A Comparative Analysis of Production and Resource Efficiency: Small versus Large Farms in U.S. Agriculture

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Abstract

Increases in human population and consumption have placed unprecedented demands on food systems and natural resources. Consequently, food production systems of the future will not only depend on, but must contribute positively to, healthy ecosystems and resilient communities. Emerging evidence advocates for the importance of small farm agriculture and localized food systems as the means in which to address many of the underlying causes of deteriorating agricultural productivity while aiding in the conservation of natural resources. This study illustrates an alternative to large conventional farming – one that provides evidence of bettering society and preserving the natural environment. Specifically, the alternative to large conventional farming makes use of a land-based perspective, which replaces farm income as the prevailing methodology of farm scale analysis and provides previously non-existing information on agricultural trends in the United States (U.S.).

The findings gleaned from utilizing this land-based perspective suggest that small farms, relative to large farms, produce a comparable amount of food per acre – supported by both direct and indirect measures. In particular, the output value gained for each unit of land input was significantly greater for small farms even though overall production efficiency favoured large farms. Further, while the extent of resource input was lower for small farms, the intensity of use per unit of land was correspondingly greater. Nevertheless, environmental merit was still indicated based on the significant proportion of woodland preserved in small farm landholdings as compared to the minor proportion preserved by large farms. Lastly, while both small and large farms provide a composite of varying social benefit, small farms display the greatest social merit in terms of job provision and public accessibility, both of which are proven to increase the resilience and sustainability of agricultural food systems.

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Introduction & Literature Review

Global Food Challenges

Contemporary agriculture faces the challenge of both increasing human population and consumption placing unprecedented demands on food systems and natural resources. In recent decades, global croplands, pastures, plantations, and urban areas have expanded. These land-use changes accompany large increases in energy, water, and fertilizer consumption, together with considerable losses of biodiversity (Rosegrant 2009). While changes in land-use have enabled humans to appropriate an increasing share of the planet's resources, they also undermine the capacity of ecosystems to indefinitely sustain food production. Agriculture faces the challenge of managing trade-offs between immediate human needs and maintaining the capacity of the biosphere to provide goods in the long term.

In post-war North America, economic incentives and technological advancements led to increased agricultural productivity through the use of high-yielding cultivars, chemical fertilizers and pesticides, mechanization and irrigation (Benton 2003). This period induced unprecedented agricultural intensification with a 700% increase in global fertilizer use and a 70% increase in irrigated cropland area (Foley et al. 2005). Today, croplands and pastures have become one of Earth's largest terrestrial biomes, rivaling forest cover in extent (Bruinsma 2009). Global croplands cover 12% of Earth's ice-free land, while pastures another 26%, together occupying 38% of Earth's terrestrial surface, establishing agriculture as the largest use of land on the planet (Foley et al. 2005). In the past four decades, agricultural intensification with technological advances, and agricultural expansion with a 12% increase in world cropland have enabled global grain harvests to double (Foley et al. 2005).

Although the modern agricultural advances of expansion and intensification have successfully increased food production, they have also resulted in extensive, and often irrevocable, environmental damage (Pimentel 1973). Agricultural expansion occurs when croplands and pastures extend into new areas and replace natural ecosystems negatively impacting biotic habitats and biodiversity. Such land clearing for crops and pasture have reduced the extent of natural habitats on arable land by more than 50% (Green et al., 2005). Habitat modification through agriculture is the most important factor in increasing species' risk of extinction (Nellemann 2009). With this loss of biodiversity in both natural and agricultural systems comes the loss of other ecosystem services, many of which are critical in agriculture for nutrient cycling, pest regulation, and pollination (FAO 2008).

Agricultural intensification, where existing lands are made more productive through the use of irrigation, fertilizer, pesticides, and mechanization, dramatically increased in recent decades to outstrip rates of agricultural expansion. Of particular concern regarding intensification is the 70% of global freshwater withdrawals devoted to irrigation (Foley et al. 2005). In addition, some irrigated lands have become heavily salinized, causing a global loss of 3.7 million acres of arable land per year (Foley et al. 2005). These losses are worsened by increasing competition for land from urbanization, industrialization, energy demand, and population growth (Msangi et al. 2009).

Agricultural expansion and intensification cannot continue indefinitely, ecologically or economically (Paneerselvam 2011, Peterson 1997). Until recently, agricultural paradigms have focused on improving production, often to the detriment of the environment. At the same time, many ecological conservation strategies have not sought to improve food production, favouring instead, resource preservation. To achieve food security and environmental sustainability, however, agricultural systems must transform to meet future food production needs while also practicing long-term conservation (Rosegrant 2003).

Changing Perspectives

The history of agriculture reveals the importance of land management for the conservation of natural resources and the preservation of biodiversity. Further, the intensified "conventional" agricultural systems that dominate most of North America have been questioned on production, environmental, and social grounds (Foley et al. 2005). With respect to production, conventional systems have contributed significantly towards intensification to produce mass, "anonymous" products rather than "local" and specific character ones (Casado 2009). With respect to the preservation of natural resources and the rural landscape, conventional systems are largely responsible for environmental externalities and tend to produce homogeneous landscapes that are hostile to most wildlife (Rosset 1999). In terms of social considerations, conventional agriculture is held accountable for both exacerbating social inequalities and the severance of humans from nature (Trevors 2010).

Rather than diversified farming systems, conventional agriculture typically favours single crop production, a practice commonly known as monocropping (Benton 2003). While economically a very efficient system, allowing for specialization in equipment and crop production, monocropping damages soil ecology through depletion or reduction in diversity of soil nutrients (Nelson 2006). Monocroppping creates an unbuffered niche for parasitic species and increases crop vulnerability to opportunistic insects, plants, and microorganisms (Nelson 2006). The result is a more fragile ecosystem with an increased dependency on commercial pesticides and fertilizers, compounded by increased mechanization and fossil fuel dependency. It is noted, however, that some conventional farmers do recognize these issues and hold great concern in promoting agrobiodiversity and soil quality using methods such no-till and precision agriculture for sparing chemical usage (Webber 2011).

The development of "alternative" or "sustainable" management is viewed as a way to ameliorate some of these impacts (Ho 2011). Although the term "sustainable agriculture" carries many different meanings, it is generally linked with farming systems that are capable of maintaining their productivity and usefulness to society indefinitely. Such systems are resource-conserving, socially supportive, and environmentally sound. This notion of sustainable agriculture addressed by U. S. Congress in the 1990 Farm Bill states that, "sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term: satisfy human food and fiber needs, enhance environmental quality and the natural resource base upon which the agricultural economy depends, make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls, sustain the economic viability of farm operations, and enhance the quality of life for farmers and society as a whole" (USDA, 2001, para 3). This rejuvenated perspective emphasizes that future food production systems will not only depend on, but must contribute positively to, healthy ecosystems and resilient communities (Nellemann 2009).

The Small Farm Alternative

As documented in the past century, mainstream economists confidently predict the demise of the small farm (Hoppe 2010, Pooran 2001). From this paradigm, small farms are labelled as backward, unproductive and inefficient, regarded as obstacles to overcome in the process of economic development. This conventional wisdom is now challenged. Many institutions advocate the multi-functional character of small farms, seen to enable greater contributions to sustainable development when compared to their large farm counterpart (Rosset 1999). Recent literature shows that small farms are an efficient and resilient mode of production, more productive and efficient than large ones, displaying the so-called “inverse relationship” between farm size and productivity (Quan 2011). Evidence suggests that small farms do so by being better able to efficiently utilize small blocks of land (Pooran 2001).

