7-2015

Energy Management at University Farms

H. Mark Hanna
Iowa State University, hmhanna@iastate.edu

Jay D. Harmon
Iowa State University, jharmon@iastate.edu

Dana D. Schweitzer
Iowa State University, schweitz@iastate.edu

Energy Management at University Farms

Abstract

Energy is an input cost to agricultural production. Knowing typical values can help farmers to evaluate management options. Diesel, propane, and electrical energy used on the farm during selected field operations, crop drying, and in swine housing were measured on Iowa State University research and demonstration farms. Baseline values were measured and tractor operation management styles were compared.

Strategies for saving fuel were demonstrated in 30 of 35 tractor operation comparisons. Comparisons of gear/engine speed, tillage depth, travel speed, and use of front-wheel-assist averaged 29, 27, 15, and 14% more energy used than the fuel-saving alternative. Single drive wheels used 8% more energy than duals, but results were mixed when comparing different tire inflation pressures.

Energy used in high-temperature drying in bins ranged from 4.67 to 7.70 Mj/kg (2010 to 3310 Btu/lb). Most energy was used from propane (96%). Propane use averaged 0.0027 L/kg (0.018 gal/bu) per percentage point of moisture removed.

Minimum ventilation fans had the highest duty factor in a curtain-sided swine finishing barn. Electrical use was greater in tunnel-ventilated than curtain-sided barns (29.0 vs. 20.9 kWh/pig space-yr) and propane use was greater in wean-to-finish than finish-only operations(10.6 L vs. 2.5 L/pig space-yr, 2.8 gal vs. 0.67 gal/pig space-yr).

Keywords

energy efficiency, field operations, fuel consumption, grain drying, machinery management, swine housing, tractor, ventilation

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Oil, Gas, and Energy

Comments

This proceeding is from 2015 ASABE Annual International Meeting, Paper No. 152189846, pages 1-24 (doi: 10.13031/aim.20152189846). St. Joseph, Mich.: ASABE. Posted with permission.

2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 152189846

Energy Management at University Farms

H. Mark Hanna, Jay D. Harmon, and Dana D. Schweitzer
Agricultural and Biosystems Engineering Department, Iowa State University

Written for presentation at the
2015 ASABE Annual International Meeting
Sponsored by ASABE
New Orleans, Louisiana
July 26 – 29, 2015

Abstract. Energy is an input cost to agricultural production. Knowing typical values can help farmers to evaluate management options. Diesel, propane, and electrical energy used on the farm during selected field operations, crop drying, and in swine housing were measured on Iowa State University research and demonstration farms. Baseline values were measured and tractor operation management styles were compared.

Strategies for saving fuel were demonstrated in 30 of 35 tractor operation comparisons. Comparisons of gear/engine speed, tillage depth, travel speed, and use of front-wheel-assist averaged 29, 27, 15, and 14% more energy used than the fuel-saving alternative. Single drive wheels used 8% more energy than duals, but results were mixed when comparing different tire inflation pressures.

Energy used in high-temperature drying in bins ranged from 4.67 to 7.70 Mj/kg (2010 to 3310 Btu/lb). Most energy was used from propane (96%). Propane use averaged 0.0027 L/kg (0.018 gal/bu) per percentage point of moisture removed.

Minimum ventilation fans had the highest duty factor in a curtain-sided swine finishing barn. Electrical use was greater in tunnel-ventilated than curtain-sided barns (29.0 vs. 20.9 kWh/pig space-yr) and propane use was greater in wean-to-finish than finish-only operations(10.6 L vs. 2.5 L/pig space-yr, 2.8 gal vs. 0.67 gal/pig space-yr).

Keywords. energy efficiency, field operations, fuel consumption, grain drying, machinery management, swine housing, tractor, ventilation.

Introduction

U. S. farms spent $16,573,188,000 for gasoline, fuels, and oils and $8,261,978,000 for utilities in 2012 according to the USDA Agricultural Census (USDA, 2014). Purchase of diesel fuel, liquid propane (LP), and natural gas are included in gasoline, fuels, and oils. Electricity, telephone charges, internet fees, and purchased water are included in utilities costs. Iowa spent more than one billion dollars including $866,990,000 on gasoline, fuels, and oils (primarily diesel fuel and LP) and $329,138,000 on utilities (primarily electricity).

University Extension staff estimate energy consumption (Hanna, 2001). Estimates are frequently based on either old or very limited data. McLaughlin et al. (2008) measured fuel use of 21.6, 13.9, and 7.3 L/ha (2.31, 1.49, and 0.78 gal/acre) for moldboard plowing, chisel plowing, and disking (tandem disk harrow) in southwestern Ontario. Tillage depth and travel speeds were within ranges normally used in the region, 187 mm (7.4 in.) and 5.6 km/h (3.5 mi/h) for moldboard plowing, 169 mm (6.7 in.) and 6.6 km/h (4.1 mi/h) for chisel plowing, and 59 mm (2.3 in.) and 6.5 km/h (4.0 mi/h) for disking.

Because of a lack of current fuel consumption data for field operations, most machinery and crop production budgets developed by Extension staff and others use values estimated from ASABE Standards (ASABE Standards 2014a, 2014b). Estimates are based on fuel consumption models for tractors from OECD tractor tests (Grisso et al., 2008) and estimation of drawbar and rotary-powered load forces from implement geometry, soil conditions, travel speed, and tillage depth.

Energy use for grain drying is also estimated from old or very limited public data. Morey et al. (1978) drying corn from 22.3% moisture content (m.c.) to 15.8% m.c. with 100 °C (212 °F) air used 5.71 Mj of energy per kg of water removed (2461 Btu/lb) using a small automatic batch dryer (10.6 m^3; 300 bu). Treatments also included use of high-temperature drying to intermediate moisture contents (e.g. 18 and 21%) followed by natural-air drying. Higher energy efficiencies were associated with treatments using least moisture reduction in the high-temperature dryer. Wilcke and Bern (1986) dried corn with unheated natural-air during two seasons. Corn dried from 24.7% to 13.0% m.c. used 3.02 Mj/kg (1300 Btu/lb) energy per water removed. Corn dried the following year from a lower initial moisture content, 19.7%, to 14.3% used 4.10 Mj/kg (1760 Btu/lb). Limited field observations such as these, along with modeling estimates, have been used by Extension staff to estimate crop drying energy consumption (Morey and Cloud, 1980). Wilcke and Bern (1985) estimated propane energy consumption in a high-temperature dryer to range from 0.0015 to 0.0037 L/kg per percentage point of moisture removal (0.01 to 0.025 gal/bu/pt) and electrical consumption to range from 0.00028 to 0.0012 kWh/kg/pt (0.007 to 0.03 kWh/bu/pt). Electrical consumption in a natural-air dryer was estimated to range from 0.011 to 0.017 kWh/kg/pt (0.28 to 0.42 kWh/bu/pt) for drying corn from 20% m.c. and 0.012 to 0.028 kWh/kg/pt (0.31 to 0.71 kWh/bu/pt) for drying corn from 24% m.c.

In order for swine producers to gauge energy consumption and the need for energy conservation measures, benchmarks for energy usage are needed. Energy benchmarks for swine production are not widely available. This is due to the wide variation in production facilities and the fact that energy usage is often aggregated within whole farm usage. Harmon et al. (1998) compared three styles of swine finisher (22 kg to 114 kg) and found that a hybrid ventilated finishing building that utilized fans for cold weather ventilation and sidewall ventilation curtains for warm weather ventilation used 10.9 kWh/pig space-yr of electricity and 2.3 L of propane/pig space-yr (0.6 gal/pig space-yr). Other studies have reported utility cost in terms of cost per pig marketed without identifying the individual contribution of electricity and heating fuel. Navia et al (2007) found that finishing pigs required an average utility cost of $1.70 (Canadian) per pig marketed with a range of $1.30 to $2.10. Predicala and Navia (2008) reported the same average with a broader range of $1.2 to $2.60/pig marketed. Likewise, Finbin (2014) reports that 58 wean-finish (6 kg to 122 kg) farms reporting in Minnesota in 2012 and 2013 reported utilities cost of $0.64 (US)/ pig marketed with fuel and oil reported to be $1.25/pig marketed. These numbers illustrate that there are inconsistencies in how energy usage is reported and partitioned and highlight the need to find a more uniform, descriptive way of reporting the data.

