Farming system changes in the prairie grassland ecoregions of Canada, 1991 to 2006

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In recent years, issues related to sustainable farming, natural resource conservation, and global climate change have created a demand for information about the economic and environmental implications of agricultural production systems. In order to make informed decisions, policy makers and other stakeholders need to know the structure, function, and demographic situation of different farming systems; their location and biophysical resources; how they perform with respect to financial and social benefits; how they change over time in response to changes in technology; markets and input costs; and how they affect the natural environment.

This study was initiated as part of a program to estimate the impacts of the emerging bioeconomy on the agricultural landscape and the environment. Specifically, our aim was to develop the capacity to predict the impact of biofuel production scenarios on soil carbon and greenhouse gas (GHG) emissions. Recognizing that widespread production of grain and cellulosic ethanol and oilseed biodiesel may have different implications for different farm types and regions, we are integrating economic (policy) models with biophysical process models and incorporating a “whole-farm” or “farming systems” approach into our predictive modeling. This report outlines our initial exploratory efforts to develop interdepartmental working protocols, a knowledge base and methodologies of identifying farming systems and characterizing system changes in the grassland ecoregions of Alberta and Saskatchewan. Once we gain an understanding of the normal evolution of systems versus periodic and dramatic changes in systems, we will move toward identification of the drivers of change, and models will be developed for prediction of changes that can be expected under different policy and economic scenarios.

Farming systems may be considered from an activity perspective or from an economic viewpoint, but they are usually defined in terms of two key components: (1) the production system, which consists of biophysical (land, water, and climate) and economic (inputs, outputs, and technology) components and (2) the management system, comprised of the farm operator and his/her knowledge, access to resources, and decision-making abilities (Sorensen and Kristensen 1992; Keating and McCown 2001). From the perspective of concepts and levels, Colin and Crawford (2000) outlined a hierarchy of systems related to agricultural production, identifying cropping systems at the plot level, farming systems at the farm level, and agrarian systems at regional levels. Similarly, Ker

(1995) described farming systems as decision-making and land-use units, which included crops and/or livestock systems along with relevant biophysical, economic, and management factors.

Despite the broad conceptual range in defining farming systems, most of the literature outlining applied studies relates to identification of a few specific farm units within a local area and comparison of the performance of one or a few management practices, such as nutrient use strategies, tillage routines, or crop rotations (e.g., Australian Farming Systems Association Conference Papers Database, http://afsa.asn.au/cgi-bin/afsapapers/display.cgi?search=1&searchtext=99). Land use is important in analysis of farming systems, and three types of studies can be identified (van Ittersum 1998): (1) exploratory studies, which are designed to enhance knowledge and to identify a range of viable options; (2) projective models, which analyse past changes in relation to biophysical and socioeconomic parameters and attempt to identify and project trends; and (3) predictive studies, which model land-use changes as a consequence of changes in policies or technologies (Stoorvogel and Antle 2001).

Methodological approaches to farming systems research vary with the purpose of study. A wide range of procedures and techniques have been used, from statistical techniques (De Koning et al. 1999) to linear programming (Bouman et al. 1999), simulation models (Crissman et al. 1998), database management systems, geographic information systems (GIS), and biophysical models. It is becoming clear that simulation and prediction of land-use change requires integration of economic models with biophysical-process models, such as the linkage of site-specific biophysical models with economic models, as proposed by Antle and Capalbo (2001), or GIS-based biophysical and economic modeling, as proposed by Stoorvogel et al. (2004).

This study constitutes Phase l of a larger, more comprehensive project to develop the capability to predict agricultural land-use change. Our aim was to develop knowledge and test technologies of incorporating farming systems into our predictive economic–biophysical modeling exercises. Our specific objectives were to develop and implement a farming systems typology, to identify groups of farms that have and have not undergone a change in system over the past 15 years, and to determine whether those groups exhibited differences in socioeconomic characteristics. Our region of inference was the arid grasslands ecozone of Canada, in which climatic conditions restrict production options to spring cereals, oilseeds, hay, and native rangeland.