The literature also reveals the economics of global food production that encourage farms to increase their operation size to capitalize on economies of scale (Hoppe 2010). While the value placed on economic efficiency and competitiveness is explicable, many have emphasized the importance of small farms in terms of expressing explicit concerns about the environment (Meyer 2010). As part of their multi-functional character, small farms often have multiple objectives that transcend profit maximization, namely resource conservation. The literature suggests that small farm operators are more likely to practice organic farming and utilize biological and integrated approaches to pest, disease, and soil management than are large farms (Rosset 1999). It is argued that small farmers make better stewards of natural resources to conserve biodiversity and better safeguard the sustainability of production (Rosset 1999). This emerging evidence reveals the importance of small farm agriculture to address many of the underlying causes of deteriorating agricultural productivity and aid in the conservation of natural resources (State of the World 2010, Ho 2011).

Study Rationale

A 2001 study among U.S. farms suggests that research to examine production efficiency for a detailed breakdown of farm size groups is needed (Pooran 2001). The authors suggest that this research would provide valuable information about optimal farm size in pursuit of agricultural productivity, economic efficiency, and environmental sustainability.

Accordingly, this study employs a size-based grouping of farm categories as measured in acres of total farm landholdings. This land-based perspective is a novel contribution to the field of agricultural studies as an alternative approach to defining and assessing farm scale which is typically defined by annual gross farm income (Hoppe 2010). A review of the literature shows that very few farm scale comparisons by physical size exist, while none are found in relation to high income country – or first world – agriculture. The perspective employed in this study is therefore justified as an intervention to the prevailing methodology of farm scale analysis to provide previously non-existing information regarding U.S. agriculture.

The objective of this study is to show that an alternative to large conventional farm agriculture exists, and one with evidence of bettering society and preserving the natural environment. To lay the foundation for such an examination, two research questions were posed:

1. Can small farms produce a food output per acre comparable to large farms?
2. What evidence is there of environmental and social betterment provided by small farms as compared to large farms?

The study's U.S. perspective is significant given U.S. products account for a considerable portion of the global supply, being the largest producer corn in the world and providing over 50% of the world's soybeans (EPA 2009). Furthermore, the U.S. based analysis offers an indicative model for understanding agriculture in an industrialized nation (Grey 2000). As such, the study serves as a suggestive analysis for Canadian agriculture, because comprehensive and detailed agricultural data for Canada are not publicly available. Though methodological and policy differences exist, the U.S. picture offers the next best representation of Canadian agriculture.

As well, if small farm food production per acre is shown comparable to large farms while more environmentally and socially beneficial, results implicate the former to play a significant role in the future of sustainable food systems. Further, as global change to sustainable food production is required, cognisant of the substantial global role U.S. agriculture plays, it is clear that the greatest and most immediate vector of change is U.S. based.

Methods

Research Design

The study aims to show small farms produce a comparable food output per acre to large farms while providing superior social and environmental benefit. A comparative analysis of small and large farms is employed to assess human and natural resource efficiency in producing a group of food types. Comparisons are drawn using indicators for food production, productivity, social and environmental measures.

Perceptions as to what constitutes farm size have changed considerably over time (Pooran 2001). The approach adopted in this study defines small and large farms on the basis of physical extent, measured in acres. As the goal of the study is to investigate the effect of farm size difference, farm sizes are based on the maximum size difference present in the dataset. The small farm category represents those farms of 99 acres or less, while the large farm category describes those of 2,000 acres or more. Furthermore the categorical groups reflect prevailing U.S. agriculture trends (Gardner 2003). A major portion of all farms, 54%, are classified in the small farm group while the large farm category accounts for a mere 3.6% of all farms while sharing a disproportionate 26.7% of the total market value of products sold (Table 1).

Data Source

The data employed are sourced from the 2007 U.S. Census of Agriculture, made available electronically from the United States Department of Agriculture (USDA). The dataset is the only detailed, comprehensive, and uniform source of U.S. agricultural production statistics (Census of Agriculture 2009). Furthermore, the dataset is well disaggregated, enabling a comprehensive understanding of how different groupings within the U.S. agriculture system and society occur. The wealth of background work – rigorously collected, interpreted, and recorded – indicates the data's pre-established validity and reliability, thus providing a larger and higher-quality dataset unfeasible for the researcher to collect independently.

Data Analysis

Four indicator groups address food production, productivity, environment, and social considerations for small and large farm groups. The indicators represent the typical measure for all farms within each category. The variables selected for each indicator are derived directly from the dataset, with research assumptions noted and justified.

<u>Food Indicators</u>

Food indicators are designed to assess the ability of small and large farms to produce a composite of seven food types. These food types are representative of the major agricultural commodities produced and consumed (EPA 2009). Dependent on data availability a direct measure of food output per unit of production land is achieved, supplemented by an indirect measure considering the value of the food sold per acre of production land. Direct measures are comparable in bushels per acre while indirect measures assume an equivalent selling price to facilitate comparison. Crop-based food production serves as the truest indicator as there is a complication in interpreting the data for animal-based food production. The dataset does not inform the source of animal feed as it will vary widely for each farm, for example, some beef are grass fed, others entirely corn feed, while still others a combination of the two sources. This uncertainty in animal feed source implicates each farm's efficiency in animal-based food production. It is therefore stated that the interpretation of animal-based products necessitates further study to sufficiently address and incorporate key factors in determining animal and animal product production.

Grain and Oilseed: Corn, wheat, and soybeans together represent the dominant grain and oilseed output of both farm categories (Table 9 in Appendix A). Inferred from each category's total bushels harvested of corn for grain, wheat for grain, and soybeans for beans, a direct measure of food quantity output per unit of production land is achieved. The indirect measure of grain and oilseed production considers the value of grain sold per acre of cropland harvested for corn, wheat, and soy. To limit error with respect to crop end-use for either human consumption or animal feed, only wheat and corn for grain, as opposed to silage, are included in the analysis. To glean further certainty, data disaggregation was performed to infer true grain production excluding soybeans which are often classified as an oilseed.

Vegetables: Vegetable production is measured indirectly by the value of vegetables, cucurbits, potatoes, and sweet potatoes sold per acre of land in vegetables. A direct measure is not possible since the quantities in volume or weight are not provided by the dataset.

Fruits: Fruit production is measured indirectly by the value of fruits, tree nuts, and berries sold per acre of land in orchards. A direct measure is not possible since the quantities in volume or weight are not provided by the dataset.

Beef: Beef production is measured both directly and indirectly. The former measures the number of beef cows per acre of pastureland while the later measures the value of beef sold per acre of pastureland. This indicator assumes that the beef cows exist on and utilize the pastureland and that the value of beef sold is sourced from the beef cows in each farm's inventory.

Dairy: Dairy production is measured both directly and indirectly. The former measures the number of dairy cows per acre of land in buildings and other uses, while the later measures the value of milk and other dairy products of cows sold per acre land in buildings and other uses.

This land use designation accounts for land in barns, buildings, and other forms of infrastructure. It is assumed that the dairy cows exist on and utilize this land primarily and that the value of dairy sold is produced for human consumption.

Pork: Pork production is measured both directly and indirectly. The former measures the number of hogs and pigs per acre of land in buildings and other uses, while the later measures the value of hogs and pigs sold per acre of land in buildings and other uses. This indicator assumes that the hogs exist on and utilize the land in buildings and that the value of hogs and pigs sold is produced for human consumption.

