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Energy costs for grain drying and field operations

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Introduction

Iowa spends about one billion dollars annually on the purchase of diesel fuel, electricity, propane, gasoline, and natural gas. Specifically, Iowa spent more than one billion dollars on energy in 2012 including $866,990,000 for gasoline, fuels, and oils (primarily diesel fuel and LP) and $329,138,000 for utilities (primarily electricity) according to the USDA Agricultural Census (USDA, 2014). Correspondingly, farm enterprises nationwide spent $16,573,188,000 for gasoline, fuels, and oils and $8,261,978,000 for utilities in 2012. Purchases 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.

Controlling input costs is important to maintaining profitability. Although fuel and energy are not the most expensive inputs for crop or livestock production, they are typically the easiest to manage. Therefore, university Extension professionals provide estimates of energy consumption (Hanna, 2001). These estimates are frequently based on either old or very limited data. McLaughlin et al. (2008) measured fuel use of 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, 7.4 in. and 3.5 mi/h for moldboard plowing, 6.7 in. and 4.1 mi/h for chisel plowing, and 2.3 in. and 4.0 mi/h for disking.

Due to a lack of current fuel consumption data for field operations, most machinery and crop production budgets developed by Extension professionals and others use values estimated from American Society of Agricultural and Biological Engineers 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 consumption for grain drying has typically been estimated from old or very limited public data. Morey et al. (1978) dried corn from 22.3% initial moisture content (m.c.) to 15.8% final m.c. at air temperatures of 212 °F and consumed 2461 British thermal units of energy per pound of water removed (Btu/lb) using a small, 300-bushel automatic batch dryer. Treatments also included the use of high-temperature drying to achieve intermediate moisture contents (e.g. 18% or 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. consumed 1300 Btu/lb. The following year, corn dried from a lower initial m.c. of 19.7% to a final m.c. of 14.3% consumed 1760 Btu/lb. Limited field observations such as these, along with modeling estimates, have been used by Extension professionals to estimate energy consumption for crop drying (Morey and Cloud, 1980). Wilcke and Bern (1985) estimated propane energy consumption in a high-temperature dryer to range from 0.01–0.025 gallons per bushel per percentage point of moisture removal (gal/bu/pt) and electrical consumption to range from 0.007–0.03 kWh/bu/pt. Electrical consumption in a natural-air dryer was estimated to range from 0.28–0.42 kWh/bu/pt for drying corn from 20% m.c. and 0.31 to 0.71 kWh/bu/pt for drying corn from 24% m.c.

Measurement of on-farm energy consumption is needed to either validate older measurements or establish new benchmarks using more current technology. Comparison of energy management techniques at multiple Iowa State University Research and Demonstration farms helps farmers to evaluate and adopt improved energy management strategies.

Objective

Measure baseline energy consumption values and compare on-farm management techniques where possible at Iowa State University research and demonstration farms.

Methods and materials

Iowa State University has research, demonstration, and teaching farms located statewide. Grain drying facilities are located at the Northeast, Ag 450, and Armstrong (Southwest) farms illustrated in Figure 1. Instrumentation was installed at these three farms in 2013 to measure propane and electricity used for drying corn. In addition, tractor diesel fuel measurements for field operations are being collected at each of the farm locations shown in Fig. 1 except the Ag 450 farm near Ames, Iowa. Results from tractor field trials are available and reported here from the Northern, Northeast, Agricultural Engineering and Agronomy, Armstrong, and Southeast farms.

