of integrated crop-livestock systems (adapted from Powell *et al*., 2004). Solid lines represent commonly observed changes between states of crop-livestock integration. Dashed lines represent changes between integration states using specific examples discussed in the paper

In areas where farmers have shifted production from mixed farming to specialised crop production, several risks have been identified. These include increased costs (chemicals and machinery), greater reliance on synthetic fertilisers over animal manures, the move away from largely organic systems to largely synthetic systems (risk of chemical residues, herbicide resistant weeds), and greater vulnerability to price variability in major crop commodities. Development of markets for livestock products would promote mixed systems.

Research is needed on integrating animal and crop production, both on an individual farm-scale, and on a larger industrial scale. Local farming systems are complex, intensively managed, and productive on an area basis. However, the profitability and sustainability of current systems is poor, and the integration of forage resources with cropping may provide solutions. Traditional Chinese farming systems have been highly integrated and there is opportunity for advancement through combining traditional knowledge and practice with newer technologies (GIS, computer simulation tools, etc.) for analysing resource use efficiency.

India

Livestock production in India is divided into urban, peri-urban, rural and transhumant systems (Misri, 1999). In urban and peri-urban systems cattle and buffalo are used for milk production. Dry animals are moved to rural areas where fodder is more available. Many farms around the urban centres specialise in forage production for the urban dairies, and crop-livestock interaction is minimal. Feed resources for these dairy animals include *Brassica* *napus* (rape), *Zea mays* (maize), *Pennisetum* spp. (millet), *Sorghum* spp., *Avena sativa* (oats), *V. unguiculata*, *M. sativa*, *Trifolium alexandrinum* (berseem clover), and crop residues (Misri, 1999). Indian urban and peri-urban dairy systems represent a form of area-wide integration (Figure 1). As milk collection from rural areas is limited by transportation and processing facilities, dairies became concentrated around urban areas.

The long-term sustainability of urban dairies is being questioned due to environmental concerns, competition for resources with people, lack of nutrient recycling (in most instances animal manure is dried into fuel cakes and sold for fuel) and the high cost of transporting forage. An alternative system for milk production has recently been implemented. Co-operatives have pooled resources for collection, processing, transportation and marketing of milk and milk products. As a result AMUL, the largest co-operative society in India (2.3 m producer members and 0.6 billion US $ annual sales; www.amul.com) is the major supplier of milk products, and has encouraged the development of smaller local co-operatives in different parts of India for fresh milk supply. The transportation of milk and milk products is less expensive than transportation of crop residue or green feed. This new system of milk production represents a shift from area-wide integration to integration at a more local level.

In rural areas, over 70% of farms are mixed enterprises (Singh *et al*., 1997), with a higher proportion of mixed operations in less productive arid and semi-arid zones. Animals are grazed on community pastures, wastelands, forests, and crop fields post harvest. Nomadic tribes use the transhumant system for rearing goat and sheep (Misri, 1999). During the non-crop period livestock is grazed on crop stubble and weeds. In some areas, agreements are made so that transhumant sheep and goats contribute nutrients to cropland through nighttime corralling. In addition to sustainability and ecological benefits, mixed farming in India provides socio-economic benefits such as rural employment (especially for women), social status, alternate sources of income, family nutrition and maximum return from limited land and capital.

Population pressure has reduced the permanent pasture area in India to 4% of total land area (Maehl, 1997). Invasion of pasture, forest and lakes by exotic weed species like *Parthenium hysterophorus*, *Eupatorium odoratum*, *Eichhornia crassipes* (water hyacinth) has further reduced grazing area available for livestock. Reduced pasture resource increases pressure on crop residues, which already contributes 66% of feed resources in the county (*O. sativa*, *Triticum*, *Sorghum* and *Pennisetum* spp.) (Zerbini & Thomas, 2003). However feed shortages are still severe (Singh *et al*., 1997; Kalloo, 2004). Therefore, efficiency of producing fodder, both spatially and temporally, is the top priority for sustainability of the livestock industry in India. Perennial crops or trees are also introduced in silvi-pastoral systems or silvi-horticulture systems to extend forage availability during the period when other feedstuffs are unavailable. Restoration of degraded grazing land and identification of suitable forage species for problem lands are also needed (Misri, 1999).