Poultry and eggs: Poultry and egg production is measured both directly and indirectly. The former measures the number of poultry birds per acre of land in buildings and other uses, while the later measures the value of poultry and eggs sold per acre of land in buildings and other uses. Poultry sold includes layers for egg and meat production, pullets for laying flock replacement, broilers and other meat-type chickens, and turkeys. This indicator assumes that the poultry and egg inventory exists on and utilizes the land in buildings and that the value of poultry sold is produced for human consumption.

Productivity Indicators

Agricultural productivity is measured as the ratio of agricultural outputs to agricultural inputs, indicating the efficiency of production. Productivity indicators assume equivalent purchasing and sale prices for inputs and outputs, respectively.

Total Factor Productivity: A measure of the overall agricultural productivity which compares the ratio of total outputs to total inputs, represented by total market value of agricultural products sold and total farm production expenses. Total farm production expenses include the money spent on items or services, which differs from an assessment of cost which defines the amount required for an item or service, an analysis not achievable with the dataset. Total market value of agricultural products sold is equivalent to total sales and represents the gross market value before taxes and production expenses.

Partial Productivity: Measures which infer total output in terms of a single input to assess their individual efficiency of use in gaining output value. Inputs assessed include land measured in acres, and fertilizer, pesticides, fossil fuels, and hired labour all measured in value purchased.

Environmental Indicators

Environmental indicators concern measure the farm's environmental performance related to resource inputs, water usage, and general conservation practices. The resource input indicators assume that small and large farms have equivalent purchasing prices, and that inputs are intended for the purpose of food production.

Fertilizer Input: Fertilizer use is inferred from the dollar value of commercial fertilizer, lime including rock phosphate and gypsum, and soil conditioners purchased per acre treated with fertilizer. Commercial fertilizer is that which is manufactured chemically, as distinguished from natural fertilizer such as manure. The extent of fertilizer use measures by the proportion of total cropland treated with commercial fertilizer. This measure also compares to the proportion of cropland treated with organic fertilizer in the form of manure.

Pesticide Input: Pesticide use is inferred from the dollar value of pesticides purchased per acre treated with commercial pesticides. Commercial pesticides include insecticides, herbicides, fungicides, and others. The extent of use measures the proportion of total cropland treated with chemicals to control weeds, grass, brush, nematodes, and diseases in crops and orchards.

Fossil Fuel Input: Fossil fuel use is inferred from the dollar value of gasoline, fuels, and oils purchased per acre of land in farms. This measure uses the cost of all gasoline, diesel, natural gas, Liquid Petroleum gas, motor oil, and grease products, excluding fuel for personal use of automobiles and any other use outside of farm-work on the operation.

Water Usage: Inferred from the acres of land irrigated, the indicator is an indirect measure of water used for food production. This measure includes harvested grain cropland, land in vegetables, and land in orchards watered by any artificial or controlled means.

Conservation Practices: Land preserved in woodlots, enrolled in conservation programs, and used for organic production serve as conservation practice indicators. Land enrolled in the Conservation Reserve Program is a program established by the USDA which takes land prone to erosion out of production for 10 to 15 years and devotes it to conservation uses. Organic agriculture, including organic cropland and pastureland, is defined by the National Organic Standards (Census of Agriculture 2009).

Social Indicators

Social indicators concern the farm's impact on, and involvement with, the social systems and local communities within which it operates.

Employment: The social benefit of job creation is inferred from the number of hired labour workers per acre of farmland.

Pay: The measure of pay is inferred from the total dollar value of hired labour paid per number of hired labour workers.

Accessibility: The social accessibility indicator is inferred from the proportion of total sales sold directly to individuals for human consumption as well as the proportion of farms engaging in such direct selling activity. An additional measure of accessibility is inferred from the proportion of farms involved in agri-tourism and recreational services.

Diversity: Diversity indicators measure the proportion of principle operators who are female or where more than one race is reported in the data.

Results

The research results cover five main components relating to both small and large farm categories: 1) farm characteristics which include quantity, size, and total market value; 2) the ability of a farm to produce a diverse group of food types; 3) the efficiency of food production; 4) the extent and use of natural resources as well as conservation practices; and 5) social measures of employment, accessibility, and diversity.

Farm Characteristics

Numerically, small farms are the dominant group representing 54% of all U.S. farms compared to 3.6% representing the large farm category (Table 1). This trend, however, does not persist when considering land and market holdings. Large farms govern the majority of all U.S. agricultural land accounting for 54% of the total, and hold 27% of the total market value of all U.S. agricultural products sold. Conversely, small farms govern close to 5% of all agricultural land and provide 15% of the agricultural market (Table 1).

TABLE 1 Small and large farm characteristics for quantity, size, and total market value

Profile Item	Small Farm	Large Farm	Ratio of Small to Large Farm
Number of farms	1,199,038	80,393	14.91 :1
Percentage of total farms (%)	54.40	3.60	15.11 :1
Average size (acres)	42.75	6,181.00	0.01 :1
Agriculture land (acres)	41,712,226	496,945,963	0.08 :1
Percentage of total U.S. agricultural land (%)	4.52	53.89	0.08 :1
Market value of agricultural products sold ($)	45,412,449,000	79,279,971,000	0.57 :1
Percentage of total U.S. agricultural market value (%)	15.28	26.67	0.57 :1

Further dissimilarities are indicated by the differing proportions of land-use designations for the typical small and large farm. The majority of large farm landholdings are designated as permanent pasture and rangeland, which account for 61% of the landholding, whereas small farms dedicate their largest proportion of land, 47%, to cropland (Table 2).

TABLE 2 Land use of total farmland for small and large farms

Land Use	Small Farm	Large Farm	Ratio of Small to Large Farm
Cropland (%)	46.81	32.21	1.45 :1
Woodland (%)	17.61	4.36	4.04 :1
Permanent pasture and rangeland (%)	26.25	61.22	0.43 :1
Land in house lots, barn lots, ponds, roads, ditches, wasteland, etc. (%)	9.33	2.20	4.23 :1
Total (%):	100	100	- -

Food Indicators

On average, small and large farms generate comparable grain and oilseed yields with small farms slightly more productive at 81.22 bushels per acre compared to 78.79 bushels per acre for large farms. To reinforce this statistic, the value sold per acre of grains is again slightly higher for small farms, generating $360.23 per acre as compared to $334.31 for large farms (Table 3). The disaggregated grain analysis shows that small farms' wheat productivity is higher, while corn and soy production are lower as compared to large farms. Meanwhile, indirect productivity measures of value sold per acre indicate that individual productivity for wheat, corn, and soy are comparable, with large farms reaping more value per acre for wheat and corn, while small farms generate more value per acre of soy. Discrepancies between grain production for small and large farms are minor, with a maximum disparity of 16% (Table 3).

Fruit and vegetable production was similarly comparable with small farms gaining 8% more value for vegetables and 7% less for fruit sold per acre as compared to large farm measures (Table 3). Statistics indicate a more severe divergence from comparable values for animals and their products. With the exception of milk, small farms are largely more productive in terms of both quantities produced and dollar value sold per acre of land used in production (Table 3).

TABLE 3 Direct and indirect food production indicators; where direct productivity measures food quantity produced per acre of production land. Grains in bushels/acre of harvested cropland, beef in beef cows/acre of pastureland, dairy in dairy cows/acre of land in buildings and other uses, pork in hogs/acre of land in buildings and other uses, and poultry in poultry/acre of land in buildings and other uses. Indirect productivity measures for each food type the gross dollar value sold/acre of production land.