The study was driven by the need to predict implications of biofuel production on soil and air quality, as it is anticipated that a burgeoning market for grain and oilseeds will lead to the conversion of hay, pasture, and rangeland to annual crop production. With time, as cellulosic ethanol production becomes economically viable, there will be additional pressure to convert marginal land that is currently in a natural (grassland, shrubland) or seminatural (rangeland, native hay) state to more intensively managed perennial biomass crops. Since some farms are more likely to undergo land-use changes than others, and some are more likely to change more quickly in response to outside influences, it is essential that the approach be more comprehensive than a simple spatial analysis of crops and soils. Factors such as operator characteristics (age, education, and family situation), enterprise type, investment needs, regulatory requirements, and support programs are examples of nonbiophysical determinants of farm-level response to new or changing market opportunities. In order to predict the location, extent, and timing of land-use changes likely to occur, a thorough understanding and documentation of the characteristics of farms which undergo change, and the type of change that different farming systems are prone to, must be developed.

The premise of this study was that the Census of Agriculture (CoA), with its five-year timeframe, complete farm coverage, broad range of variables and spatial and longitudinal links, could be a prime resource in farmland change analysis. Specific objectives were as follows:

- Develop a farming systems typology that could be based on specific combinations of crops and livestock and that could be applied to every farm in the census
- Apply the typology to every farm in each of the census years (1991, 1996, 2001, and 2006)
- Trace each farm and its system type and characteristics for each intercensus period (1991 to 1996, 1996 to 2001, and 2001 to 2006)
- Generate a structural and socioeconomic profile of farms remaining in each system versus farms that underwent change within each intercensus period
- Compare and contrast the system profiles of changed versus unchanged farms

Follow-on work will be directed toward using the relationships between system changes and socioeconomic characteristics to develop projective and predictive capabilities. A companion study is being conducted in order to identify the potential and constraints that soil and climatic resources impose on land-use change options.

Materials and Methods

Our study area included the Moist Mixed Grassland, Fescue Grassland, Mixed Grassland, and Cypress Upland Ecoregions of Alberta and Saskatchewan (figure 1). Arid conditions of these regions limit agricultural activities to dryland production of spring cereals, canola, tame hay, and native range and irrigated grain and specialty crops, such as alfalfa, potato, sweet corn, and sugar beet. We felt that the limited range in crop and management options would be a benefit in this exploratory stage, but the methodology would eventually need to be extended to the entire country.

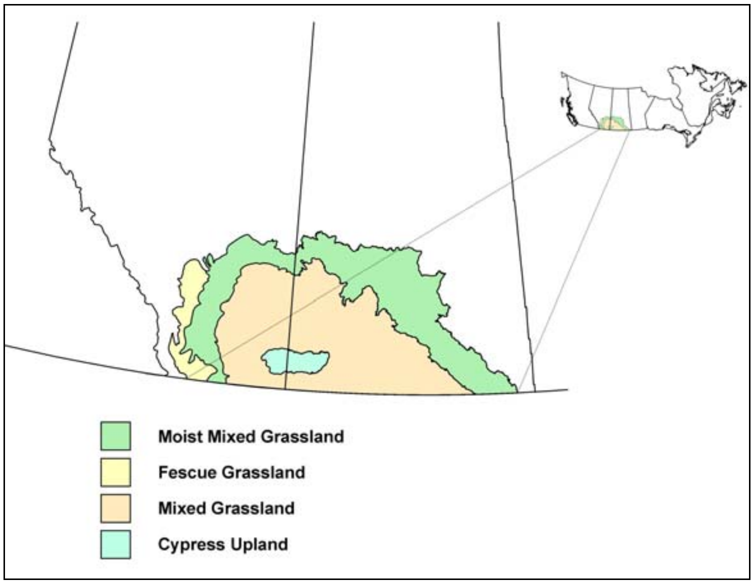

Figure 1. Map of the study site in Canada.

Canada's Census of Agriculture database (Statistics Canada 2007), collected every five years on every farm in the country, provides information on over 100 variables, including type of operating arrangement; area of each crop and land-use type, such as rangeland and other land (forest, wetlands, and building sites); number of each type of livestock; use of specified conservation practices (conservation tillage, contour cultivation, grassed waterways, etc.); area of manure, fertilizer, and pesticide application; individual and total income and expenses; size and number of each type of machinery; and estimated value of capital items. The census definition of a farm is any operation with at least $2,500 in sales of agricultural products within the past year, including maple sugar and Christmas tree sales. Each farm operator is identified by a unique code that can be used to trace his/her farm through different census years, but the farm disappears from the series with a change of operator. Thus, one farm will disappear and a new one will appear with the transfer of farm operations from a parent to a child.