Measurement of on-farm energy use is needed to either validate older measurements or establish new benchmarks using more current technology. Comparison of energy management techniques on local research and demonstration farms helps farmers to evaluate and adopt improved energy management strategies.

Objective

Measure baseline energy use values and compare management techniques where possible on university research and demonstration farms.

Methods and materials

Iowa State University has research and demonstration farms located throughout the state. Larger farms have 200 acres or more of cropland. Individual farms reflect local differences in soil and climate, as illustrated in Figure 1. Although much cropland is used for smaller scale research plots, larger tracts of 'bulk' acres are frequently tilled and seeded on smaller ISU farm locations near the central Agricultural Engineering and Agronomy Research Farm, the Northwest (Allee) Research Farm, and on the Ag 450 teaching farm near Ames. On-site grain drying for ISU farms is present at the Northeast, Southwest (Armstrong), and Ag 450 farms. Livestock operations on outlying farms are limited due to distance from campus, but a swine feeding operation is present on the Ag 450 teaching farm near Ames.

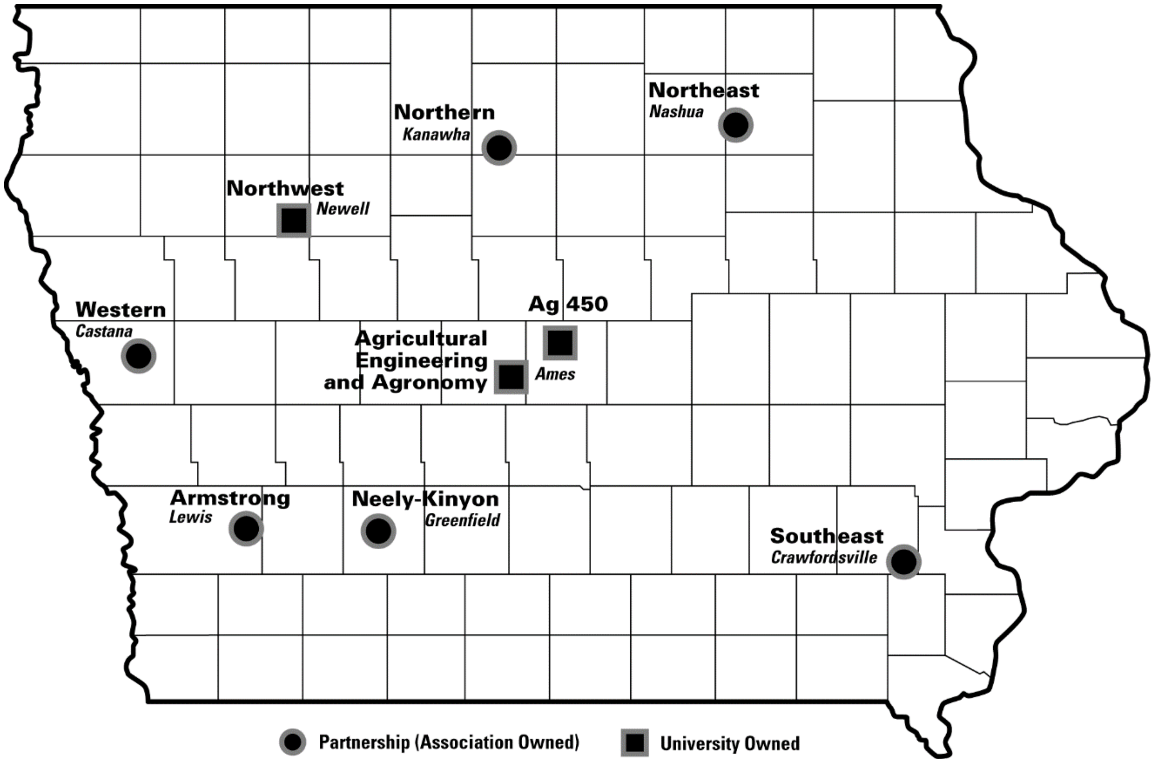

Figure 1: ISU Research & Demonstration farm locations.

Field operations

Each farm participating in the tractor study selected a tractor for fuel measurement that was commonly used for field operations. Selected tractor models are shown in Table 1. A gravimetric fuel measurement system was used to avoid potential back-pressure problems in return fuel lines on diesel engines from flow meters. A 49 l (13 gal) auxiliary fuel tank was mounted atop a 100 kg (220 lb) load cell on each tractor. Weight on the load cell is displayed in the tractor cab. Plumbing was added for diesel fuel to be supplied and returned from the engine via either the main or auxiliary fuel tank, depending on the setting for a single flow control valve. Net weight of fuel consumed (supply – return) was measured by recording difference in auxiliary tank weight before and after an observation in the field.

Table 1. Tractors[a] used for fuel measurements by location

Farm location	Tractor (kW, hp)
Agricultural Engineering Agronomy	John Deere 7730 (114, 153)
Northeast	John Deere 7430[b] (105,141) and 6170R[c] (107, 143)
Northern	John Deere 7410 (79, 106)
Northwest	John Deere 2955 (64, 86)
Southeast	John Deere 7430 (105, 141)
Southwest	John Deere 7420 (87, 117)
Western	John Deere 6420 (70, 94)

[a] Brand names are used for convenience of the reader and do not imply endorsement or critique by the authors.

[b] Used during 2013.

[c] Used during after 2013.

Although field work on the research farms is frequently done on small plot areas, an objective was to measure fuel consumption of 2.3 kg (5 lb) or more during single observations as the load cell measures fuel in 0.045 kg (0.1 lb) increments. Another objective was to obtain multiple replications if land area and timing of trials allow. Small plots or farm scheduling frequently conflicted with these objectives. Limited replications reduced the ability to measure statistical significance beyond overall trends in data in some cases. Field area covered by each observation was calculated from implement width and field distance traveled (either measured manually or with on-board electronics when available on the tractor). Fuel consumption was then calculated as l/ha (gal/acre).

Crop drying

Grain drying energy consumption was measured at the Ag 450, Southwest (Armstrong), and Northeast Farms. Bin dryers are used to accommodate crop size and harvest rate on the farms. Harvest of research plots frequently slows harvest rate compared to commercial farms. Propane consumed for drying was measured by four 910-kg (2000-lb) load cells underneath the feet of propane tanks recording weight. A data logging system recorded tank weight every 30 minutes during drying. Electrical energy was measured for drying fans and mixing augers. Energy use was calculated from measurements of electric current every 30 minutes during grain drying and measurement of electrical power factor twice during the first drying season in electrical circuits supplying fan and stirring equipment energy.

At the Ag 450 and Northeast Farms, grain is dried as a 'batch-in-bin' system with a vertical stirring auger mixing the entire grain mass while a fan blows heated air up through grain from the plenum. At the Ag 450 Farm, harvesting from larger land areas filled the bins within a day. At the Northeast Farm, bins were filled during plot harvest. Bin fill was completed within 3 to 6 days resulting in shallower layer drying during earlier stages of the batch. During fall 2013 at the Ag 450 and

Northeast Farms, three batches of drying were accomplished, two batches in one bin and a single batch in a second bin at both locations. Fall 2014 drying was similar except that at the Ag 450 Farm only a single batch was dried in each drying bin.

The drying bin at the Southwest Farm has a bottom sweep auger that transfers grain dried by plenum air to a center vertical auger. The vertical auger lifts grain either back to the top of the bin grain mass where it is distributed (recirculating batch mode) or lifts and transfers dried grain completely out of the bin into an adjacent storage bin (continuous flow mode). Because heated air moves in the opposite direction of grain flow, this is termed a counter-flow dryer, and was operated in both 'continuous' mode with dried grain immediately leaving the dryer and 'batch' mode with dried grain being recirculated to the top of the grain mass inside the bin. Drying temperatures of 140°F and 180°F were used with each mode during fall 2013. During fall 2014 'continuous' drying was done at 140°F and 'batch' drying was done at 180°F. Full bin capacity is 9000 bushels. To accommodate plot harvest rate, total grain available, and to observe drying in a shallower layer, the bin was filled between about 1900 to 3900 bushels during both batch- and continuous-flow drying modes. After high-temperature drying measurements and at the end of harvest, the bin was filled with corn to be dried with natural air (fan only). After fall 2013 harvest, samples from multiple grain probes in late winter showed the drying front had progressed about 2.1 m (7 ft) during late fall drying before grain in the bin was removed. Weather conditions following fall 2014 harvest allowed natural-air drying to be completed by late November. Because of prior inactivity, the high-temperature drying system at the Southwest Farm was refurbished before measurements started in fall 2013.