	Food Type	Small Farm	Percentage of Total U.S. Production (%)	Large Farm	Percentage of Total U.S. Production (%)	Productivity Ratio of Small to Large Farm
Direct Productivity (quantity/acre)	Grain and Oilseed(bushels)	81.22	1.28	78.79	37.58	1.03 :1
	Wheat	41.61	0.62	38.92	62.88	1.07 :1
	Corn	125.18	1.34	148.84	34.88	0.84 :1
	Soy	36.54	1.52	39.47	31.35	0.93 :1
	Vegetables	-	4.78	-	49.63	- -
	Fruit	-	18.66	-	28.11	- -
	Beef (beef cow)	0.34	11.32	0.04	34.76	9.05 :1
	Milk (dairy cow)	0.24	10.15	0.12	13.83	2.06 :1
	Pork (hog or pig)	16.99	31.98	2.01	10.64	8.46 :1
	Poultry (chicken or turkey)	1,138	46.33	15.55	1.78	73.24 :1
Indirect Productivity (dollar value sold/acre)	Grain and Oilseed	360.23	-	334.31	-	1.08 :1
	Wheat	204.98	-	210.98	-	0.97 :1
	Corn	426.88	-	483.75	-	0.88 :1
	Soy	318.65	-	310.49	-	1.03 :1
	Vegetables	4,141.87	-	3,302.61	-	1.08 :1
	Fruit	3,196.28	-	3,421.02	-	0.93 :1
	Beef	406.00	-	59.92	-	6.78 :1
	Milk	796.76	-	435.41	-	1.83 :1
	Pork	1,281.28	-	268.11	-	4.78 :1
	Poultry and Eggs	754.55	-	108.79	-	6.94 :1

Productivity Indicators

In terms of production expenses, small farms spend about eight times more per acre of land compared to large farms, a trend which holds true for the majority of production input types (Table 4). With respect to agricultural sales, small farms receive a dollar value about seven times greater than large farms per acre of land (Table 4). This trend, however, does not hold true for a disaggregation of agricultural output types whereby large farms reap a sales value per food output type up to 93% more than the same food output for small farms (Table 4).

TABLE 4 Input and output measures represent production expenses and sales, respectively. Specific input and outputs represent particular variables of interest relating to food production and environmental indicators.

Economic Indicator	Small Farm	Large Farm	Ratio of Small to Large Farm
Input ($/acre)	1,011.14	122.85	8.23 :1
Fertilizer	21.76	13.32	1.63 :1
Pesticides	12.06	8.16	1.48 :1
Fossil fuels	49.66	7.38	6.72 :1
Hired labour	102.47	11.59	8.84 :1
Feed	331.29	13.06	25.37 :1
Rent for land, buildings and grazing fees	8.08	11.29	0.72 :1
Rent and lease for machinery, equipment, vehicles	2.92	1.20	2.43 :1
Property taxes paid	44.88	2.29	19.58 :1
Output ($/acre)	1,088.71	159.53	6.82 :1
Grains ($/bushel)	0.87	12.08	0.07 :1
Beef ($/beef cow)	1,195.64	1,597.44	0.75 :1
Dairy ($/dairy cow)	3,298.54	3,720.91	0.89 :1
Pork ($/hog)	75.41	133.45	0.57 :1
Poultry and Eggs ($/poultry bird)	23.21	57.26	0.41 :1

The foremost indicator for production efficiency, total factor productivity, indicates that for every dollar invested in small farm production, $1.08 is returned in sales, as opposed to the greater value of $1.30 returned in sales for large farm production (Table 5). Partial factor productivity, however, shows small farm proficiency in returning almost seven times more value per unit of land, and over four times more value for fertilizer and pesticide input (Table 5).

TABLE 5 Total factor productivity measures the ratio of agricultural outputs to agricultural inputs. Partial factor productivity measures the ratio of agricultural outputs (total sales) to certain agricultural inputs (production costs) of interest, indicating the efficiency of these inputs to gain output value.

Productivity Indicator	Small Farm	Large Farm	Ratio of Small to Large Farm
Total Factor Productivity	1.08	1.30	0.83 :1
Partial Factor Productivity			
Land (acres)	1,088.71	159.53	6.82 :1
Fertilizer	50.03	11.98	4.18 :1
Pesticides	90.25	19.56	4.61 :1
Fossil fuels	21.92	21.60	1.01 :1
Hired labour	10.62	13.77	0.77 :1
Feed	3.29	12.22	0.27 :1
Rent for land, buildings, and grazing fees	134.66	14.13	9.53 :1
Rent and lease for machinery, equipment, and vehicles	372.81	132.63	2.81 :1
Property taxes paid	24.26	69.60	0.35 :1

Environmental Indicators

The extent of commercial fertilizer, pesticides, and water use is comparatively less for small farms as compared to large farms, with pesticide application and irrigated land as stark outliers for large farm (Table 6). The value in dollars spent on resource inputs, however, is comparatively larger per acre for small farms, particularly with respect to fossil fuel expenditures (Table 6). Small farms, however, participate in comparatively more activities designated as having environmental benefit (Table 7).

TABLE 6 Resource-use inferred from the dollar value purchased per acre treated, while the extent of use is shown by the proportion of area treated. Commercial fertilizer includes fertilizer, lime, and soil conditioners of non organic origin. Chemicals include insecticides, herbicides, fungicides, and other pesticides used to control weeds, grass, brush, nematodes, and diseases in crops and orchards. Fossil fuel resources include all gasoline, diesel, natural gas, liquid petroleum gas, motor oil, and grease products, excluding fuel not for farm-work. Water usage includes harvested grain cropland, land in vegetables, and land in orchards that are watered by any artificial or controlled means.

Resource Input	Small Farm	Large Farm	Ratio of Small to Large Farm
Fertilizer			
Percentage of cropland treated with manure (%)	9.20	2.79	3.30 :1
Percentage of cropland treated with commercial fertilizer (%)	42.72	67.83	0.63 :1
Value purchased/acres treated ($/acre)	108.83	60.97	1.79 :1
Pesticides			
Percentage of cropland treated with pesticides (%)	50.93	96.14	0.53 :1
Value purchased/acres treated ($/acre)	50.60	26.34	1.92 :1
Fossil Fuels			
Value purchased/total farmland ($/acre)	49.66	7.38	6.72 :1
Water			
Percentage of harvested grain cropland irrigated (%)	3.08	13.68	0.23 :1
Percentage of land in vegetables irrigated (%)	40.82	78.98	0.52 :1
Percentage of land in orchards irrigated (%)	65.73	89.17	0.74 :1

TABLE 7 The USDA Conservation Reserve Program takes land prone to erosion out of production for 10 to 15 years and devotes it to conservation uses. Organic production is defined by National Organic Standards.

Conservation Practice	Small Farm	Large Farm	Ratio of Small to Large Farm
Percentage of farmland preserved in woodland (%)	17.61	4.36	4.04 :1
Percentage of farmland enrolled Conservation Reserve Program (%)	8.05	1.98	4.06 :1
Percentage of cropland and pastureland used for organic production (%)	0.54	0.24	2.27 :1

Social Indications

Small farms employ 20 times as many people per acre of farmland as large farms, while paying about half as much per individual (Table 8). In terms of social accessibility, small farms engage more in direct selling to individuals, while large farms participate more in agri-tourism and recreational services. In terms of principal operator demographics, small farms have greater gender and race diversity (Table 8).

TABLE 8 The value of agricultural products sold directly to individuals represents the value sold from roadside stands, farmers' markets, pick-your-own sites, etc. Agri-tourism and recreational services represents income from recreational services such as hunting, fishing, wine tours, hay rides, etc. Diversity indicators represent gender and race diversity among principal operators.