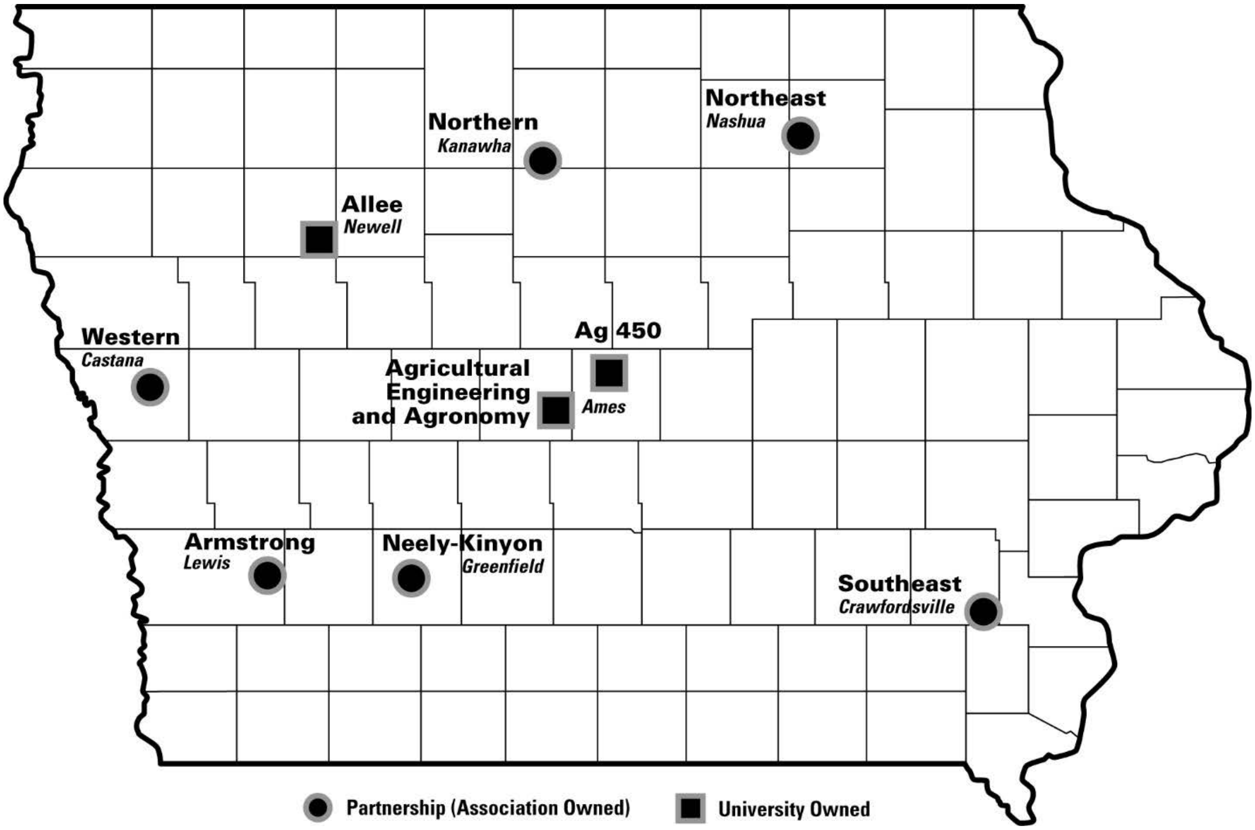

Figure 1. ISU Research & Demonstration farm locations collaborating with the ISU Farm Energy team to collect energy measurements.

Field operations

Each farm participating in the tractor study selected a tractor for fuel measurement that was primarily used for field operations. Tractor models include a John Deere 7730 (Agricultural Engineering and Agronomy farm), John Deere 7430 (Northeast and Southeast farms), John Deere 7420 (Armstrong farm), and John Deere 7410 (Northern farm). A gravimetric fuel measurement system is used instead of a flow meter to avoid potential back-pressure problems in return fuel lines on diesel engines. A 13-gallon auxiliary fuel tank is mounted atop a 220-pound 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) is measured by recording difference in auxiliary tank weight before and after an observation in the field.

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

Grain drying

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

At the Ag 450 and Northeast farms, corn 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 generally completed within about three to six days, resulting in shallow-layer drying during earlier stages of the batch. During 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.

The drying bin at the Armstrong farm has a bottom sweep auger that transfers corn dried by plenum air to a center vertical auger. The vertical auger lifts corn either back to the top of the bin grain mass where it is distributed (recirculating batch mode) or lifts and transfers dried corn 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 corn immediately leaving the dryer and 'batch' mode with dried corn 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. 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 1900–2500 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). Samples from multiple grain probes in late winter showed the drying front had progressed about 7 ft. during late fall drying before corn in the bin was removed. Bin and fan specifications are shown in Table 1.