Bin and fan specifications are shown in Table 2.

Table 2. Bin capacity and fan power

		Capacity		Bin diameter		Fan power	
Location	Bin	m^3	bu	m	ft	kW	hp
Ag 450	west	342	9700	9.1	30	5.6	7.5
Ag 450	east	324	9200	8.2	27	7.5	10
Northeast	east	310	8800	8.5	28	9.3	12.5
Northeast	west	419	11,875	9.1	30	11.2	15
Southwest		317	9000	9.1	30	19.4[a]	26[a]

[a] Two 9.7 kW (13 hp) fans

Beginning moisture content was determined by measuring individual loads with a moisture meter used by local farm staff. An equivalent moisture content, based on the amount of corn dry matter and water added to the bin, was calculated for corn that was dried. If time was available, farm staff at the Ag 450 and Northeast Farms measured daily intermediate moisture contents during drying from multiple samples taken in the top layer of corn in the bin. Ending moisture content was measured in the same manner at Ag 450 and Northeast Farms. At the Armstrong Farm, ending moisture content was measured from the exit moisture sensor on the drying system for 1770-l (50-bu) corn increments being transferred during five-minute periods and then calculating equivalent moisture content for total corn dried during a drying period.

Energy required to remove water from the grain was the sum of propane used for the dryer burner and electrical energy for drying fans and the stirring and recirculating augers. Total energy consumed was divided by the amount of water removed to provide a measure of energy use for drying in MJ/kg (Btu/lb) of water removed.

Swine housing

Two approaches were used in obtaining energy usage data with swine production. In one approach a swine finishing facility was instrumented to collect detailed information on fan energy usage, including duty cycles, and heating energy usage. The second approach focused on more global data by seeking monthly energy data from production units.

The detailed monitoring occurred at the Iowa State University Ag 450 farm. This farm is managed by students in a management class and includes a swine finishing facility. This barn has four rooms 12.2 m x 18.3 m (40 ft x 60 ft). Each has a capacity of 300 pigs. The rooms have three fan stages and utilize sidewall ventilation curtains for warm weather. The first stage includes two Aerotech Classic AT10SP fans with 124 W (1/6 hp) electric motors and rated at 30 m^3/min (1060 cfm) at a static pressure difference of 25 Pa (0.1 inches of water). The exact fan models for the second and third fan stages could not be confirmed because all markings had been worn away from the fans. The building owner stated that the second and third stage fans were each 249 W, 61 cm (1/3 hp, 24") Hired Hand Funnel Flow fans rated at 178 m^3/min (6280 cfm) at a static pressure of 25 Pa (0.1 inches of water). This resulted in a nominal maximum mechanical ventilation capacity of 416 m^3/min or 1.4 m^3/min-pig (14,680 cfm or 49 cfm/pig). A make-up air furnace was mounted on the exterior of each room.

Monitoring equipment was installed on the ISU Ag 450 swine finishing unit to gather information on electrical and propane usage. During fall of 2012 electrical monitoring began on two of the four rooms within the swine finisher with monitors providing an amperage output of the three fan stages within each room every 30 seconds. This was used to establish duty factors and fan energy usage on each fan stage. In September, 2013 propane meters were added to all 4 rooms. Pulse counts were produced for each cubic foot of propane used on a 15 minute basis.

The second approach was done by locating entities willing to share energy usage information. One cooperator represented a swine production company that shared data for five different 2400-head, tunnel ventilated, wean-to-finish facilities. Another source was an electrical utility within Iowa which shared data from 7 different farms. In addition, one swine producer provided five years of data from two of his swine buildings. These were summarized and categorized by building type.

Results and discussion

Field operations

Fuel use measurements during selected field operations and treatment comparisons are shown in Tables 3 – 12. Farm staff were encouraged, when possible, to compare different treatments. These included using different transmission gear and engine speed settings at the same travel speed, different travel speeds, different tillage depths, different tire inflation pressures (a lower inflation pressure as specified by the tire or tractor manufacturer for wheel load, and an over-inflated condition), operation with and without front-wheel-assist engaged, or operation with single or dual tires. American Society of Agricultural and Biological Engineers machinery management standards and data, S496.3 and S497.7, were also used to calculate expected fuel use.

A summary of observed differences in the various treatment comparisons is shown in Table 13. Farm managers and agricultural economists frequently want to know fuel use for various field operations to incorporate into crop input budget estimates. Average, least, and greatest fuel used by field operations for treatments observed are shown in Table 14.

Limited replications (often 3 or 4) generally precluded the ability to detect statistically significant differences. Failing to shift up to a higher gear and reduce engine speed (Tables 3 – 5) caused an average 29% more fuel use and was demonstrated in 13 of 14 comparisons. Increasing travel speed required an average of 14% more fuel and was demonstrated in 5 of 7 comparisons (Tables 6 and 7). When tillage depth was increased, fuel use increased in all 3 comparisons by an average of 27% (Table 8).

Slightly more fuel was used in 3 of 5 comparisons between correctly and overinflated tires (Table 9), but results varied. Average fuel difference including all 5 comparisons was slightly negative (-1%) and no comparisons were statistically significant. Not using front-wheel-assist consumed an average of 8% more fuel in 4 comparisons (Table 10, 3 statistically significant).

Treatments comparing field operations with and without the use of dual rear-drive wheels were done at the Northwest Research Farm (Tables 11 and 12). In both cases, an average of 8% additional fuel was used with only single-tire wheels, although neither was statistically significant. Additional comparisons from these Tables at the Northwest Farms were used as appropriate for gear/engine speed, travel speed, and depth treatments in summary Tables 13 and 14.

Fuel-saving strategies were generally well demonstrated for shifting up and throttling back during reduced drawbar loads, reducing tillage depth, and making use of front-wheel-drive. Fuel savings were also demonstrated at lower travel speeds, although savings were not as great as transmission and depth, and results were mixed as engine speed and torque characteristics were matched to loads. Fuel savings were demonstrated in two comparisons of single vs. dual drive tires. Fuel savings observed were marginal (often within the range of measurement accuracy) and least apparent when comparing tire inflation. Overall, 30 of 35 treatment comparisons showed expected trends in fuel savings and 14 of the comparisons were statistically significant.

Theoretical fuel use values calculated using procedures from ASABE standards were generally greater than observed values for travel speed, tillage depth, and tire inflation comparisons, but lower than observed values for gear/engine speed, front-wheel-assist, and dual vs. single tire comparisons (Table 13). Variations between observed and estimated values may be due to in-field factors such as turns on short plot rows or inherent variability in applying ASABE estimation techniques. Grisso et al. (2008) reported the ASABE standard often over-predicted fuel use unless adjusted for individual tractor test data.

Fuel used by various field operations had a wide range of treatment mean values (Table 14). This suggests better estimates for crop input budgets may be made if additional fuel saving strategies are known and employed by tractor operators. Comparing tillage fuel consumption values with those reported by McLaughlin et al. (2008), fuel use was greater for moldboard plowing, less for disking, and at most sites less for chisel plowing.

Table 3. Observed and theoretical fuel use at the Northeast Iowa Research Farm with gear/engine rpm.