Social Measures	Small Farm	Large Farm	Ratio of Small to Large Farm
Employment (hired labour worker/acre)	0.02	0.0009	20.38 :1
Percentage working 150 days or more (%)	27.06	47.67	0.57 :1
Pay ($/hired labour worker)	5,729.25	13,203.76	0.43 :1
Accessibility			
Percentage of farms selling directly to individuals (%)	8.26	2.05	4.03 :1
Percentage of sales sold directly to individuals (%)	1.16	0.06	18.75 :1
Percentage of farms engaged in agri-tourism (%)	0.54	5.54	0.10 :1
Percentage of all U.S. farms engaged in agri-tourism (%)	27.61	19.08	1.45 :1
Diversity			
Percentage of female operators	17.64	4.94	3.57 :1
Percentage of operators with more than one race reported (%)	0.67	0.33	2.00 :1

Discussion

Data Analysis

Food Production

Food production indicators show that, per acre, small farms produce a food output comparable to large farms. The measure of bushels produced per acre harvested serves as the truest indicator of food production. While small and large farms are capable of producing corn, wheat, and soy in a similar quantity, small farms are slightly more efficient in wheat production, and slightly less efficient in corn and soy production. The small farm strength wheat production is significant as an indicator of food production ability because over 70% of all U.S. wheat is used directly for human food products, contrasted by only 12% of corn produced used for human food products (FAO 2008). Even though the wheat and corn data used in analysis are designated for the specific purpose of grain, as opposed to silage for the purpose of animal feed, the end-use of soy production is less clear in the data. As a result, large farm proficiency in soy production does not necessarily indicate a benefit toward human food provision.

While arguably the grain used as feed in the meat industry feeds humans indirectly, the energy conversion for this process is extremely inefficient. For cattle, it takes, roughly 7 kilograms of grain to produce a 1-kilogram gain in live weight. For pork, the number is close to 4 kilograms per kilogram of weight gain, and for poultry, it is just over 2 kilograms (Brown 2002). To lighten the pressure on natural resources used agriculture, the market would ideally shift production to the animals that convert grain most efficiently.

Animal-based measures, however, are complicated due to animal feed requirements, where the source of feed is not determinable from the data. Thus, the results for animal-based food production necessitate careful interpretation and a more detailed study not feasible with the available data. Nevertheless, animal-based measures are included in the discussion as a starting point for examination. As a result of the uncertainties within the data on animal-based production, the indicators for land crops, including grain, vegetable, and fruit production, are stronger measures of food production relative to the animal-based measures.

With these uncertainties noted, the results indicate, with respect to meat, dairy, and egg production, that small farms are more productive per acre. Small farms vastly outstrip large farms for poultry and egg production measuring the number of poultry birds per acre. This large difference is partially attributable to the difference in industry classification, whereby 4% of all small farms are classified as poultry industry compared to 0.3% of large farms, showing the small farm poultry industry 13 times larger overall (Figure 1). Furthermore, it is notable that small farms account for nearly half of the total U.S. poultry and egg production (Table 3), whether classified as a poultry operation or not.

A similar statistic, where small farms produce more hogs and pigs per acre, is likely due in part to the small farm hog and pig industry being three times more prevalent than the large farm hog and pig industry (Figure 1). The same logic however, cannot explain small farm dominance in dairy and beef production because relatively more large farms are classified as dairy and beef industry (Figure 1). Explanation may instead be attributed to the sheer size of landholding, where the typical large farm pastureland is twice the acreage of the typical small farm (Table 2). This landholding discrepancy factored in, however, shows small farm beef output is still larger relative to large farm production (Table 3). As well, dairy production is similarly reasoned whereby small farm land in buildings, assumed to house dairy processing, is four times that of a large farm (Table 2). This discrepancy factored in still shows small farms produce more milk

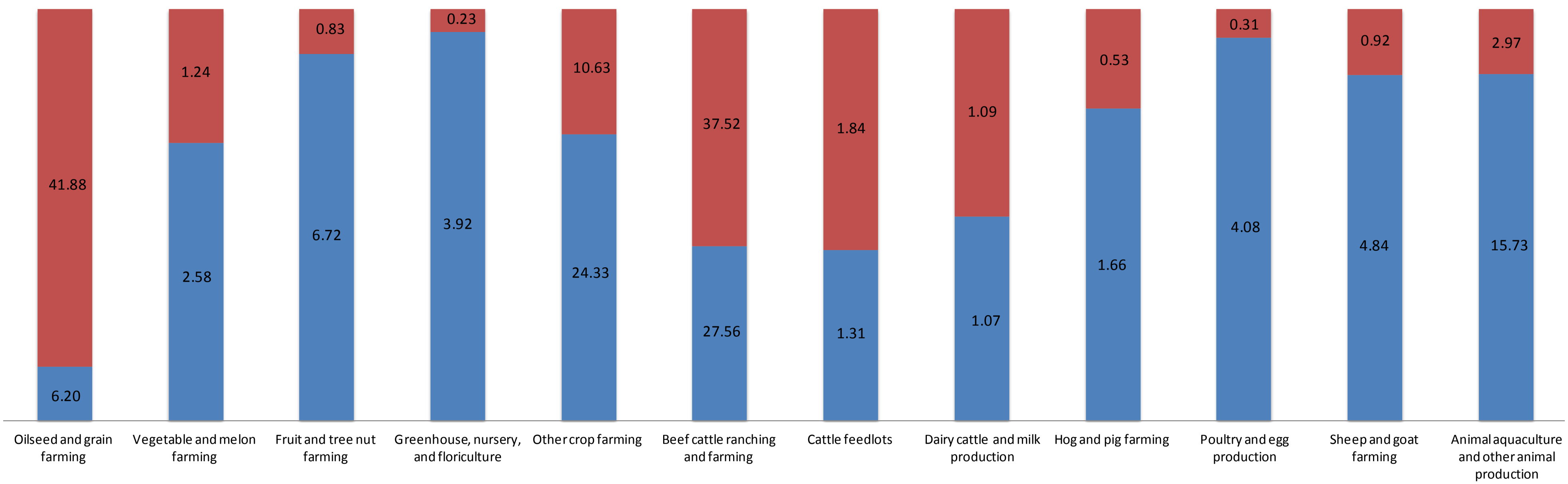

FIGURE 1: Industry classification as a percentage of overall classification types for the average small (blue) and large (red) farm.

compared to large farms despite equal representations of the dairy industry (Figure 1).

The results for indirect measures of food production serve to support and reinforce the results of direct measures, where similar statistics show small farms generally more productive per acre. Slight discrepancies exist concerning wheat, corn, and vegetables, with a maximum 12% difference in value sold per acre harvested favouring large farm corn production (Table 3). It is interesting to note that indirect measures reduce the disparities between small and large farm direct food production measures, particularly with respect to meat, dairy, and egg production. For example, small farms produce 73 times the amount of poultry birds per acre yet the dollar value sold in poultry and eggs is reduced to only 10 times that of large farms per acre (Table 3).

As well, results indicate that large farms reap a greater gross dollar value for units of food sold, suggesting that large farms sell their products at a higher cost value. In turn, this ability results in a higher gross profit margin to contribute greater value to the operation, implicating the economic viability of the farm. This may attribute to a market bias towards the purchasing and selling of large farm products over that of a small farm. The influence of government payments on agriculture structure interests policy makers and economists alike. Increases in farm payments heighten concern that government payments are hastening the concentration of agricultural production to the detriment of small farms. It is argued that government payments have allowed large farms to increase their competitive advantage over smaller producers, making it much more difficult for small farms to make a profit from their farming operations (Key and Roberts 2007).

