Cashing in the Joules:
The Economics of Energy Inputs in Dryland Wheat Farming

Erik Anderson, Russell Callahan, Tucker Colvin, Collin McClure, Michaela O'Donoghue, Nate Powell-Palm

Introduction-

According to the 2012 Agricultural Census, wheat is the most economically significant crop in Montana, using more than 6 million of the state's arable acres, and accounting for a 2 billion dollar per year industry. Though the types of wheat planted in a given year vary due to market pressures and weather, the three most prolifically planted varieties in Montana are spring wheat, winter wheat and durum wheat. In 2012 5.6 million acres of wheat were planted in Montana, yielding 180 million bushels and accounting for 8.6% of total US production (Census of Agriculture 2012). Organically grown wheat is becoming increasingly popular with growers in Montana. In 2011, Montana produced 1 million bushels of organic spring wheat on 38,000 acres compared to 0.6 million bushels on 33,000 acres in 2008 (Figure 1; NASS, 2012; NASS, 2008).

In this analysis the energy and economic inputs of conventional and organic spring wheat production are compared to understand differences in energy use and economic feasibility. The energy and costs associated with fertilizer, herbicides, machinery use, and transport are examined. In

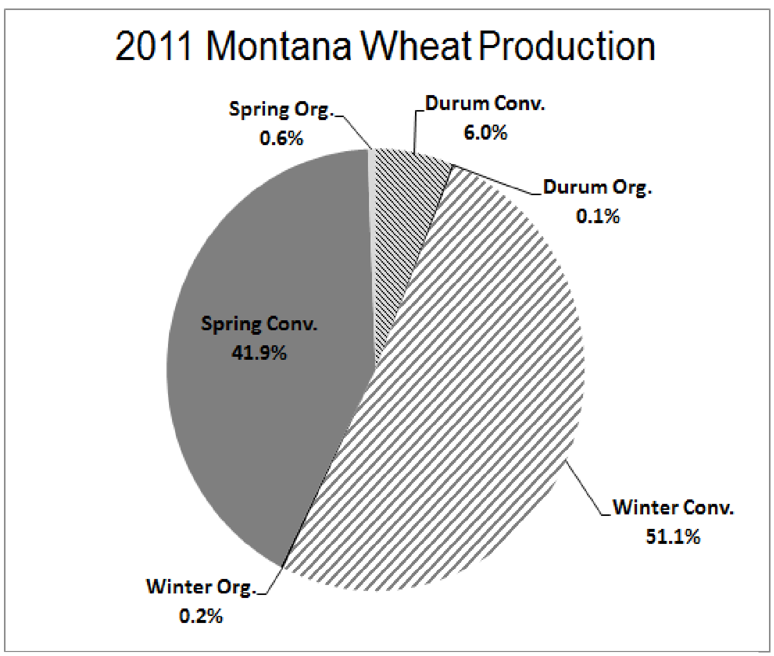


Figure 1: Bushels of different types of wheat harvested in Montana in 2011 (NASS, 2012; NASS 2008).

conventional systems, synthetically produced fertilizers and pesticides are used to provide nutrients to plants and mitigate pests. In organic systems cover crops and tillage are used in place of synthetically produced materials. Conventional wheat production is highly energy intensive due to the extensive use of fossil fuels. (Meisterling et al. 2009). In organic system there are additional machinery inputs required for tillage and extra seeding. After the wheat is harvested it is transported to a mill and then a processing plant; these energy requirements are equal across systems. Although inputs in conventional systems are higher, the premium price commanded by organic wheat appears to make organic wheat production more profitable.

Methods-

In this analysis statewide averages for yield, background soil nutrient levels, and herbicide application rates were used. An average yield of 31 bushels/acre for conventional systems and 28 bushels/acre for organic was assumed, with a bushel being equivalent to 60 pounds (NASS 2011). Both systems were assumed to be dryland (no irrigation used); with tillage employed in the organic system and not in the conventional. Additionally, a 2 year fallow rotation was assumed. In this rotation a crop is grown every other year. In off years, the conventional system's land is left in fallow and the organic system's land is used to grow a cover crop. These assumptions were used throughout this analysis for calculations, but it must be noted that these values are variable depending on location and antecedent conditions.

Fertilizer-

Background soil nutrient levels were assumed for the site and are listed in Table 1. Application rates for the conventional system were determined from Montana State University Agricultural Extensions (Dinkins and Jones, 2013): 99 lbs of available N per

Table 1. Assumed background soil nutrient levels and fertilizer application rates for the conventional system. Data from Dinkins and Jones, 2013.

Nutrient	Assumed Soil Background Levels	Application Rate
Nitrogen	73 lbs/acre as N	17 lbs/acre as N
Phosphorus (P_2O_5)	15 ppm as P_2O_5	20 lbs/acre as P_2O_5
Potassium (K_2O)	192 ppm as K_2O	40 lbs/acre as K_2O

acre needed for the crop (Jacobsen et al. 2003). The energy coefficients are listed in Table 2 for production, transportation, and application of fertilizers as well as a range of possible coefficients and production processes.