Statistics Canada is bound by confidentiality provisions which prohibit releasing data in a manner that would allow data to be attributed to an individual or single business entity. Any data for release are thus subject to aggregation or suppression in areas or variables with few farms reporting. Practical adherence to the confidentiality legislation generally restricts the release of data to an aggregation of 5 farms or more, depending on the sensitivity of the data. The database is nonetheless extremely useful, and Statistics Canada and Agriculture and Agri-Food Canada (AAFC) have collaborated in the interpolation of the census data from census-specific spatial units to Soil Landscapes of Canada polygons (Huffman et al. 2006) in order to create a socioeconomic database on a natural spatial stratification. The resultant database has been integrated with biophysical information from the soils database in a variety of environmental and production-related national assessments (Palko et al. 1996; Huffman et al. 2000; Yang et al. 2007).

For this project, use of individual farm records was required, rather than aggregated data as in previous studies. In order to identify farms within the study area, a map of Census Consolidated Sub-Divisions (CCSD; census-defined polygons to which farm data are linked) was intersected with a map of ecoregions. All farms in a CCSD entirely within the study area were extracted for analysis (figure 2). Use of individual farm records required special arrangements between the two federal departments, as these microlevel data are only accessible by Statistics Canada personnel due to the confidentiality provisions. In this case, objectives and analytical needs were provided by AAFC scientists to Statistics Canada researchers, who then conducted the analysis and suppressed data where necessary to ensure confidentiality before releasing it to AAFC.

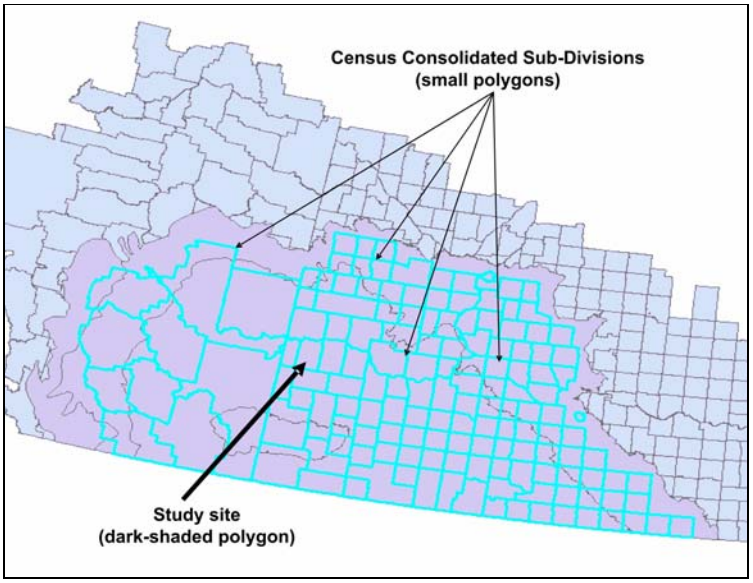

Figure 1. Intersection of Census Consolidated Sub-Division and ecoregion boundaries in the study area.

The systems typology was established a priori on the basis of crop mix and livestock density and formed a continuum from intensive livestock operations to mixed farms, and to cash crop farms. All other structural, management, and socioeconomic variables were used for characterization of systems and system changes. The first step was to create crop and livestock classification variables, with crops grouped on the basis of agronomic practices and potential biofuel uses and livestock numbers converted to animal units based on manure excretion rates (Hofmann and Beaulieu 2006). Crop groupings are presented in table 1, while animal unit values are shown in table 2. Several ratio variables for use as specific criteria were created, as shown in table 3.

Table 1. Grouping of census crop variables for farming systems classification.

Annual crops	Perennial crops	Specialty crops
Cereal grains	Alfalfa	Tobacco
Oilseeds	Tame hay	Vegetables
Pulse crops	Improved pasture	Berries
Soybeans	Unimproved pasture	Grapes
Corn (Maize)	Forage seed	Tree fruit
Other field crops		Nursery crops
		Potatoes
		Sugar beets

Table 2. Animal units of each census livestock type for farming systems classification.