Productivity Indicators

Statistics noted in food production analysis suggesting large farms sell products at a higher value, is further evidenced by productivity indicators showing dollar value in sales per unit of food is significantly higher for large farms (Table 4). Small farms reap roughly half as much value per hog and poultry bird, with sales for dairy and beef production almost comparable to large farms (Table 4). The largest discrepancy is marked by grain sales, whereby small farms sell one bushel of grain for a mere 7% of what large farms do (Table 4). Once again, these results suggest a market bias toward large farms.

Small farms however, have a higher dollar value gained per acre of farmland, where they are almost seven times more efficient (Table 4). This statistic is supported by the literature showing small farms better able to efficiently utilize small blocks of land (Pooran 2001). Lower land efficiency for large farms may, however, result from the sheer size of the landholding. Landholding size discrepancy is misleading for productive efficiency quantification since the possibility exists that these vast lands are not utilized in production or are unusable, as "in other areas, pastureland is barely graze-able and is only marginally better than wasteland (Census of Agriculture 2009)". Marginal land may suggest unsustainable uses resulting in land degradation.

Production inputs show small farms spend 8 times more per acre and for every significant input expense save for rent for land, buildings, and grazing fees (Table 4). The largest discrepancy is the amount spent on feed, where small farms spend 25 times that of large farms (Table 4), accounting for 33% of the average small farms total production expenses (Figure 2), likely attributable to the 1,138 poultry birds produced per acre (Table 3). Small farms large feed expense suggests they produce less of their feed on site as compared to large farms. Results also show that small farms spend almost 9 times more on hired farm labour as compared to large farms (Table 4) possibly due to the prevalence of labour intensive farming such as vegetable production which is twice as significant for small farms in terms of industry classification (Figure 1).

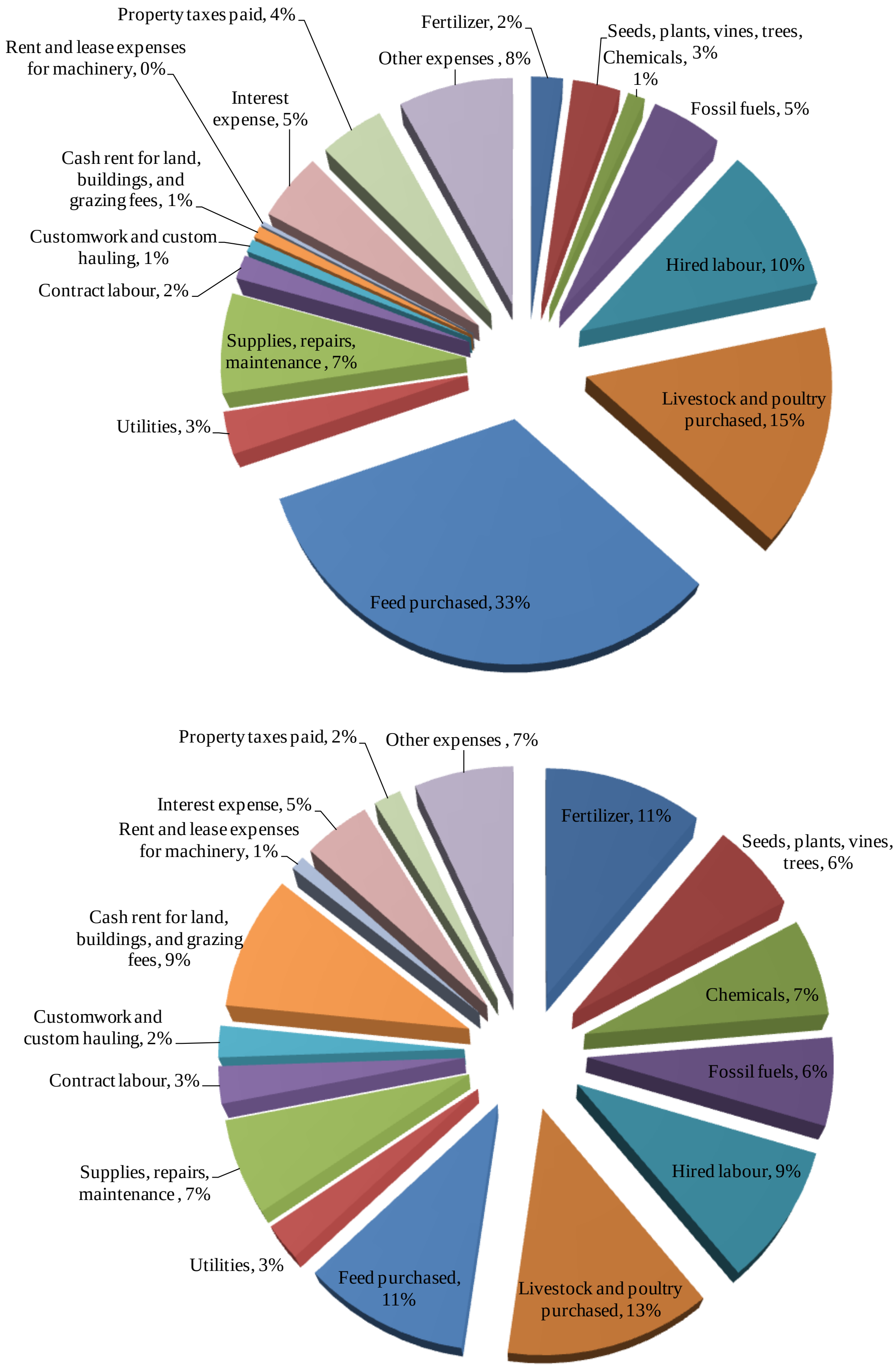

FIGURE 2 Itemized production expenses as a percentage of total farm production expenses for the average small (top) and large farm (bottom).

Fertilizer, pesticide, and fossil fuel expenditures per acre indicate either increased relative usage or increased relative sales costs. Differing costs for inputs may be due to agricultural subsidies, where the production of certain products is more heavily subsidized (Beitel 2005). Corn production, for example, receives most of the agricultural subsidies (Alston et al. 2007), suggesting in turn that “oilseed and grain farming” industries receive larger subsidies, to lower farm production costs. 42% of the large farm category is classified as “oilseed and grain farming” contrasted to the mere 6% of small farms classified in this heavily subsidized industry (Figure 1).

Large farm productive efficiency is 120% greater than small farms to deriving value from agricultural outputs relative to agricultural inputs (Table 5). The disaggregated analysis of productive efficiency shows small and large farms arrive at their overall productive efficiency differently. Small farms have a lower efficiency in deriving value from human labour, attributable to the larger amount of workers employed (Table 8). Small farms, however, are more efficient users of fertilizer, pesticides, and land, corresponding to efficiencies four, five and seven times greater than large farms, respectively.

Resource-use efficiency carries implications for environmental considerations suggesting that a farm with lower resource efficiency is less sustainable in. Total factor productivity shows that every dollar invested in small farm production returns $1.08 in sales, contrasted to the greater value of $1.30 returned in sales for large farm production. It is inferred that the $0.22 difference per acre is the value of sustainability from improved natural resource efficiency.

Environmental Indicators

Small farms treat a greater proportion of land with manure relative to large farms (Table 6). Organic fertilizers such as manure increase physical and biological nutrient storage mechanisms in soils, essential to mitigate risks of over-fertilization, improve soil structure, and help prevent topsoil erosion (Nazarko 2004). Further, small farms treat a smaller proportion of land with commercial fertilizers commonly used to treat corn, barley, sorghum, rapeseed, and soy croplands (Hussain 2009), which represent almost 40% of the large farm's output (Figure 3). Furthermore, small farms treat 50% of cropland with pesticides, as compared to the 96% of large farm cropland treated (Table 6).