Table 1. Bin capacity and fan power

Location	Bin	Capacity	Bin diameter	Fan power
		(bu)	*(ft)*	*(hp)*
Ag 450	west	9,700	30	7.5
Ag 450	east	9,200	27	10
Armstrong		9,000	30	26[a]
Northeast	east	8,800	28	12.5
Northeast	west	11,875	30	15

[a] Two 9.7 kW (13 hp) fans

Beginning m.c. was determined by measuring individual loads with a moisture meter used by local farm staff. An equivalent m.c., 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 during drying, farm staff at the Ag 450 and Northeast farms measured daily intermediate moisture contents from multiple samples taken in the top layer of corn in the bin. Ending m.c. was measured in the same manner at Ag 450 and Northeast farms. At the Armstrong farm, ending m.c. was measured from the exit moisture sensor on the drying system for 50-bu corn increments being transferred during five-minute periods and then calculating equivalent m.c. for total corn dried during a drying period.

Energy required to remove water from the corn 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 Btu/lb of water removed.

Results and discussion

Field operations

Fuel use measurements during selected field operations and treatment comparisons are shown by farm location in Tables 2–8. Farm staff were encouraged, when possible, to compare different treatments. These included using different transmission gear and engine throttle settings at the same travel speed, different travel speeds, different tillage depths, or different tire inflation pressures (a lower inflation pressure as specified by the tire or tractor manufacturer for wheel load, and an over-inflated condition). Machinery management standards and data from ASABE S496.3 and S497.7 were also used to calculate expected fuel use.

Table 2. 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	*Gal/acre*	*Gal/acre*
Field cultivation, 5 mi/h	3	C1/2080	0.803	0.499
	3	C2/1710	0.657	0.434
LSD[a]			0.053	
Strip till, 5.2 mi/h	3	C1/2170	2.098	1.175
	3	C2/1710	1.391	1.031
LSD[a]			NS	
Stalk chopping, 5.0 mi/h	3	C1/2060	0.951	0.593
	3	C2/1750	0.644	0.532
LSD[a]			0.059	

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

Table 3. Observed and theoretical fuel use at the Armstrong (Southwest) Iowa Research Farm with gear/engine rpm.

Operation	No. of replications	Treatment	Fuel use observed	Fuel use theoretical
		Gear/engine rpm	*Gal/acre*	*Gal/acre*
Moldboard plowing, 4.5 mi/h	1	B2/2250	4.84	2.90
	3	B3/2000	4.57	2.70
	4	B4/1700	3.67	2.46
LSD[a]			NS	
Disking, 4.6 mi/h	4	B3/2200	0.339	0.640
	4	C1/2000	0.385	0.604
LSD[a]			NS	
Planting, 4.0 mi/h	4	B2/2225	0.457	0.474
	5	B3/1850	0.389	0.418
	4	B4/1500	0.367	0.367
LSD[a]			NS	

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

Table 4. Observed and theoretical fuel use at the Southeast Iowa Research Farm with travel speed, fall 2013.

Operation	No. of replications	Treatment, travel speed	Fuel use observed	Fuel use theoretical
		Mi/h	*Gal/acre*	*Gal/acre*
Chisel plowing	3	3.8	1.118	1.271
	3	4.5	1.388	1.201
LSD[a]			NS	

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

Table 5. Observed and theoretical fuel use at the Northern Iowa Research Farm with travel speed, fall 2013.

Operation	No. of replications	Treatment, travel speed	Fuel use observed	Fuel use theoretical
		Mi/h	*Gal/acre*	*Gal/acre*
Chisel plowing	3	4.6	0.911	1.288
	3	5.1	0.693	1.266
	3	5.5	1.101	1.254
LSD[a]			NS	

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

Table 6. Observed and theoretical fuel use at the Southwest Iowa Research Farm with travel speed, spring 2013.

