Potential of Forages in Crop Diversification and Crop Rotation

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ABSTRACT

Redesign of agricultural systems according to ecological principles has been proposed for the development of sustainable systems. We review a wide variety of ecologically-based crop production practices that focus on forage crops in farming systems and discuss their potential role in enhancing the profitability, environmental sustainability and resilience. Crop-livestock systems that most closely mimic natural systems through appropriate integration of diverse components appear to offer the greatest potential benefits. These systems are more energy efficient and combine high productivity with low ecological footprint. Greater understanding of ecological relationships within crop-livestock systems are required to purposefully and proactively redesign agricultural systems for profitability, sustainability and resilience.

Key words: Crop diversification, Crop-livestock systems, Forages, Resilience

Introduction

The long-term sustainability of the agriculture sector depends on its ability to thrive economically while protecting our natural resource base and building resilience to stresses and shocks. Many problems in modern agriculture stem from reliance on simplified production systems consisting mainly of annual monocultures. Uncoupling of crop and livestock production has exacerbated the problem (Russelle *et al.,* 2007).

Gliessman (2010) argues that improvements in efficiency of input use and input substitution (e.g. herbicides instead of tillage) are not enough to address our challenges. Instead, he argues that farming systems must be redesigned based on a new set of ecological relationships. In other words, agricultural systems require systemic change. This review seeks to highlight the role of forages and forage-based rotations as part of redesigned systems.

Defining the goals

A wide range of approaches have been developed to evaluate the potential value of alternative agricultural practices, including both ecological and social components (e.g. Darnhofer *et al.,* 2010b). While assessment approaches differ, common themes of profitability, sound environmental practice (sustainability) and resilience (both ecological and social) recur throughout the literature.

Environmental Sustainability: Sustainable agriculture practices are based on biological and ecological processes, principally the interactions between soils, crops and animals (Malézieux, 2012). Such systems protect natural capital, minimize nutrient losses and use of non-renewable inputs, include recycling and feedback mechanisms, make optimal use of ecological niches, and include high levels of biodiversity, while continuing to be productive (Koohafkan *et al.,* 2012).

Profitability: Profitability refers to the capacity of an enterprise to generate more revenue through the sale of its products than it costs to produce those products. Profitability can be enhanced by increasing production, obtaining a higher price for products or by reducing costs. Major operating costs include purchased inputs (fertilizers and pesticides), seed, fuel and labour; thus any reduction in these inputs while maintaining yield and quality increases profitability.

Resilience: Resilience refers to the ability of a system to undergo change while still retaining control of its structure and function (Cabell and Oelofse, 2012). Heterogeneity in space and time, as well as functional and response diversity are key components of both ecological and social resilience. Resilience also requires a certain tension between adaptability and efficiency (Darnhofer, 2010a); redundancies within the system and apparent sub-functional diversity may be associated with lower short-term productivity but also provide greater capacity to recover from shocks (Lin. 2011).

Farmers play an important role in developing resilience, not only through their farming practices, but also through their ability to learn and adapt. Darnhofer *et al.,* (2010a) identify three elements that affect adaptive capacity: the ability of the farm manager to learn, the flexibility of a system (both its operation and strategic flexibility) and its diversity.

Forages in rotation

The benefits of perennial forages in rotation are well documented (e.g., Entz *et al.,* 2002; Olmstead and Brummer (2008). Forages improve yields of annual rotation crops; in a long-term study in northern Alberta, wheat yields after forage were 66-114% percent greater than continuous wheat for eight years after forage termination (Hoyt, 1990).

Perennial legumes can have a major impact on soil nutrient status (Kelner *et al.,* 1997), however, hay and silage systems remove large quantities of nutrients from the soil. Phosphorus (P) depletion can occur within a relatively short time frame, especially under organic management where nutrients are not replaced; however, returning livestock manure to the system can close the nutrient cycle and prevent depletion of soil nutrients (Welsh *et al.,* 2009). Grazing instead of haying would automatically cycle most of the nutrients within the system (Sigua *et al.,* 2006), without the cost of removing hay and applying manure.

Perennial forages provide non-nutrient benefits such as enhanced soil health and pest suppression (Entz *et al.,* 2002 and references therein) and environmental benefits; such as reduced nutrient leaching, increasing C deep in the profile (Olmstead and Brummer, 2008; Malhi *et al.,* 2009) and wildlife, in particular nesting birds and pollinators (Arnold *et al.,* 2007).

The mixed farm

The goal of integrating crops and livestock is “integration of function rather than mere diversification” (Schiere *et al.,* 2002). There are many different levels of integration ranging from small-holder systems to area-wide integration where farmers work together across regions (Russelle *et al.,* 2007).

Integration of crops and livestock can result in semi-closed nutrient cycles. For example, organic and biodynamic dairy farms in Ontario and Australia had P balances near zero on average. However, nutrient exports in agricultural products can result in a negative P balance even on mixed farms, especially when little or no feed is purchased (Lynch, 2006; Cornish 2007).

Central in mixed systems is availability of animal manure in the farming system. Many studies have observed excellent crop response to manure application, with yields often equal to or near the yield obtained with synthetic fertilizers (Buckley *et al.,* 2011; Rothamsted plots, pers observation). Much of the benefit to crops is through nutrient supply but non-nutrient benefits are also important. In a moisture-limited growing season in Utah, for example, application of composted manure increased the moisture retention capability of soil, improving yield (Stukenholtz, 2002).