Pesticide use raises a number of environmental concerns. These chemicals are responsible for a plethora of human and environmental effects, where over 98% of sprayed insecticides and 95% of herbicides reach unintended destinations, including non-target species, air, water and soil (Miller 2004). Pesticides are the foremost cause of water pollution and contribute to soil contamination to reduce nitrogen fixation, and ultimately reduce biodiversity both on and off the farm (Hussain 2009). The small farm statistic showing less extensive pesticide use is supported by the literature which suggests that small farm operators are more likely to practice organic farming and utilize biological and integrated approaches to pest, disease, and soil management than are larger farms (Rosset 1999).

While the extent of pesticide and fertilizer application is clearly less for small farms, the intensity of use less clear. Inferred from the value purchased in pesticides and fertilizer per acre treated, results suggest that small farms are more intensive in application. Assuming small and large farms purchased these inputs at the same sales cost, the measure indicates the quantity used, with small farm usage outstripping large farm use per acre (Table 6). If however, the

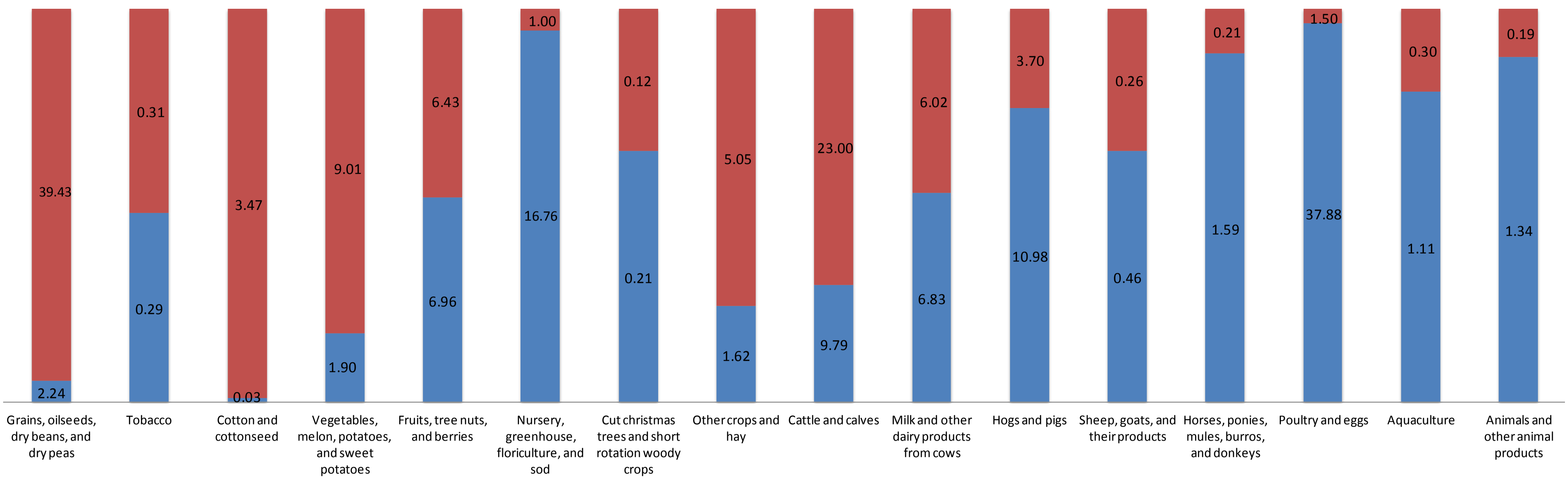

FIGURE 3 Product outputs as a percentage of total sales for the average small (blue) and large (red) farm.

purchasing price is unequal, a situation which is likely when considering the merits of bulk purchasing, the results are interpreted differently. A similar logic is applied to fossil fuel usage, where it is shown small farms purchase almost seven times more than large farms per acre (Table 6). Additional analysis measuring fossil fuel expense per acre of cropland, rather than total acres in farm landholding (Table 6), shows the ratio of use slightly improved, while still favouring large farms as small farms purchase a value of fossil fuels 4.6 times greater per acre of cropland.

It is possible, however, that large farms are simply more efficient in the usage of these resources, potentially due to more advanced technologies for application. As well, results indicate small farms as more fertilizer intensive, suggestive of the type of farming, where, for example, crop production is inherently more chemically intensive than a cattle ranching operation which requires very low fertilizer input per acre of pastureland.

With respect to water usage, small farms irrigate less cropland, land in vegetables, and orchards (Table 6). This measure, however, is a weak indicator of water usage given regional differences in rainfall. Thus, it functions more strongly as a measure of crop suitability to local climate. Small farm crop production is therefore more optimally suited to its local climate, a factor critical in minimizing agricultural intensification forcing land productivity through increased and unsustainable resource-use (Foley et al. 2005). This result challenges literature which suggests large farms are situated on higher quality land than small farms (Peterson 1997).

Lastly, it is shown that small farms preserve more woodland, by a factor of four as compared to large farms (Table 7). Woodland preservation represents alternative and diversified land use with associated environmental benefits of habitat conservation, biodiversity conservation, and carbon sequestration (Nodvin 2008, Benton 2003).

Social Indicator

Small farms provide more employment, especially for females, and sell more directly to the public (Table 8). Results indicate small farms enhance empowerment and community responsibility, whereby landowners who rely on local business are more likely to have a stake in the well-being of the community and its citizens. In turn, local landowners, as evidenced by 90% of small farm acreage designated as family or individually owed (Figure 4 in Appendix A), are held accountable for negative externalities in the community. In addition, a personal connection to food is tied to small farms where it is argued consumers of today have little connection to agriculture and food production (Cone 2000). As a consequence, they have little connection with nature, and lack an appreciation for the cultivation of the earth for production of food that sustains society.

Four times as many small farms sell directly to individuals though farmers' markets, community supported agriculture to connect consumers with the people growing their food (Table 8). This food stream re-establishes links between food producers and consumers and encourages both to take responsibility for the quality of their food and the natural resources that produce it (Grey 2000). The present growth of alternative agri-food movements, such as localism, farmers' markets, community shared agriculture, food sovereignty, and others reflect a widening disenchantment with conventional agriculture and food (Friedland 2010, Godfray 2010). Local access to food, as evidenced by small farms, improves food accessibility and distribution to increases the resilience of the whole food system, critical in achieving food security.

Overall, the findings show that: (a) small farms relative to large farms produce a comparable amount of food, measured in both quantity of food and dollar value sold per acre of production land, (b) productive efficiencies favour large farms, (c) the extent of resource input is lower for small farms, and (d) both small and large farms provide a composite of varying social benefit.

Implications

The findings of this study carry implications for the discipline of agricultural studies, agriculture practice and policy, and for society at large. This study contributes to the field of agricultural studies as an alternative approach to defining and assessing farm systems from a land-based perspective. The results reinforce certain studies and challenge others with respect to small farm agricultural productivity.

A land-based perspective for defining agricultural scale, an intervention to the norm, is particularly important given constraint on present and future land, both locally and globally. With regard to agricultural practice, the results suggest farms of scale are not needed to fulfill yield requirements per acre. With regard to agricultural systems, the value of diversity in ownership, land use, biological organization, and community is evidenced by supporting literature and indicated by small farm results.

With regard to policy, as small farms are capable of producing food amounts comparable to large farms, with less extensive resource inputs, perhaps policy should restrict the farm size. As well, given a simultaneous and conflicting push for farm consolidation and small farm support, this research clarifies and supports literature to confirm the merits of small farm agriculture. The implications of this research suggest that small farms play an economically, environmentally, and socially viable role in U.S. food production.