Animal	Units	Animal	Units
Dairy cows	1.689	Hogs	0.076
Bulls	1.143	Goats	0.071
Steers	0.714	Sheep	0.049
Beef cows & heifers	0.662	Turkeys	0.009
Horses	0.623	Laying hens	0.003
Calves	0.321	Pullets & broilers	0.002
Bison & deer	0.234	Other poultry	0.007
Boars & sows	0.101		

Table 3. Ratio variables generated for use as farming systems class criteria.

Ratio variable	Components
AGLAND (agricultural land)	Annual crops + Perennial crops + Specialty crops
FARMLAND (farmland)	Agland + Summerfallow
RANNCF (Ratio of annual crops)	(Annual crops + Summerfallow) / Farmland
RPERCF (Ratio of perennial crops)	Perennial crops / Farmland
RSPECF (Ratio of specialty crops)	Specialty crops / Farmland
RANUFL (Ratio of animal units)	Animal units / Farmland

Distribution histograms of each classification variable were generated and used to identify natural breaks in data, which were used with expert judgement to establish a preliminary classification. A hierarchical system of classes, subclasses, and sub-subclasses was developed, and several iterations of data review and class limit adjustment were required in order to finalize the classification system.

The classification criteria were applied to each farm within the study area for each of the census years evaluated (1991, 1996, 2001, and 2006), and each farm was given a class, subclass, and sub-subclass identifier. The unique operator code was used to identify each farm as "traced," "disappeared," or "appeared" within each intercensus period. Although farms that "disappeared" or "appeared" can and will be characterized and analysed in future efforts, we only considered "traced" farms for this study. We compared farming systems and changes on the basis of fundamental characteristics: (1) farm size, (2) number of cattle, (3) capital value, (4) gross margin, (5) off-farm work, and

(6) operator age. These variables represented only a small fraction of data available in the census, but they provided a concise basis for a comparison of the systems, as well as a review of differences among farms that remained in each system versus those that moved out of each system within a five-year period.

Results and Discussion

The grasslands study area covered 25 Mha (62 million acres) in southern Alberta and Saskatchewan. The four ecoregions are more commonly referred to as the Brown and Dark Brown Soil Zones and are comprised of predominantly Chernozemic soils. The region receives an average of 400 mm of precipitation annually, and the growing season moisture deficit requires use of moisture enhancing practices, such as snow trapping, strip cropping, and summer-fallowing. Local areas with better growing conditions are devoted primarily to wheat, barley, canola, and tame hay, while large tracts of poorer soils are used for native range and pasture and smaller areas support irrigated crops. Census data for the study area recorded a total of 33,296 farms in 1991, 31,930 in 1996, and 28,617 in 2001, and approximately 75% of farms could be traced from one census to the next (table 4).

Table 4. Characteristics of traced farms in Year 1 of each intercensus period.

Census year	Total number of farms	Number of traced farms	Annual crops (%)	Range-land (%)	Summer-fallow (%)	Hay & pasture (%)	Total cattle (000)	Total pigs (000)	Value of land, buildings & machinery ($M)	Total annual gross margin ($M)
1991	33,296	26,120	36	31	23	7	1,855	655	14,499	574
1996	31,930	23,582	39	32	18	8	2,472	723	17,852	959
2001	28,617	21,501	41	32	14	10	2,765	1,180	20,073	740

The farming systems classification scheme had three farm groups at the class level, eight at the subclass level (table 5), and 11 at the sub-subclass level (not shown). The study area consisted primarily of farms in three of the subclasses: annual crop farms (Cash Crop), mixed farms–annual (Mixed), and mixed farms–perennial (Ranches). These three subclasses were the focus of our characterization analysis. We also included livestock farms (Feedlots) in the analysis because of the distinctive nature and significant financial aspects of this type of farm. The four systems included 95% of all farms that could be traced in each period in the study area. The proportion of farms that retained the same system designation versus those that changed systems in each five-year period is presented in table 6, while changes in characteristics (relative to their value in Year 1) of farms in the two groups are presented in table 7.

Table 5. Farming systems classification.