Operation	No. of replications	Treatment	Fuel use observed		Fuel use theoretical	
		Gear/engine rpm	L/ha	Gal/acre	L/ha	Gal/acre
2013						
Field cultivation, 8 km/h (5 mi/h)	3	C1/2080	7.51	0.803	4.67	0.499
	3	C2/1710	6.15	0.657	4.06	0.434
LSD $_{\alpha=0.05}$[a]			0.50	0.053		
Strip till, 8.4 km/h (5.2 mi/h)	3	C1/2170	19.62	2.098	10.99	1.175
	3	C2/1710	13.01	1.391	9.64	1.031
LSD $_{\alpha=0.05}$[a]			NS[b]	NS[b]		
Stalk chopping, 8.0 km/h (5.0 mi/h)	3	C1/2060	8.90	0.951	5.55	0.593
	3	C2/1710	6.02	0.644	4.98	0.532
			0.55	0.059		
2014						
Field cultivation, 8.0 km/h (5.0 mi/h)	3	C1/2080	5.60	0.599	4.21	0.450
	3	C2/1720	3.79	0.405	3.68	0.394
LSD $_{\alpha=0.05}$[a]			NS[b]	NS[b]		
Subsoiling, 5.9 km/h (3.7 mi/h)	3	B1/2100	11.86	1.268	13.34	1.426
	3	B3/1500	9.97	1.066	11.74	1.256
LSD $_{\alpha=0.05}$[a]			NS[b]	NS[b]		

[a] Least significant difference between treatments at a 95% confidence level.

[b] No significant difference at the 95% confidence level.

Table 4. Observed and theoretical fuel use at the Southwest Iowa Research Farm, with gear/engine rpm.

Operation	No. of replications	Treatment	Fuel use observed		Fuel use theoretical	
		Gear/engine rpm	L/ha	Gal/acre	L/ha	Gal/acre
2013						
Moldboard plowing, 7.2 km/h (4.5 mi/h)	1	B2/2250	45.3	4.84	20.20	2.90
	3	B3/2000	42.7	4.57	18.52	2.70
	4	B4/1700	34.3	3.67	16.56	2.46
LSD $_{\alpha=0.05}$[a]			NS[b]	NS[b]		
Disking, 7.4 km/h (4.6 mi/h)	4	B3/2200	3.17	0.339	5.99	0.640
	4	C1/2000	3.60	0.385	5.65	0.604
LSD $_{\alpha=0.05}$[a]			NS[b]	NS[b]		
Planting, 6.4 km/h (4.0 mi/h)	4	B2/2225	4.28	0.457	4.43	0.474
	5	B3/1850	3.64	0.389	3.91	0.418
	4	B4/1500	3.43	0.367	3.43	0.367
LSD $_{\alpha=0.05}$[a]			NS[b]	NS[b]		
2014						
Moldboard plowing, 6.9 km/h (4.3 mi/h)	3	B2/2250	35.21	3.764	27.69	2.961
	4	B3/2000	32.81	3.508	25.95	2.774
	3	B4/1700	26.72	2.857	23.85	2.551
LSD $_{\alpha=0.05}$[a]			4.55	0.486		
Planting, 6.4 km/h (4.0 mi/h)	4	B2/2200	4.04	0.432	3.10	0.453
	4	B3/1900	3.52	0.376	2.78	0.412
	4	B4/1520	3.64	0.389	2.37	0.361
LSD $_{\alpha=0.05}$[a]			NS[b]	NS[b]		

[a] Least significant difference between treatments at a 95% confidence level.

[b] No significant difference at the 95% confidence level.

Table 5. Observed and theoretical fuel use at the Northern and Western Iowa Research Farms, with gear/engine rpm.

Operation	No. of replications	Treatment	Fuel use observed		Fuel use theoretical	
		Gear/engine rpm	L/ha	Gal/acre	L/ha	Gal/acre
Northern						
Field cultivation, 10.1 km/h (6.3 mi/h)	2	C2/2170	4.05	0.433	3.71	0.396
	1	C4/1480	2.82	0.301	3.00	0.321
LSD $_{\alpha=0.05}$[a]			NS[b]	NS[b]		
Western						
Planting, 8.3 km/h (5.2 mi/h)	8	B4/2150	5.37	0.574	3.04	0.325
	8	C2/1900	4.63	0.495	2.77	0.296
LSD $_{\alpha=0.05}$[a]			0.25	0.027		
Grain drill, 8.3 km/h (5.2 mi/h)	8	B4/2150	5.20	0.556	3.91	0.418
	8	C2/1900	3.65	0.390	3.60	0.385
LSD $_{\alpha=0.05}$[a]			0.41	0.044		

[a] Least significant difference between treatments at a 95% confidence level.

[b] No significant difference at the 95% confidence level.

Table 6. Observed and theoretical fuel use during chisel plowing with different travel speeds.

Location	No. of replications	Treatment, travel speed		Fuel use observed		Fuel use theoretical	
		Km/h	Mi/h	L/ha	Gal/acre	L/ha	Gal/acre
Southeast	3	6.0	3.8	10.46	1.118	11.49	1.271
	3	7.2	4.5	12.98	1.388	10.44	1.209
LSD $_{\alpha=0.05}$[a]				NS[b]	NS[b]		
Northern	3	7.4	4.6	8.52	0.911	12.05	1.288
	3	8.2	5.1	6.48	0.693	11.84	1.266
	3	8.9	5.5	10.30	1.101	11.73	1.254
LSD $_{\alpha=0.05}$[a]				NS[b]	NS[b]		
Southwest	1	4.82	3.00	9.89	1.057	11.49	1.228
	1	6.92	4.30	9.13	0.976	10.44	1.116
	1	7.56	4.70	8.82	0.943	10.31	1.102

[a] Least significant difference between treatments at a 95% confidence level.

[b] No significant difference at the 95% confidence level.

Table 7. Observed and theoretical fuel use during disking at the Southwest Farm and rotary mowing and hauling corn at the Western Farm with different travel speeds.

Operation	No. of replications	Treatment, travel speed		Fuel use observed		Fuel use theoretical	
		Km/h	Mi/h	L/ha	Gal/acre	L/ha	Gal/acre
Disking	4	7.2	4.5	2.41	0.258	6.28	0.672
	4	8.0	5.0	2.77	0.296	6.26	0.670
LSD $_{\alpha=0.05}$[a]				NS[b]	NS[b]		
Mowing hay	4	7.2	4.5	5.86	0.626	4.90	0.524
	4	8.5	5.3	6.79	0.726	4.65	0.497
LSD $_{\alpha=0.05}$[a]				0.15	0.016		
Hauling corn[c]	4	27	17	1.60	0.171	1.54	0.164
	4	32	20	1.92	0.205	1.55	0.166
LSD $_{\alpha=0.05}$[a]				0.02	0.002		

[a] Least significant difference between treatments at a 95% confidence level.

[b] No significant difference at the 95% confidence level.

[c] Fuel use, L/km or Gal/mi

Table 8. Observed and theoretical fuel use with tillage depth at the Southwest Iowa Research Farm..

Operation	No. of replications	Treatment, disking depth		Fuel use observed		Fuel use theoretical	
		cm	in	L/ha	Gal/acre	L/ha	Gal/acre
<u>2013</u>							
Disking, 7.4 km/h (4.6 mi/h)	4	8	3	3.31	0.354	4.99	0.533
	4	13	5	3.55	0.379	6.64	0.710
LSD $_{\alpha=0.05}$[a]				NS[b]	NS[b]		
<u>2014</u>							
Disking, 7.6 km/h (4.7 mi/h)	4	10	4	2.14	0.229	5.34	0.571
	4	15	6	3.03	0.324	7.21	0.771
LSD $_{\alpha=0.05}$[a]				NS[b]	NS[b]		

[a] Least significant difference between treatments at a 95% confidence level.

[b] No significant difference at the 95% confidence level.

Table 9. Observed and theoretical fuel use with tire inflation at the Ag Engineering Agronomy Farm during 2013, and the Northern and Southwest Iowa Research Farms during 2014..