The U.S. based results relate to Canada in terms of overall farm structure, largely similar to Canada except for dairy and poultry farming. Canada's supply management system for these two industries differs from the U.S. unregulated counterparts. Regulated industries carry implications for both farm size and generally lower prices for consumers. A range in U.S. farm size occurs because any farm can produce poultry or milk while not included in that particular industry board. In Canada however, the farm size range for milk and poultry production is restricted through regulation. The U.S. analysis therefore works well with the occurrence of dairy and poultry farm size range for an interesting overall assessment agriculture structure. Nevertheless, the crop-based food production indicators are good parallel measures of Canada's agriculture, establishing a base for Canadian study.

Lastly, with regard to how this study relates to the rest of the world, the U.S. agriculture assessment provides a cohesive understanding of one the world's most industrialized nations who provide a considerable portion of the world's agricultural supply. The positive results for U.S. small farm agriculture supported in this study therefore bode well for small farm agriculture globally. Evidenced by land pressures on a global scale, further research in defining optimal farm size is essential to developing a strategy for the future of sustainable global food systems.

Project Critique

The limitations of the study are largely related to the data set employed whereby a lack of specific data limits certain inferences. Certain desired data for this analysis include the hours worked by labourers for the most accurate measure of human resource efficiency and job provision to inform productivity and social indicators. As well, volume and weight of dairy, vegetable, and fruit data are required for a complete measure of food production. Specifically, with regard to the complication of interpreting animal-based production, data concerning the source and type of feed used for animal-based production would increase confidence in result interpretation.

With regard to methodology and study design employed, a potential improvement lies in the procurement of a conclusive result to resolutely prove or disprove the hypothesis. To do so numerically, the creation of a metric to represent overall efficiency for small and large farms was considered. For quantitative analysis, food productivity would function as the dependent variable, while resource indicators serve as independent variables to determine various resource efficiencies. When comparing efficiency values the larger numerical value would indicate a more efficient resource-use, where resource efficiency indicators are expressed as an average or range of values representative of each farm category.

Additionally, indicators grouped according to which efficiency it measures would inform overall efficiency index estimations achievable by the weighted product of resource-use efficiency, productive efficiency, environmental and social benefit indicators. The weighting required for this metric, however, would be assigned subjectively and arbitrarily to introduce significant bias. Thus, the rationale for this study's methodology was to avoid bias and subjectivity in analysis and rather to carry out a study, as objective as possible, of the data and interpret results in the context of the literature.

Future Work

Parallel to the limitations of the study with regard to scope and breadth, future work could carry out a similar study using different designations of land-based farm scale. Such a study employing differing constraints on farm size for small and large farms or the entire range in farm sizes could show a less polarizing view of the U.S. farm structure and potentially shed light on optimal farm size. Furthermore, innumerable opportunities for future research based on this study are presented. It is suggested primarily that this future study consider the 2012 U.S. Census of Agriculture, where the level of data disaggregation in census data facilitates trend analysis to interpret the direction and magnitude of change over time.

It is also suggested that a future study occur using data specific to Canada, however, since the limitations of a study are largely correlated to data availability, the lack of Canadian data to support such a study is the limiting factor. Agricultural data representative of Canada, in this detail, is either not collected or made publicly available. As a researcher it is therefore suggested this information is collected and made publically available. Furthermore, as agriculture policy ultimately influences what is produced, the results of this study as well as future work are indirectly determined by policy. Therefore a more detailed and rigorous analysis of policy is suggested to provide both recommendations for best practices and for results to be more meaningful with regard to Canadian agriculture.

Summary

This study was undertaken to perform an analysis of agricultural scale between small and large farms from a land-based perspective. The purpose was to determine primarily whether small farms are able to produce as much food per acre as large farms, and secondly, if they are able to do so, what environmental and social merits do small farms have as compared to large farms. The results of this study suggest that small farms relative to large farms do produce a comparable amount of food, as supported by both the direct and indirect measures of food production. While it is found that overall productive efficiency favours large farms, it is shown that the value reaped for each unit of land input is significantly greater for small farms.

To address the second portion of the study objective, it is shown that the extent of resource input is lower for small farms but that the intensity of use per unit of land is also greater. Environmental merit is nevertheless indicated by the significant proportion of woodland preserved in small farm landholdings as compared to the minor fraction preserved by large farms. Lastly, while both small and large farms provide a composite of varying social benefit, small farms have the greatest evidence of social merit in terms of job provision and public accessibility proven to increase the resilience and sustainability of agricultural food systems the world over.

This study makes a novel contribution to the field of agricultural studies by providing an alternative approach to defining and assessing farm systems from a land based perspective. The approach is justified given the land resource pressures evident on a global scale. An assessment of the U.S. agriculture structure is particularly useful for a cohesive understanding of one of the world’s most industrialized nations that also provides a considerable portion of the world’s agricultural output. The implications of this research suggest that small farms play an economically, environmentally, and socially viable role in U.S. food production. Further research in defining optimal farm size is essential to developing a strategy for the future of sustainable global food systems.

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Appendix A

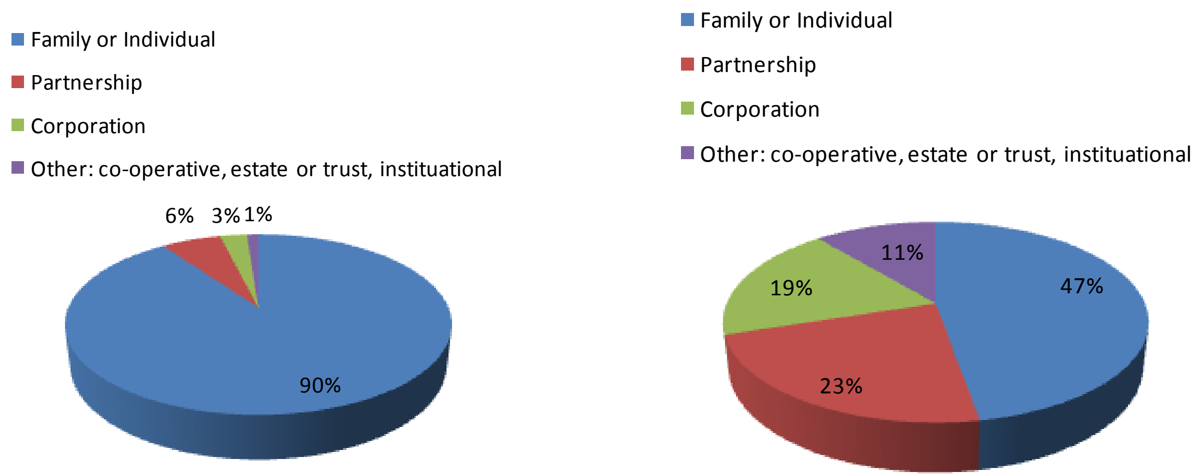

FIGURE 4 The proportional acreage organization by ownership type for the average small (left) and large (right) farm

TABLE 9 Percentage of total sales of grains, oilseeds, dry beans, and dry peas for small and large farms

Proportion of total sales of grains, oilseeds, dry beans, and dry peas (%)	Small Farm	Large Farm	Ratio of Small to Large Farm
Corn	57.15	46.20	0.03
Wheat	5.96	21.74	1.24
Soybeans	33.76	20.37	0.27
Sorghum	0.63	3.10	1.66
Barley	0.40	1.36	0.20
Rice	0.86	3.07	0.29
Other	1.24	4.16	0.28
Total	100	100	0.30