Class	Subclass	Criteria
Intensive Livestock Farms (very high livestock density)	Livestock (**Feedlots)**	RANUFL > 0.8 & ANUNIT >= 5
Crop Farms (very low livestock density)	Specialty Crop Farms	RANUFL<0.005 & RSPECF>0.333
	Annual Crop Farms (**Cash Crop**)	RANUFL<0.005 & RANNCF>=0.75
	Perennial Crop Farms	RANUFL<0.005 & RPERCF>=0.75
	Mixed Crop Farms	RANUFL<0.005 & FRMLND>0
Mixed Farms (mixed crops and livestock)	Mixed Farms - Specialty	FRMLND>0 & RANUFL>=0.005 & RSPECF>0.333
	Mixed Farms - Annual (**Mixed**)	FRMLND>0 & RANUFL>=0.005 & ANNCF>=RPERCF
	Mixed Farms - Perennial (**Ranch**)	FRMLND>0 & RANUFL>=0.005 & RPERCF>RANNCF

Table 6. Proportion of farms retaining systems versus changing systems (%).

		Year 2			
Year 1		**Feedlot**	**Cash crop**	**Mixed**	**Ranch**
Feedlot	1991-1996	50.8		49.2	
	1996-2001	49.3		50.7	
	2001-2006	49.1		50.9	
Cash Crop	1991-1996		85.9	14.1	
	1996-2001		86.6	13.4	
	2001-2006		83.2	16.8	
Mixed	1991-1996		29.1	70.9	
	1996-2001		36.7	63.3	
	2001-2006		41.6	58.4	
Ranch	1991-1996			24.2	75.8
	1996-2001			21.0	79.0
	2001-2006			18.7	81.3

Table 7. Change in farm characteristics and operator age of farms that maintained system versus those that changed systems in each 5-year period.

		Relative change between Year 1 and Year 2								
		Farm size			Total cattle			Value of land, buildings, & machinery		
Year 1	Year 2	91-96	96-01	01-06	91-96	96-01	01-06	91-96	96-01	01-06
Feedlot	Feedlot	0.31	0.42	0.16	0.67	0.81	-0.12	0.54	1.21	0.13
Feedlot	Mixed	1.76	2.13	1.48	-0.45	-0.56	-0.47	1.31	1.05	0.85
Cash Crop	Cash Crop	0.06	0.09	0.10	0.12	-0.19	-0.11	0.30	0.19	0.29
Cash Crop	Mixed	0.12	0.06	0.11	76.00	113.39	104.84	0.34	0.24	0.25
Ranch	Ranch	0.00	0.02	0.07	0.17	0.03	0.17	0.31	0.26	0.35
Ranch	Mixed	-0.19	-0.08	0.10	0.19	-0.13	0.09	0.25	0.27	0.52
Mixed	Mixed	0.08	0.11	0.13	0.26	0.12	0.18	0.33	0.32	0.30
Mixed	Cash Crop	0.04	0.02	0.06	0.39	0.05	0.18	0.25	0.15	0.23

Table 7. Continued.

		Relative change between Year 1 and Year 2						Operator age (yrs)			
		Gross margin			Off-farm work						
Year 1	Year 2	91-96	96-01	01-06	91-96	96-01	01-06	1991	1996	2001	2006
Feedlot	Feedlot	0.52	-0.39	0.10	0.06	0.01	0.03	42	43	48	49
Feedlot	Mixed	0.32	0.32	-0.46	-0.86	-0.85	-0.07	39	43	44	49
Cash Crop	Cash Crop	1.03	-0.31	0.02	0.04	0.03	-0.04	47	48	50	54
Cash Crop	Mixed	1.41	-0.29	0.12	-0.79	-0.84	-0.02	43	46	49	52
Ranch	Ranch	0.34	-0.14	0.12	0.00	0.02	-0.02	53	52	51	53
Ranch	Mixed	0.65	-0.28	0.21	-0.87	-0.86	-0.06	47	49	48	52
Mixed	Mixed	0.82	-0.10	0.09	-0.01	0.02	-0.09	44	45	48	52
Mixed	Cash Crop	0.47	-0.34	-0.16	-0.84	-0.87	-0.15	47	46	47	52

Primary system changes that occurred over the study period were shifts from Feedlots, Cash Crop, and Ranches to Mixed, as well as shifts from Mixed to Cash Crop. Farms classified as Feedlots were the most volatile, with 50% of farms designated as Feedlots in Year 1 switching to Mixed by Year 2. Cash Crop was the most stable group class, with about 85% retaining class designation from Year 1 to Year 2; the remainder switched to Mixed. Between 30% and 40% of Mixed farms became Cash Crop in each intercensus period, while about 20% to 25% of Ranches became Mixed.