Operation	No. of replications	Treatment, travel speed	Fuel use observed	Fuel use theoretical
		Mi/h	*Gal/acre*	*Gal/acre*
Chisel plowing	1	3.00	1.057	1.228
	1	4.30	0.976	1.116
	1	4.70	0.943	1.102
LSD[a]			NS	

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

Table 7. Observed and theoretical fuel use at the Southwest Iowa Research Farm with tillage depth.

Operation	No. of replications	Treatment, disking depth	Fuel use observed	Fuel use theoretical
		Inches	*Gal/acre*	*Gal/acre*
Disking, 4.6 mi/h	4	3.0	0.354	0.533
	4	5.0	0.379	0.710
LSD[a]			NS	

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

Table 8. Observed and theoretical fuel use at the Ag Engineering Agronomy Farm with tire inflation during summer and fall, 2013.

Operation	No. of replications	Treatment, tire pressure	Fuel use observed	Fuel use theoretical
		rear/front, psi	*Gal/acre*	*Gal/acre*
Chisel plowing, 4.8 mi/h[a]	3	10/20	1.591	1.286
	3	20/30	1.610	1.286
LSD[b]			NS	
Chisel plowing, 4.8 mi/h[c]	3	10/20	1.414	1.286
	3	20/30	1.433	1.286
LSD[b]			NS	

[a]Summer, after small grain harvest.

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

[c]Fall, after grain harvest.

Limited replications generally precluded the ability to detect statistically significant differences. An expected trend of saving fuel was noted in five of six instances when shifting up to a higher gear and reducing engine speed while maintaining travel speed (Tables 2 and 3). Fuel savings ranged from 18–34% when comparing the five trials with fuel savings from this strategy. Fuel used during chisel plowing at various travel speeds was compared at three farm locations. Fuel use increased with speed at the Southeast farm (Table 4), but had lower fuel use at an intermediate speed at the Northern farm (Table 5) and decreased with travel speed at the Southwest farm (Table 6) although only single observations were made at this site. Fuel use tended to increase with disking depth (Table 7). 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 some sites less for chisel plowing.

A lower, 'correct', tire inflation was compared with an over-inflated condition during chisel plowing at the Agricultural Engineering Agronomy farm. An initial comparison was done following small grain harvest in mid-summer and a second comparison was made in the fall after grain harvest. In both cases differences were marginal and within the range of measurement accuracy although absolute difference was in the expected direction for fuel savings (Table 8).

Comparing theoretical fuel use estimated by ASABE machinery management standards with observed data showed variations. Observed fuel use was 50% or more greater than estimates at low gear/high engine rpm settings at the Northeast farm and for moldboard plowing at the Southwest farm (Tables 2 and 3). Conversely, disking treatments at the Southwest farm used only about 60% of estimated fuel (Tables 3 and 7). Estimated fuel use declined very slightly with travel speed during chisel plowing and aligned closer to mixed field observations (Tables 4–6). 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.

Grain drying

Conditions and energy consumption during crop drying are shown in Tables 9 and 10, respectively. Several factors involved in the drying process preclude making 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 factors that may have affected energy consumption during drying.

Table 9. Conditions during corn drying at Iowa State University farms during fall 2013.

Location	Drying style	Capacity	Drying air temp.	Date		Outside air temp.
		Wet bu[a]	*°F*	*Beginning*	*Ending*	*°F*
Ag 450 west	stirred batch	9,150	110	24-Oct	28-Oct	40.1
Ag 450 west	stirred batch	9,000	110	3-Nov	12-Nov	38.0
Ag 450 east	stirred batch	7,200	110	4-Nov	12-Nov	37.4
Northeast east	stirred batch	6,790	130	15-Oct	24-Oct	36.7
Northeast east	stirred batch	7,190	130	29-Oct	8-Nov	42.2
Northeast west	stirred batch	7,980	130	6-Nov	13-Nov	32.3
Southwest	counterflow batch	2,430	180	21-Oct	21-Oct	43.6
Southwest	counterflow batch	2,470	140	22-Oct	22-Oct	41.9
Southwest	continuous flow	2,190	140	24-Oct	24-Oct	40.9
Southwest	continuous flow	1,900	180	25-Oct	25-Oct	44.6

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

Table 10. Energy used for corn drying at Iowa State University farms during fall 2013.