Manure application to farmland also enhances soil C, microbial biomass, microbial activity, and populations of nematodes and natural enemies of crop pests. Carry-over effects on crop yield and other benefits to subsequent years are also commonly observed. Reeve *et al.,* (2012) observed positive effects on crop yield, soil organic C and microbial biomass 16 yr after compost application in dryland wheat.

The overall benefit of mixed farms with perennial forages was recently demonstrated by Davis *et al.,* (2012). In their study, mixed farming produced better sustainability, resilience and profitability outcomes than the prevailing corn-soybean complex. This story was so compelling that is was featured in the New York Times.

It is important to recognize that mixed farms can fall out of balance. Manure application at high rates and/or frequency can result in nutrient accumulation in soils, contamination of surface and ground water, and increased GHG emissions (Ashjaei *et al.,* 2010). Appropriate management practices such as those described by Shoenau and Davis (2007) and others can effectively mitigate the potential for nutrient loss and environmental contamination. Improved manure processing and application practices allow for novel approaches to using manure on cropland. Transporting liquid manure long distances is energy intensive (Wiens *et al.,* 2008) and has prompted research on methods to separate solid and liquid components of liquid manures and on the agronomic effects of the resulting components (e.g. Bittman *et al.,* 2011). Implements for improved application of solid manure are also being developed (e.g. Laguë *et al.,* 2006). Composting manure may enhance its agronomic and soil health benefits (Lynch *et al.,* 2005).

Dynamic crop-livestock integration

Cheap and available energy, a drive to specialize and the loss of rural workers are reasons why mechanized mixed farms have been adopted. However, the opportunity costs to such specialization, where animals are removed from pastures and placed into confinement have increased as attention is paid to environmental consequences and animal health and welfare concerns. One farmer commented "Animals like to walk and plants like to stay put – but our agricultural system assumes the opposite". Therefore, reintegrating grazing within mixed systems has become an important goal as we strive for more sustainable. Results of a large on-farm study in Manitoba, Canada showed a higher net return ($156/acre) when the perennial phase in the rotation was grazed vs hayed ($104/acre) (Khakbazan, pers comm).

Grazing forages is also becoming more important as consumers shift their preference to grass-finished animal products. Farm-based production groups to facilitate forage-finishing have recently become established (eg. Manitoba Grass-Fed Beef Association; http://manitobagrassfedbeef.ca/).

Two additional innovations being attempted by farmers in an effort to increase grazing include 1) winter grazing and 2) green manure grazing. Alternative winter feeding systems, in which cattle are fed baled or swathed forages on pasture or cropland or allowed to graze crop residues such as corn stover have reduced overall costs by reducing

Table 1: A comparison of three beef production systems: Western Canada

Production system	Animal considerations	Profitability	Sustainability	Resilience
Feedlot system	-Breeds designed for grain finishing -Forage only during juvenile stage	-Cost of production high -Net return variable -Risk high	-Low energy and water use efficiency -Biodiversity low	-Cropping system low resilience to drought or flooding -Animal health poor
Mixed farm with hay and manure spreading	-Variety of breeds used. Some interest in more efficient feed utilization	-Cost of production lower -Net return variable -Risk medium	-Energy and water use efficiency improved over feedlot system -C sequestration better -Biodiversity better	-Cropping system resilience improved due to better rotation -Animal health improved
Mixed farm with emphasis on pasture, i.e., forage-finished system	-Breeds designed for forage-finishing -Forage only diet throughout lifetime	-Cost of production low -Net return high due to price premium and lower production costs -Risk low	-Energy and water use efficiency high; close to natural state. -Soil C sequestration high -Biodiversity high -Food quality high	-Cropping system resilience high. -Animal health close to natural state

forage harvest and manure hauling costs (McCartney *et al.,* 2004), if costs associated with watering systems, forage wastage, and checking cattle are not excessive (Nayigihugu *et al.,* 2007). These feeding systems also have potential to enhance nutrient return to farmland and the performance of subsequent crops. In two Saskatchewan studies, soil N and P concentrations, nutrient recovery, and subsequent crop productivity were increased in at least some field locations after bale or swath grazing on annual cropland or grass pasture (Kelln *et al.,* 2012).

Green manure legumes are gaining popularity as a strategy to reduce N fertilizer costs and reverse declining soil health. Integrating grazing livestock into green manure or cover cropping systems is the best way to make green manuring profitable (Thiessen Martens and Entz, 2011). While research into these systems is limited, results indicate that crop yields following grazed green manures are equal to those following green manures that were not grazed (Franzluebbers and Stuedemann, 2007). Because grazing increases N availability, animals can be used to regulate N mineralization in ecological farming systems (Cicek *et al.,* 2015). The effects of grazing cover crops on soil health are a major motivator for those producers who are using this system. Fraase *et al.,* (2010) reported that soil bulk density decreased from 2009 to 2010 where turnip (*Brassica campestris* var. *rapa* Linn.) and "cocktail" cover crops were produced and grazed. In other regions, researchers have found that grazing increased soil microbial biomass (Franzluebbers and Stuedemann, 2008a) but had no effect on bulk density or soil aggregate stability (Franzluebbers and Stuedemann, 2008b).

Conclusions

Crop-livestock systems that embrace ecological principles and local ecologies contribute to better outcomes for the agricultural systems. Grasslands play a central role in such designs. We have argued that these systems require systemic change if profitability, sustainability and resilience are to be optimized. The challenge to align Canadian prairie agricultural systems with ecological principles is immense, especially in the current context of agricultural development where short-term productivity and economic efficiency are emphasized. However, the more holistic goals encompassed in ecologically-based systems are fundamental to the long-term success of any sector or society and are worthy of serious pursuit.

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