Farms that switched from Feedlots to Mixed had greater increases in total farm size and value of land, buildings, and machinery, and showed decreased livestock numbers compared to those farms that remained classified as Feedlots. However, those farms remaining as Feedlots had slightly greater improvement in gross margins over the study period. Operators of farms that changed from Feedlot to Mixed were slightly younger than those who stayed, and they reduced their off-farm work substantially.

Farms that shifted from Cash Crop to Mixed increased farm size slightly more and herd size dramatically more than those that remained as Cash Crop operations. Growth in capital value was about equal for both groups, while those that switched had slightly improved gross margins. Farmers who shifted to a Mixed operation were younger and decreased their reliance on off-farm work to a much greater extent than those who maintained a Cash Crop operation.

Farm size grew slightly on farms that were Ranches in both Year 1 and Year 2, but farms that switched from Ranch to Mixed declined slightly in size. Cattle herd size and asset value grew at approximately the same rate in both groups, but gross margin improved slightly more in farms that switched systems. Farmers who changed from a Ranch designation tended to be younger than those who remained, and their level of off-farm work dropped more than those who remained as Ranches.

One change that represented a drop in animal density and that occurred in relatively large numbers in the study was the switch from Mixed to Cash Crop. Farms that remained Mixed grew in size at a faster rate than those that switched, but herd size grew significantly in both groups. Those farms that did not change systems had higher growth in capital value and gross margins, and operators tended to be younger and maintained their level of off-farm work to a greater extent than those that switched from Mixed to Cash Crop.

Structural and financial changes in farming systems outlined here document trends that are commonly recognized, such as declining farm numbers and transitions into either large, intensive, specialized farms with full-time operators or smaller, mixed farms with operators who work off-farm. However, the analysis also revealed some other, less widely recognized trends, such as the growth in size of smaller, mixed farms; the similarity in rate of change of financial characteristics of all farms; the general increase in livestock density; and the dramatic association of systems change with reduced off-farm work. Identification of these more subtle changes highlights the value of this analysis of individual farm census records and reveals aspects which should figure prominently in future modeling and prediction of land-use change in the agricultural landscape.

Summary and Conclusions

This was an initial, exploratory study to use Census of Agriculture data for developing the knowledge, framework, and methodology required to incorporate a farming systems approach into integrated policy–environmental modeling. In this phase, the feasibility of developing and applying a systems typology and of interpreting the results to identify changes in the structure of the farming industry was tested. The study was conducted in the grassland ecoregions of Alberta and Saskatchewan in western Canada and covered the years 1991 to 2006.

We identified four systems in the study area: Feedlots (including both cattle and hog operations), Cash Crop, Ranches, and Mixed farms. Analysis of changes between and within systems indicated several trends. Farms that remained in a system over the years tended to be larger and more heavily capitalized, but had lower gross margins and operators tended to be older and did not rely on off-farm work. Farms that changed either crop distributions or animal densities sufficiently to change system classes tended to be smaller and operators were younger and tended to shift away from off-farm work. Primary changes in the 1991 to 2006 period were decline in farm numbers, growth in size of remaining operations, and dramatic increase in cattle numbers.

The Census of Agriculture in Canada is a rich database with significant potential for new and expanded uses in policy and environmental modeling, and it enabled us to establish the protocols of AAFC-directed research using farm-level data. Realization of the full potential of these data will require continuous and long-term application of rigorous statistical procedures, such as multivariate analysis to reduce redundancy and analysis of variance to identify significance. A wide range of variables could also be statistically clustered in a procedure similar to that used to identify sample sites in order to create the farm classification system (Huffman et al. 2006).

This study suggests significant potential for improving evaluation of planning and policy scenarios. For example, establishment of a grain-ethanol plant would have earlier and more significant impacts on nearby Cash Crop farms, while a cellulosic-ethanol or solid biofuel processing plant that provides an improved market for biomass crops on marginal land would have more significance to Ranches and Mixed operations. Incorporation of the number and area of farms in each system into an economic or soil organic carbon model would enhance the outcomes of modeling exercises, either as a facility siting exercise or in impact analysis. Similarly, identifying and mapping the location and characteristics of Feedlots would be of benefit in transportation, emergency response, and water-demand studies.

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