Location/operation	No. of replications	Treatment, tire pressure		Fuel use observed		Fuel use theoretical	
		rear/front, kP	rear/front, psi	L/ha	Gal/acre	L/ha	Gal/acre
<u>Ag Engineering Agronomy Farm</u>							
Chisel plowing[a], 7.7 km/h (4.8 mi/h)	3	69/138	10/20	14.87	1.591	12.03	1.286
	3	138/207	20/30	15.05	1.610	12.03	1.286
LSD $_{\alpha=0.05}$[b]				NS[c]	NS[c]		
Chisel plowing[d], 7.7 km/h (4.8 mi/h)	3	69/138	10/20	13.23	1.414	12.03	1.286
	3	138/207	20/30	13.40	1.433	12.03	1.286
LSD $_{\alpha=0.05}$[b]				NS[c]	NS[c]		
<u>Northern Farm</u>							
Chisel plowing[d], 5.8 km/h (3.6 mi/h)	3	97/235	14/34	10.22	1.093	12.94	1.383
	4	138/235	20/34	10.45	1.117	12.94	1.383
LSD $_{\alpha=0.05}$[b]				NS[c]	NS[c]		
<u>Southwest Farm</u>							
Chisel plowing[d], 5.8 km/h (3.6 mi/h)	3	69/221	10/32	11.31	1.209	11.44	1.223
	3	138/221	20/32	10.82	1.157	11.44	1.223
LSD $_{\alpha=0.05}$[b]				NS[c]	NS[c]		
Disking, 7.6 km/h (4.7 mi/h)	4	69/221	10/32	2.69	0.288	6.27	0.671
	4	97/221	14/32	2.49	0.266	6.27	0.671
LSD $_{\alpha=0.05}$[b]				NS[c]	NS[c]		

[a] Summer, after small grain harvest.

[b] Least significant difference between treatments at a 95% confidence level.

[c] No significant difference at the 95% confidence level.

[d] Fall, after grain harvest.

Table 10. Observed and theoretical fuel use at the Western Iowa Research Farm, with and without mechanical front wheel drive.

Operation	No. of replications	MFD[a]	Fuel use observed L/ha	Fuel use observed Gal/acre	Fuel use theoretical L/ha	Fuel use theoretical Gal/acre
Planting, 8.3 km/h (5.2 mi/h)	8	disengaged	5.17	0.553	2.94	0.314
	8	engaged	4.82	0.515	2.86	0.306
LSD $_{\alpha=0.05}$[b]			0.25	0.027		
Grain drill, 8.3 km/h (5.2 mi/h)	8	disengaged	4.54	0.486	3.83	0.409
	8	engaged	4.31	0.461	3.69	0.395
LSD $_{\alpha=0.05}$[b]			NS[c]	NS[c]		
Hauling bales[d]	4	disengaged	1.92	0.330	2.78[e]	0.478[e]
	4	engaged	1.70	0.293	2.43[e]	0.418[e]
LSD $_{\alpha=0.05}$[b]			0.12	0.021		
Rotary mowing, 6.9 km/h (4.3 mi/h)	4	disengaged	7.27	0.777	4.84	0.517
	4	engaged	5.53	0.591	4.84	0.517
LSD $_{\alpha=0.05}$[b]			1.38	0.148		

[a] Mechanial front wheel drive.

[b] Least significant difference between treatments at a 95% confidence level.

[b] No significant difference at the 95% confidence level.

[d] Fuel use, L/km or Gal/mi

[e] Draft used for roller packer

Table 11. Observed and theoretical fuel use at the Northwest Research Farm during field cultivation using dual wheels, varying depth, and travel speed.

Operation	No. of Replications	Treatment Wheels	Treatment Travel speed km/h	Treatment Travel speed mi/h	Treatment Depth cm	Treatment Depth in.	Fuel use observed L/ha	Fuel use observed Gal/acre	Fuel use theoretical L/ha	Fuel use theoretical Gal/acre
Field cultivation	6	dual	7.7	4.8	13	5	7.79	0.833	4.75	0.508
	6	dual	7.7	4.8	13[a]	5[a]	6.68	0.714	4.75	0.508
	5	dual	8.2	5.1	13	5	6.16	0.659	4.72	0.505
	5	single	8.2	5.1	13	5	6.91	0.739	4.72	0.505
	6	dual	7.7	4.8	8	3	5.86	0.627	3.44	0.368
LSD $_{\alpha=0.05}$[b]							1.37	0.146		

[a] Loose soil in second pass; other field cultivation operations were secondary tillage, but first pass on firm ground.

[b] Least significant difference between treatments at a 95% confidence level.

Table 12. Observed and theoretical fuel use at the Northwest Research Farm during planting using dual wheels, varying gear/throttle operation, and travel speed.

Operation	No. of replications	Treatment							
		Wheels	Gear/engine rpm	Travel speed		Fuel use observed		Fuel use theoretical	
				km/h	mi/h	L/ha	Gal/acre	L/ha	Gal/acre
Planting	5	dual	5/2100	8.0	5.0	2.26	0.242	2.05	0.220
	4	dual	5/2400	9.3	5.8	2.28	0.244	2.09	0.223
	4	single	5/2100	8.0	5.0	2.35	0.251	2.05	0.220
	4	dual	6/1675	9.7	6.0	1.80	0.192	1.66	0.177
	5[a]	single	6/1675	9.7	6.0	1.78	0.190	1.66	0.177
	4[a]	single	6/1900	11.3	7.0	1.82	0.195	1.68	0.180
	4	single	6/1675	10.0	6.2	1.82	0.195	1.64	0.175
LSD $_{\alpha=0.05}$[b]						0.31	0.033		

[a] Soil previously field cultivated at 8 cm (3 in.) depth; other treatments were previously field cultivated at 13 cm (5 in.) depth.

[b] Least significant difference between treatments at a 95% confidence level.

Table 13. Number of treatment comparisons showing expected trend and statistical significance, percentage treatment difference in observed fuel use, and average difference of ASABE predicted values from observed values.

Treatment comparison	No. of comparisons			Percentage difference of observed fuel use			Average percentage difference of ASABE predicted value
	Total	Trend[a]	Statistical significance[b]	Average	Greatest	Least	
Gear/engine speed	14	13	6	29.2	51	-12	-9
Travel speed	7	5	4	14.6	59	-21	20
Tillage depth	3	3	1	27.1	41	7	57
Tire inflation	5	3	0	-1.4	2	-8	28
Front wheel assist	4	4	3	14.2	31	5	-9
Dual vs. Single tires	2	2	0	7.9	12	4	-19

[a] Expected trend observed.

[b] Statistically significant at the 95% confidence level.

Table 14. Observed fuel use on university farms by field operation.

Operation	No. of means[a]	Average		Least[b]		Greatest[c]	
		L/ha	Gal/acre	L/ha	Gal/acre	L/ha	Gal/acre
Chisel plow	16	11.00	1.176	6.48	0.693	15.06	1.610
Plant	14	3.66	0.391	1.80	0.192	5.37	0.574
Field cultivate	12	5.88	0.629	2.82	0.301	7.79	0.833
Disk	10	2.92	0.312	2.14	0.229	3.60	0.385
Moldboard plow	6	36.18	3.868	26.72	2.857	45.27	4.840
Grain drill	4	4.43	0.473	3.65	0.390	5.20	0.556
Rotary mower	4	6.36	0.680	5.53	0.591	7.27	0.777
Subsoiler	2	10.92	1.167	9.97	1.066	11.86	1.268
Strip till	2	16.32	1.745	13.01	1.391	19.62	2.098
Stalk chopper	2	7.46	0.798	6.02	0.644	8.90	0.951
Move bales[d]	2	0.73	0.312	0.69	0.293	0.78	0.330
Haul corn[d]	2	0.44	0.188	0.40	0.171	0.48	0.205

[a] Number of treatment means used to calculate average.

[b] Least treatment mean for field operation.

[c] Greatest treatment mean for field operation.

[d] Fuel use L/km or Gal/mi.

Crop drying

Conditions and energy used during crop drying are shown in Tables 15 - 18. Several factors involved in the drying process limit the ability to make direct comparisons between locations, individual bins at the locations, and even drying batches in a specific bin. Factors that affect drying include different incoming corn moisture, different corn moisture at the end of drying, different ambient air conditions during drying, and different loading rates resulting in different depths of corn that fans had to push air through. Although direct comparisons are not possible, relative measurements can be useful to assess what may have affected energy consumption during drying.

Table 15. Conditions during corn drying at Iowa State University farms during fall 2013.