Crop-livestock integration is weakest in more productive agriculture regions of India (*O. sativa*-*Triticum* system area) (Figure 1). The use of tractor power, fertilisers and irrigation has contributed to less integration in these areas. Valuable crop residues are often burnt (Devendra & Sevilla, 2002). Small farming operations in the northern states like Punjab, Haryana, Uttar Pradesh and Rajastan are specialising in growing forages under irrigation in more than 30% of the cropped area to sell to livestock owners (Devendra & Sevilla, 2002), representing a form of area-wide integration. Sustainability problems (salinity, low fertility, weed problem, soil structure damage, shortage of organic matter) are increasing in these regions.

Southern Australia

The southern Australian crop-livestock system is driven by the need to remain profitable in the face of declining terms of trade and threats to sustainability. Local population pressure is not a factor, if anything, declining rural population and reduced labour availability is an issue.

The southern Australia wheat-sheep farming system is constantly adapting to the prevailing market and biological constraints. Indeed, this high degree of flexibility is one of the appealing features of the system. Farmers continue to practice variations of this system precisely because it has proven resilient in the face of declining terms of trade, and because it provides options for management of sustainability threats. Within the proposed model (Figure 1), the southern Australia farming system currently fits somewhere between the 'mixed system' and the 'specialised crop system'. In south Australia there is an association between average annual rainfall and the relative emphasis put on livestock and grain enterprises. As rainfall decreases and grain yield declines and becomes less reliable, livestock becomes more attractive.

In response to declining profitability of wool throughout the 1990's there has been an intensification of cropping at the expense of pastures and livestock in the medium to high rainfall zones, but not in the low-rainfall zone where reliable cropping options are not available. Since 2000, wool profitability has increased, and sheep meat has been profitable, resulting in an increase in livestock numbers and area under pasture. In addition, constraints to the sustainability of intensive cropping, such as herbicide resistant weeds and dryland salinity, have forced some growers to reintroduce pastures into their cropping systems. Pastures provide many options for non-selective herbicide management options, and can provide a high water use option if a perennial such as *M. sativa* is used.

Australian researchers are making good use of analytical tools (e.g. MIDAS, GrassGro and APSIM) to explore; 1) grazing management options where annual and seasonal climate variability provides major challenges; and 2) analysing rotational sequences where knowledge of soil water and nitrogen is critical for managing integrated crop and livestock production, under a variable climate. When used in conjunction with farmer knowledge, these tools can provide valuable insights into both the biology of the system, and farmer decision-making processes.

Uruguay and Argentina

Both Uruguay and Argentina have a long history of integrated crop-livestock production. Ley pasture systems based on *Festuca* and *Lotus* spp. are rotated with *Triticum*, *Zea mays* and other grains. A recent transition from integrated to specialised cropping (*Zea mays*, *Glycine max* (soybeans) under no-till management) has been most dramatic in the flat, productive soils in Buenos Aires province in central Argentina (Figure 1). In nearby southern Uruguay, where the land is hilly and susceptible to water erosion, mixed systems have been maintained as they have proven more sustainable than specialised cropping (Martino, *pers. comm.*).

Intensive cropping is driven largely by short-term profitability, sometimes at the expense of sustainability. An important question for Argentinian researchers is whether no-till grain cropping provides as many soil benefits as integrated grain-forage rotations. Subsoil constraints, such as compaction, may increase when deep-rooted perennial plants are absent in rotations (Martino, *pers. comm.*). Also, over-reliance on glyphosate, the herbicide that ‘supports’ no-till cropping systems worldwide, is of concern. However, the argument to retain mixed farming systems must be won on economic grounds. Comprehensive analysis including market and non-market values, and taking into account climate and market variability is needed.

Northern interior plains of North America

Like southern Australia, farms in western Canada and the northern USA are driven by the need to remain profitable in the face of threats to sustainability and trade. Local population pressure is not a factor. Growing season length (frost-free days) is a constraint to plant growth. The dominant forage systems are perennial grass pastures and *M. sativa* or *M. sativa*/grass mixtures grown for conserved forage.