Location	Drying style	Capacity	Moisture content		Energy per water removed	Propane use	Electricity use
		Wet bu/acre	*Beginning %*	*Ending %*	*Btu/lb*	*Gal/pt/bu*	*kWh/pt/bu*
Ag 450 west	stirred batch	9150	17.1	13.4	2830	0.019	0.018
Ag 450 west	stirred batch	9000	19.0	14.8	3250	0.022	0.039
Ag 450 east	stirred batch	7200	18.0	14.2	3310	0.022	0.052
Northeast east	stirred batch	6790	23.6	15.0	2800	0.019	0.024
Northeast east	stirred batch	7190	23.5	14.8	2480	0.017	0.021
Northeast west	stirred batch	7980	25.4	14.8	2910	0.020	0.018
Southwest	counterflow batch	2430	20.2	14.5	2500	0.018	0.012
Southwest	counterflow batch	2470	18.6	14.8	2450	0.017	0.015
Southwest	continuous flow	2190	18.9	14.6	2010	0.015	0.013
Southwest	continuous flow	1900	17.2	14.4	2540	0.019	0.020

[a] 56 lb units or wet 'bushels'

Energy used to remove water from corn ranged from 2010–3310 Btu/lb. In these high-temperature systems, an average of 96% of the energy used was in the form propane with the remaining 4% as electricity. At the Ag 450 farm, energy consumption ranged from 2830–3310 Btu/lb. Bins were filled quickly, within about a day, causing drying fans to push air up through the entire bin depth during most of the drying. Slightly cooler outside air temperatures during drying of the second batch in the west bin and drying in the east bin required additional heating of air by the burner. To reduce overall drying costs, drying was not started until incoming corn m.c. was 17–19%. Energy requirements may have increased when drying from this lower initial m.c. as Morey et al. (1978) observed 2450 Btu/lb when corn was dried from 22% m.c. As a strategy to reduce overall energy consumption, for the second drying batch in the west bin and also the east bin, the burner was 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), but avoided propane consumption during the final drying stage.

Initial corn m.c. was the wettest at the Northeast farm. It took three to six days to completely fill each bin during plot harvest. Corn was initially dried in a shallow 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. Both corn with wetter initial m.c. and layer drying may have resulted in energy use of 2480–2910 Btu/lb with stir batch drying at this location. Lowest total energy use at this site occurred during warmer ambient air temperature conditions.

At the Southwest farm, incoming corn m.c. was 17–20%. Average outside air temperature was relatively warmer than other locations, 41–45°F. Corn depth during drying was held to only about 4 ft. during both batch- and continuous-flow modes. 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 corn meeting high-temperature air near the bin floor rather than the whole mass of corn inside the bin drying as one as with stirred batches. Energy values ranged from 2010–2540 Btu/lb. This type of counterflow bin dryer is more commonly used in a continuous-flow mode.

Reheating the dryer during the final day of operation to 180°F for a relatively small amount of corn (1900 bu) may have contributed to greater energy use as compared to continuous-flow drying the day before at 140°F.

Conclusions

The data presented support the following conclusions.

Fuel was saved during field operations in five of six cases when shifting the tractor to a higher gear and reducing engine speed while maintaining travel speed (18–34% savings). Fuel use decreased 7% when disking depth was reduced from 5 to 3 inches. Fuel consumption was less sensitive to travel speed during chisel plowing or using correct tire inflation, although fuel use was generally lower at reduced travel speed and correct inflation pressure. Observed fuel use varied (as much as 50%) from estimates calculated with machinery management ASABE Standards.

Energy used per pound of water removed during high-temperature drying ranged from 2010–3310 Btu/lb. Conditions such as initial corn moisture content and average ambient air temperature during each drying treatment were unique. Lower initial corn moisture content and/or lower ambient air temperature tended to use more energy, as did a shallow-layer counterflow drying system.

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