		Capacity		Drying air temperature		Date		Outside air temperature	
Location	Drying style	Mg	Wet bu[a]	°C	°F	Beginning	Ending	°C	°F
Ag 450 west	stirred batch	232.4	9150	43	110	24-Oct	28-Oct	4.5	40.1
Ag 450 west	stirred batch	228.6	9000	43	110	3-Nov	12-Nov	3.3	38.0
Ag 450 east	stirred batch	182.9	7200	43	110	4-Nov	12-Nov	3.0	37.4
Northeast east	stirred batch	172.5	6790	54	130	15-Oct	24-Oct	2.6	36.7
Northeast east	stirred batch	182.6	7190	54	130	29-Oct	8-Nov	5.7	42.2
Northeast west	stirred batch	202.7	7980	54	130	6-Nov	13-Nov	0.2	32.3
Southwest	counterflow batch	61.7	2430	82	180	21-Oct	21-Oct	6.4	43.6
Southwest	counterflow batch	62.7	2470	60	140	22-Oct	22-Oct	5.5	41.9
Southwest	continuous flow	55.6	2190	60	140	24-Oct	24-Oct	4.9	40.9
Southwest	continuous flow	48.3	1900	82	180	25-Oct	25-Oct	7.0	44.6

[a]56 lb units or wet 'bushels'.

Table 16. Energy used for corn drying at Iowa State University farms during fall 2013.

		Capacity		Moisture content, %		Energy per water removed		Propane use		Electricity use	
Location	Drying style	Mg	Wet bu[a]	Beginning	Ending	Mj/kg	Btu/lb	L/pt/kg	Gal/pt/bu	kWh/pt/kg	kWh/pt/bu
Ag 450 west	stirred batch	232.4	9150	17.1	13.4	6.58	2830	0.0028	0.019	0.00071	0.018
Ag 450 west	stirred batch	228.6	9000	19.0	14.8	7.56	3250	0.0033	0.022	0.00154	0.039
Ag 450 east	stirred batch	182.9	7200	18.0	14.2	7.70	3310	0.0033	0.022	0.00205	0.052
Northeast east	stirred batch	172.5	6790	23.6	15.0	6.51	2800	0.0028	0.019	0.00094	0.024
Northeast east	stirred batch	182.6	7190	23.5	14.8	5.77	2480	0.0025	0.017	0.00083	0.021
Northeast west	stirred batch	202.7	7980	25.4	14.8	6.77	2910	0.0030	0.020	0.00071	0.018
Southwest	counterflow batch	61.7	2430	20.2	14.5	5.81	2500	0.0027	0.018	0.00047	0.012
Southwest	counterflow batch	62.7	2470	18.6	14.8	5.70	2450	0.0025	0.017	0.00059	0.015
Southwest	continuous flow	55.6	2190	18.9	14.6	4.67	2010	0.0022	0.015	0.00051	0.013
Southwest	continuous flow	48.3	1900	17.2	14.4	5.91	2540	0.0028	0.019	0.00079	0.020

[a]56 lb units or wet 'bushels'.

Table 17. Conditions during corn drying at Iowa State University farms during fall 2014.

		Capacity		Drying air temperature		Date		Outside air temperature	
Location	Drying style	Mg	Wet bu[a]	°C	°F	Beginning	Ending	°C	°F
Ag 450 west	stirred batch	208.6	8210	49	120	7-Oct	18-Oct	10.9	51.7
Ag 450 east	stirred batch	202.9	7986	49	120	9-Oct	18-Oct	10.5	51.0
Northeast east	stirred batch	149.5	5884	54	130	19-Oct	23-Oct	9.7	49.5
Northeast east	stirred batch	143.1	5634	54	130	27-Oct	31-Oct	5.9	42.7
Northeast west	stirred batch	200.3	7886	54	130	2-Nov	5-Nov	6.9	44.5
Southwest	continuous flow	50.5	1990	60	140	11-Oct	11-Oct	6.3	43.4
Southwest	counterflow batch	98.6	3883	82	180	15-Oct	15-Oct	10.4	50.8
Southwest	natural air	190.5	7500			4-Nov	10-Nov	6.9	44.5

[a] 56 lb units or wet 'bushels'.

Table 18. Energy used for corn drying at Iowa State University farms during fall 2014.

		Capacity		Moisture content, %		Energy per water removed		Propane use		Electricity use	
Location	Drying style	Mg	Wet bu[a]	Beginning	Ending	Mj/kg	Btu/lb	L/pt/kg	Gal/pt/bu	kWh/pt/kg	kWh/pt/bu
Ag 450 west	stirred batch	208.6	8210	24.1	14.0	5.23	2247	0.0023	0.015	0.00067	0.017
Ag 450 east	stirred batch	202.9	7986	23.4	13.0	5.36	2306	0.0022	0.015	0.00127	0.032
Northeast east	stirred batch	149.5	5884	24.4	15.2	5.75	2471	0.0026	0.017	0.00075	0.019
Northeast east	stirred batch	143.1	5634	22.3	14.5	6.69	2876	0.0029	0.020	0.00089	0.023
Northeast west	stirred batch	200.3	7886	20.5	14.7	6.88	2959	0.0030	0.020	0.00081	0.021
Southwest	continuous flow	50.5	1990	21.4	14.9	6.42	2759	0.0028	0.019	0.00077	0.020
Southwest	counterflow batch	98.6	3883	19.9	14.7	6.01	2585	0.0026	0.018	0.00057	0.015
Southwest	natural air	190.5	7500	16.5	15.2	3.24	1391	0	0	0.01037	0.263

[a] 56 lb units or wet 'bushels'.

Energy used to remove water from grain ranged from 4.67 to 7.70 Mj/kg (2010 to 3310 Btu/lb). Morey et al. (1978) observed 5.7 Mj/kg when corn was dried from 22% m.c. Most energy was used from propane (96% average) rather than electricity in these high-temperature drying systems. Energy consumption averaged 0.0027 L/pt/kg (0.018 Gal/pt/bu) for propane and 0.00087 kWh/pt/kg (0.022 kWh/pt/bu) across all high-temperature drying tests (Tables 16 and 18). These values are near the mid-point of the ranges estimated by Wilcke and Bern (1985). Electrical energy used for natural-air drying in 2014 was slightly below the range estimated by Wilcke and Bern.

Because propane energy use predominates during high-temperature drying, a useful measure for dryer operators in the U.S. is the amount of propane used per thousand bushels of corn dried. Results from the high-temperature drying tests (Figure 2) show a strong relationship ($R^2 = 0.92$) between propane use and initial corn moisture content, with each additional moisture point requiring approximately 16.2 gal (61 L) propane per thousand bushels (i.e., 56,000 lb incoming corn).

Energy use per mass of water removed versus average outside air temperature during drying is shown by individual drying batches for each of the three drying locations in Figure 3. Greater ambient air temperature as air is pre-heated by solar energy would be expected to improve drying efficiency unless relative humidity also correspondingly increases to remain at a constant value. Energy use values at or below about 5.8 Mj/kg (2500 Btu/lb) generally occurred when ambient air temperatures were 10°C (50°F) or greater, or with the drying system at the Southwest Farm.

At the Ag 450 Farm bins were filled quickly, within about a day. As a strategy to reduce overall energy consumption, the burner was usually turned off at about 16% m.c. and fan-only energy was used to cool grain and remove the last 1 – 1.5 percentage points of moisture. This resulted in higher kWh/pt/bu values for electrical use than estimated by Wilcke and Bern (1985) in some cases, but avoided propane consumption during the final drying stage.

At the Northeast Farm, it took three to six days to completely fill each bin during plot harvest. Corn was initially dried in a shallower layer, allowing the fan to not work against as much static air pressure. In this layer drying technique, additional corn was added as drying progressed. In 2013, initial corn moisture content was wetter at the Northeast Farm.

At the Southwest Farm, incoming grain moisture content was generally drier than the other two locations. Corn depth during drying was held to only about 1.2 m (4 ft) during most batch- and continuous-flow modes (except last batch mode in 2014 was about 2.1 m, 7 ft). Batch- or continuous-flow drying was completed in one day during daylight hours for these shallow-layer dryings. Airflow was in a counterflow mode with wet grain meeting high-temperature air near the bin floor rather than the whole mass of grain inside the bin drying as one as with stirred batches. This type of counterflow bin dryer is more commonly used in a continuous-flow mode.