Traditionally, mixed farming has been practiced on poorer lands while specialised crop production is practiced in longer-season areas, where soils are more productive (Figure 1). In response to strong wheat markets in the 1970’s even traditional mixed farms abandoned livestock in favour of specialised grain production. Many of these farmers have switched back to integrated systems due to a prolonged period of low profitability and biological constraints in specialised cropping (e.g. herbicide resistant weeds, soil salinity etc.). Currently, approximately 50% of farms in the region are integrated crop-livestock enterprises (Small & McCaughey, 1999) and many farmers have reinvested in infrastructure to support livestock in addition to crops. Despite having both livestock and crops in the same enterprise, the degree of integration is limited by management time, labour and producer knowledge. Integrated farming receives much less attention from researchers and extension workers than specialised production systems.

Example of area-wide integration for nutrient management

Expansion of the livestock sector in western Canada has necessitated partnerships between livestock and crop producers, as the former looked for avenues to utilise the nutrients present in the manure generated from the livestock operations, and also meets government regulations on manure disposal. One example of area-wide integration in response to these drivers involves beef cattle, pastures, grain and hogs (Figure 1). Four individuals who collectively owned 6,000 sows and 900 steers established a company in 1994. Manure produced from the swine operation was utilized to fertilise not only annual crops, but also forage land owned by the company. Cereal harvested from the annual crops was utilized in the swine rations, while the forage land was rented to local producers. As the swine component of the operation continued to grow, the potential to further integrate the operation by adding in a second livestock species – cattle was recognized. This was a logical choice, given that much of the land surrounding the swine operations was marginal and suitable only for forage production. Currently, the operation consists of 40,000 sows, 100,000 finishing and isowean sites, 600 cow-calf pairs and 300 yearling heifers. The number of acres of forage land has increased considerably, such that the total land base now consists of 180 ha of annual cropland, 800 ha of hay, 4000 ha of pasture and an additional 1200 ha that remains undeveloped. A portion of this forage land is rented to local producers and supports an additional 1000 cow-calf pairs during the summer months. Grain for the hog operations is purchased and processed by two mills that are owned and operated by the company.

Example of area-wide integration for ethanol production

Integrating ruminant livestock into ethanol production facilities has presented a new opportunity for area-wide crop-livestock integration. In Saskatchewan, one such facility integrated ethanol production (15 million litre ethanol/yr) with a 20,000 head beef cattle feedlot. This facility currently buys calves, grain and forage resources from farmers in the consortium. Economic analysis has shown that a cluster of 5 ethanol/beef complexes will purchase four times more resources from area farmers (grains, forages and livestock) than a comparable sized US corn ethanol plant.

Organic agriculture in industrialised countries

Organic farming is creating a renewed interest in integrated farming in many parts of the world. The absence of synthetic chemical use means that pest management relies on crop rotation, and soil fertility maintenance relies on crop rotation and animal manures. Over 30% of the land base on Canadian organic farms is dedicated to forage crops (Entz *et al*., 2001b), compared with less than 10% in conventional production. Therefore, organic farming systems represent a shift from specialized to integrated production at the local farm level (Figure 1).

Organic agriculture is most developed in Europe. In Scandinavia, for example, close to 50% of dairy production is organically managed. Fodder crops for these dairies (including seed crops), must be produced organically, creating new market opportunities for farmers and new challenges for researchers.

Synthesis

Previous workers have suggested that the evolution of crop-livestock integration begins with separate crop and livestock production (subsistence systems), integration (mixed farming), then specialization (current status in many industrialized countries), and finally integration on an area-wide basis (Steinfeld; 1998; Powell *et al*., 2004). Examples in the present paper suggest that while such an evolutionary pattern clearly exists, especially in response to population pressure and economic and market development, this model does not adequately describe all types of changes in crop-livestock integration. Examples presented here also show that crop-livestock integration is a dynamic process and is practiced at different scales. It appears, therefore, that the evolution of crop-livestock systems is best described by a 'state and transition' model, where systems move to different states depending on transition events (Figure 1). The state and transition model presented here depicts how systems may respond to changes in, for example, population pressure, market opportunities and unexpected environmental changes (development of dryland salinity, herbicide resistant weeds, nutrient loading, pollution, etc.).

While there has been a strong trend to specialised crop production on better quality land in many parts of the world, interest in integrating livestock into the crop production system is gaining strength. This shift from specialized to integrated crop-livestock production is driven by biological, economic and environmental sustainability problems associated with monoculture grain systems, as well as adherence to environmental regulations. Examples presented in this paper suggest that integration occurs in both directions (left and right; Figure 1) resulting in both small-scale on-farm integration and larger scale area-wide integration (Table 1).

Table 1 A summary of the two main types of crop-livestock integration in response to biological, economic and environmental constraints of specialised crop production

Type of crop-livestock integration	Major drivers for integration and location	Requirements for successful integration
Local, on-farm integration	- Soil sustainability (e.g. soil erosion in western China); - On-farm salinity (e.g. Australia); - On-farm economic stress; - Shift to organic production; - Population pressure (e.g. western Africa); - Energy costs; - Pest resistance.	- Knowledge (education); - Labour; - Local markets; - Government support; - Access to capital.
Area-wide integration	- Excess manure nutrients at farm-scale; - Wide-spread salinization; - Necessity to share resources with urban areas; - Opportunities to recycle manure nutrients through crops.	- Co-operation between groups of specialised crop and livestock producers; - Strong environmental legislation; - Government support and facilitation: - Technology (e.g. GIS).

While both on-farm and area-wide integration provides benefits over commodity specialisation, the nature of these benefits differ. Advantages of on-farm integration over area-wide integration are related to the benefits that come with increasing on-farm diversity. On-farm diversity is often the most effective way to; 1) address site-specific problems (e.g. soil erosion on sloping land such as in western China); and 2) exploit site-specific opportunities (e.g. predator-prey relationships in ecological pest control). Local or on-farm integration will have unique social benefits in that individual farmers will retain more control of their whole production system.

Advantages of area-wide integration over on-farm integration are related mostly to labour and economic efficiency. Area-wide integration may also address regional ecological problems such as soil salinisation, better than less coordinated efforts. Area-wide integration conforms to the industrial model of centralisation and standardisation better than on-farm integration, making it a more attractive option to policy makers and investors.

Summary and conclusions

Crop and livestock producers will always be connected, either through on- or off-farm linkages between feed production and manure recycling through crops. It is argued that the spatial nature of crop-livestock integration is important, as the interaction of crops and livestock has the potential to produce large benefits for people and the environment.

Farmers, who manage crops and livestock, adapt to local land and environmental pressures and market opportunities. Examples from a number of countries (Australia, Canada, China) were provided where farms evolved from mixed systems to specialised systems, and then back. While the trend to integration from specialised production in developed countries is perhaps strongest in the organic farming sector, sustainability issues on 'conventional' farms also are driving farmers to reconsider mixed farming systems. In high population density areas such as India and China, a strong move toward specialisation and area-wide integration is apparent. These examples support the conclusions of Steinfeld (1998), that integration is often a function of population pressure, however, the examples given in this paper also demonstrate that crop-livestock systems are dynamic and farmers sometimes switch between systems.

A trend observed in many countries is that mixed crop-livestock systems have largely been abandoned on better quality soils in favour of specialised cropping. A number of sustainability issues have been highlighted in specialised crop systems, e.g. soil salinity, pests (including pest resistance), and soil health. Models such as APSIM, MIDAS and others should enable researchers to assess the combined economic and environmental costs of specialised vs. integrated systems, and enable new systems to be tested and validated.

Farmers have proved their ability to adapt their farming systems to changing social, physical and economic conditions. This adaptability is central to the evolution of crop-livestock systems, and efforts to help farmers adapt must be ongoing. There is a worrisome trend in agricultural R&D for reductionism. This is most evident in the trend for research funding towards biotechnology. Agriculture is not just about soils, plants and animals, but also about people, a consideration that is sometimes woefully lacking in policy decision-making. There is a need to strengthen knowledge and understanding (through research) of the decision-making process used by crop and livestock producers.

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