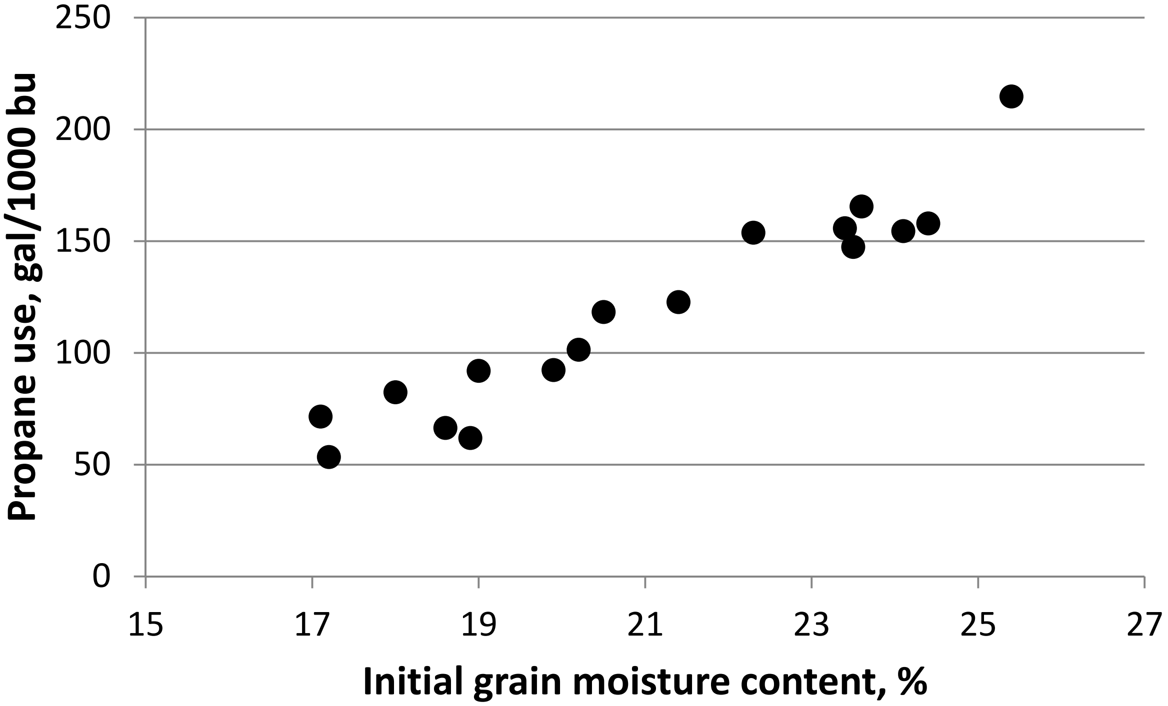

Figure 2. Propane use per 1000 bu versus initial corn moisture content.

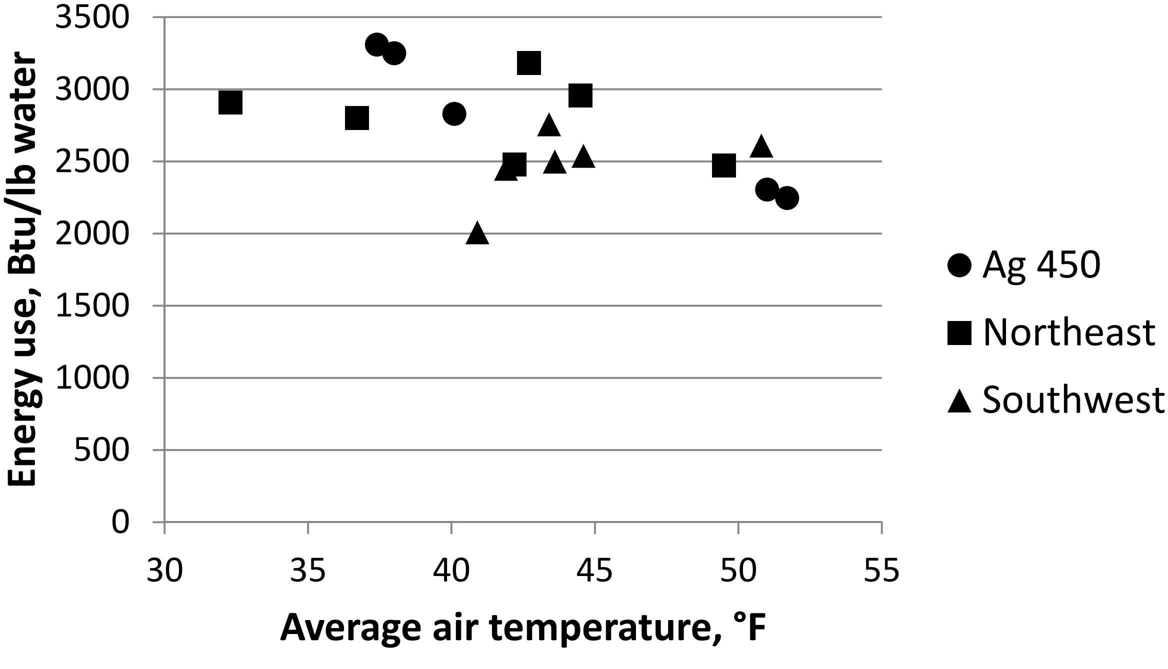

Figure 3. Drying energy used per pound of water removed versus average ambient air temperature during drying.

Swine housing

Electrical data has been processed for the Ag 450 finishing rooms for the period of December 10, 2012 through December 17, 2014. Amperage for each 30 s period was recorded and averaged for each fan. In order to translate amperage into energy usage, the typical voltage and amperage were multiplied by the power factor for each fan. Power factor was measured for each fan model using a Fluke Power Logger (Fluke 1735, Everett, Wash). For the stage 1 fans, a power factor of 0.97 was measured. For stages 2 and 3 the power factor was measured as 0.935. These were different than what was originally estimated (0.92 and 0.70).

Table 19 provides the overall data summary for electrical usage. This was tabulated continuously, including periods that pigs were not present in the building. Production facilities normally have an unpopulated period between pig groups to facilitate sanitation that ranges from a few days to a week or more so no adjustment was made for these periods.

Table 19. Electrical energy used for fan ventilation for a 300 head curtain-sided finisher, ISU Ag 450 farm.

	East room			West room		
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Duty factor	93.0%	15.8%	0.4%	97.2%	11.5%	0.54%
Avg. amps	1.55	2.12	2.36	1.55	2.45	1.66
kWh/yr[a]	2689	603	18	2824	510	15
kWh/yr-pig space	9.0	2.0	0.06	9.4	1.7	0.05
% of total	81%	18%	1%	84%	15%	0.5%
Total fan	11.0 kWh/yr-pig space			11.2 kWh/yr-pig space		

[a]kWh/yr is calculated assuming 220 V and the measured power factor for each fan, 0.97 for stage 1 and 0.935 for stages 2 and 3.

In Table 19, duty factor refers to the percentage of hours monitored which any particular fan stage was operating. In the Ag 450 facility the minimum ventilation fans typically operated even when the sidewall ventilation curtain was open. Therefore, in this situation the only time stage 1 fans did not operate was between groups of pigs when the building stood empty or during a malfunction. Stage 2 operated less than 20% while stage 3 operated less than one percent of the time. The low percentage for stage three may have been, in part, due to fan malfunctions. The total consumption per year for each fan was divided by the animal capacity of each room to yield a partitioning of energy usage by fan stage. This illustrates that selection of energy efficient minimum ventilation fans is an important consideration because of the high duty factor and high percentage of the energy expelled on the first fan stage. It should be noted that stage 3 in the west room required less amperage than the stage 3 fan in the east room. This could be because a replacement motor may have been installed on one of the fans or some other malfunction. Overall, the rooms tended to have similar electrical consumption for fan ventilation, 11.0 and 11.3 kWh/yr-pig space.

Propane usage was measured in each of the four finishing rooms. However, the heater malfunctions were frequent and the farm staff opened doors between rooms to heat the room without a functioning heater. The building as a whole, between September 23, 2013 and June 1, 2015, used a total of 40,818 L (10,783 gallons) of propane. This is equivalent to 17 L of propane per pig space/yr (4.5 gallons/pig-space-yr). The usage in this finishing facility was higher than most farmers raising pigs in a wean-to-finish use as a goal which is typically 7.6 L propane per pig space-yr (2 gal). This was likely due to the leaky nature of the building and relatively poor management of ventilation curtains.

Data received from outside sources was compiled and is presented in Table 20. As expected, electrical cost was greater for all tunnel ventilation barns (29.0 kWh/pig space-yr) versus hybrid barns that use natural ventilation during warm months through the usage of sidewall ventilation curtains (20.9 kWh/pig space-yr), independent of animal size. It was also expected that those farms which have wean-to-finish facilities (10.6 L or 2.8 gal/pig-space-yr) starting with 6 kg pigs (13 lbs) have much higher propane usage than do those that are purely finishing pigs, which start pigs at 25 kg (55 lbs) (2.5 L or 0.67 gal per pig space-yr). It should also be noted that the values vary considerably within each type of building as well as between building types. Several factors could contribute to this variation. The time of year in which the buildings are stocked can influence the energy usage. Small pigs placed in winter will increase the propane usage while having large pigs in August may add to the electrical usage due to increased need for cooling. Management such as controller settlings, maintenance and building leakage can all impact these figures as well.

Table 20. Propane and electrical usage on various swine finishing farms.

Description	Electrical Usage/yr		Propane Usage/yr		
	kWh/pig space	Years of Data	L/pig space	Gal/pig space	Years of Data
Hybrid- fans with side-wall ventilation curtains, Finishing					
2-1000 head	22.3	3.0	2.5	0.67	5.0
1-2400 head	19.0	1.0			
1-1200 head	22.1	1.0			
2-1000 head	26.8	1.0			
Average	*22.6*		*2.5*	*0.67*	
Tunnel ventilation, Finishing					
2-1200 head	30.7	1.0			
2-1200 head	26.5	1.0			
Average	*28.6*				
Hybrid-fans with side-wall ventilation curtains, wean-to-finish					
1-2400 head	14.3	1.0			
Tunnel ventilation with electric brooders, wean-to-finish					
2-2400 head	24.3	1.0			
Tunnel ventilation with gas brooders, wean-to-finish					
2-1200 head	27.9	2.9	11.7	3.1	0.7
2-1200 head	31.6	2.9	12.5	3.3	0.8
2-1200 head	35.1	1.6	9.5	2.5	1.0
2-1200 head	28.6	2.4	10.6	2.8	0.9
2-1200 head	27.5	0.8	8.3	2.2	1.0
Average	*30.1*		*10.6*	*2.8*	

Conclusions

Within the range of conditions measured, the data support the following conclusions.

Fuel was saved during field operations in 30 of 35 treatment comparisons (14 statistically significant). Fuel-saving strategies were generally well demonstrated for shifting up and throttling back during reduced drawbar loads, reducing tillage depth, and making use of front-wheel-drive (average increased fuel use of 29, 27, and 14%, respectively if fuel saving strategy was not used). Fuel savings were also demonstrated at lower travel speeds (fuel use increased an average of 15% at higher speeds) but results were more mixed as engine speed and torque characteristics matched to loads. Fuel use increased 8% when single tires were used rather than duals in two comparisons. Fuel-saving results were marginal (often within the range of measurement accuracy) and least apparent when comparing tire inflation. Fuel use values calculated using procedures from ASABE standards were generally greater than observed values for travel speed, tillage depth, and tire inflation comparisons, but lower than observed values for gear/engine speed, front-wheel-assist, and dual vs. single tire comparisons.

Energy used per water removed during high-temperature drying ranged from 4.67 to 7.70 Mj/kg (2010 to 3310 Btu/lb). Propane use was responsible for 96% of energy consumption during high-temperature drying and averaged 0.0027 L/kg (0.018 gal/bu) per percentage point of moisture removed. Conditions such as initial corn moisture content and average ambient air temperature during each drying treatment were unique. Greater ambient air temperature tended to use less energy, as did the drying system on the Southwest Research Farm.

Minimum ventilation fans had the highest duty factor (>93%) and the highest energy consumption of all the fan stages in a hybrid, sidewall curtain ventilated finishing barn indicating that selection of energy efficient stage 1 fans is an important consideration. Approximately 11 kWh/pig space-yr was used for fan ventilation in this facility. Tunnel ventilated barns tend to use more electricity than do hybrid curtain-sided barns (29.0 vs. 20.9 kWh/pig space-yr). Wean-to-finish barns tended to use more propane the do finishing barns (10.6 L vs. 2.5 L/pig space-yr, 2.8 gal vs. 0.67 gal/pig space-yr). Management, maintenance and controller settings tend to cause variation in energy usage.

Acknowledgments

This project was supported by the Iowa Energy Center. ISU Extension and Outreach Ag Engineer Shawn Shouse assisted in crop drying measurements and analysis. Student interns Kyle Wester, Jason Schuster, and Anthony Battazzi assisted in set up of instrumentation and data analysis. ISU Research and Demonstration Farms staff including Richard Vandepol, Micah Smidt, Myron Rees, Ken Pecinovsky, Bernie Havlovic, Randy Breach, Lyle Rossiter, and Kent Berns along with Greg Vogel at the Ag 450 Farm assisted in acquiring measurements and setting up instrumentation.

References

ASABE Standards. 2014a. EP496.3 Agricultural machinery management. St. Joseph, Mich.:ASABE.

ASABE Standards. 2014b. EP497.7 Agricultural machinery management data. St. Joseph, Mich.:ASABE.

BESS. 2014. Agricultural Ventilation Fans: Performance and Efficiency. Bioenvironmental and

Structural Systems Laboratory. Department of Agricultural and Biological Engineering. University of Illinois at Urbana-Champaign. http://www.bess.illinois.edu/

Finbin. 2014. Farm Financial Database. Livestock Enterprise Analysis. 2012-2013 Report. http://www.finbin.umn.edu/FinB.dll/generate?RecId=296489. Downloaded June 3, 2014.

Grisso, R. D., D. H. Vaughn, and G. T. Roberson. 2008. Fuel prediction for specific tractor models. Applied Engineering in Agriculture 24(4):423-428.

Hanna, H. M. 2001. Fuel required for field operations. Iowa State University Extension publication PM 709.

Harmon, J.D., T.J. Baas, S.J. Hoff and H. Xin. 1998. Case Study Comparison of Three Styles of Swine Finishers. Iowa State University Swine Research Reports. http://www.extension.iastate.edu/Pages/ansci/swinereports/asl-1588.pdf. Accessed June 2, 2014.

McLaughlin, N. B., C. F. Drury, W. D. Reynolds, X. M. Yang, Y. X. Li, T. W. Welacky, and G. Stewart. 2008. Energy inputs for conservation and conventional primary tillage implements in a clay loam soil. Transactions of the ASABE 51(4):1153-1163.

Morey, R. V., R. J. Gustafson, H. A. Cloud, and K. L. Walter. 1978. Energy requirements for high-temperature drying. Transactions of the ASAE 21(3):562-567.

Morey, R. V., and H. A. Cloud. 1980. Saving energy in corn drying. University of Minnesota publication M-161.

Navia, E.C., B.Z. Predicala, D.L Whittington, and J. Patience. 2007. Benchmarking Energy Costs in Swine Barns. Prairie Swine Centre Research Report. http://www.prairieswine.com/pdf/36264.pdf. Accessed June 2, 2014.

Predicala, B. and E. Navia. 2008. Evaluating Energy Usage and Energy Conservation Strategies for Swine Barns. Centre on Swine. 15-1. Prairie Swine Centre, Saskatoon, Canada.

USDA. 2014. 2012 Census of Agriculture. United States Department of Agriculture Publications.

Wilcke, W. F., and C. J. Bern. 1985. Comparing corn drying energy costs. Iowa State University publication AE-3025.

Wilcke, W. F. and C. J. Bern. 1986. Natural-air corn drying with stirring: II. Dryer performance. Transactions of the ASAE 29(3):860-867.