Table 2 Range in energy coefficients used in fertilizer production as well as the coefficients chosen for this study.

Nutrient	Range in Production Coefficients (MJ/lb) *	Production coefficient (MJ/lb) used in this study **	Fertilizer production process
Nitrogen	19.45 - 27.32	25.7 MJ/lb - N	Anthropogenic N fixation
Phosphorus	0.96 - 5.96	4.3 MJ/lb - P_2O_5	Mining, ore extraction
Potassium	2.09 - 5.61	3.18 MJ/lb - K_2O	Mining, ore extraction

*Piringer 2006

**Burgess et al. 2012

In this system a nitrogen fixing pea crop is used to provide additional nitrogen for the wheat crop the subsequent year it was assumed the pea crop fixed 95 lbs N/acre, which on top of the background soil N levels in Table 1, accounts for the nitrogen demand of the wheat crop the following year (McCauley 2011). There were no phosphorus or potassium inputs in this organic system.

<u>Herbicides-</u>
It was assumed that herbicides were the primary weed control mechanism employed in conventional production systems. Glyphosate is the most commonly used herbicide in Montana (Henderson et al. 2010). The energy inputs necessary to produce glyphosate were used to calculate the energy expenditures as part of the conventional production system. The energy required to produce glyphosate, the active ingredient in Roundup, is 162 MJ/lb, an application rate of 3.5 lbs/acre was assumed (Meisterling et al. 2009; NC State 2014). The organic system utilizes an air seeder and tiller as part of a pest management strategy, and energy coefficients for these are covered in the Fuel and Machinery section.

<u>Machinery-</u>
During harvest both systems used the same machinery and required the same amount of fuel and tractor hours. The ‘Overhead’ values include machinery operations such as transport, storage, maintenance, operation, lubricant etc. Energy values for each implement were derived from Burgess et al. (2012), Meisterling et al. (2009), and Zentner et al. (1984).

Transport-

After harvest the wheat is transported to a mill and then to processing where it is made into food products. It was assumed that the grain was shipped, on average, 150 miles (240 km) from the farm to the mill where the wheat is processed and turned into flour. The ground flour was then assumed to travel 1600 miles (2600 km) to a bakery or processing plant. These distances were adapted from a similar set of values set forth in Meisterling et al. (2009). In this study the average distance from Bozeman, MT to the two most populous areas in the United States (Los Angeles and New York City) were used to calculate the distance from elevator to processing plant. (Meisterling et al. 2009). Calculations for energy use were completed with coefficients for train and tractor-trailer transport. The coefficient used for train transport is 0.28 MJ/ton/km and 2.1 MJ/ton/km for truck transport (Vanek and Morlock 2000). The transportation coefficient of the wheat from the farm to the mill was determined by averaging tractor-trailer and train transport coefficients. Transport coefficients from the mill to the processing location were determined using the train transport coefficient.

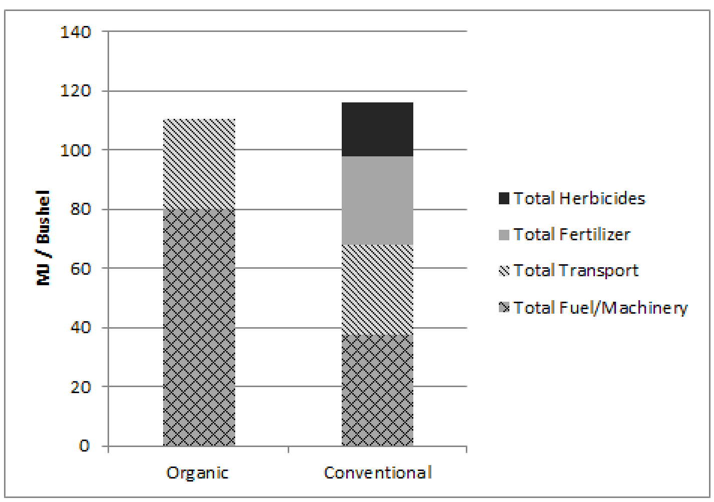
Economics-

To illustrate the differences between the economic profitability of both conventional and organic wheat systems, several parameters were assumed. Specifically, when analyzing the weed control cost of both systems, the price of the herbicide in conventional systems combined with the application costs was used to calculate the total expense. For this same weed control factor, two disc passes were assumed per year. The estimated cost of this tillage work was derived from North Dakota State Custom Farming Survey, which details subcontractor rates (Table 4); specifically, an hourly cost that includes everything from machinery to fuel to the operator’s time. The conventional system fertilizer cost was estimated using prices and rates recommended by Rocky Mountain Supply in Belgrade, MT for standard NPK formulas that would be delivered from the manufacturer to the farm. The organic farm's fertility is derived from crop rotation and leguminous cover crops. To estimate the cost of this type of fertility, the estimated costs of planting, cover crop seed, and the necessary tillage were combined. The seed cost for both systems varied slightly with the organic seed total cost exceeding that of the conventional system due to the higher seeding rate.

Results-

When comparing the conventional and organic systems, neither system stood out as more energy intensive. With this in consideration, our results indicate that conventional wheat production is slightly more energy intensive (116.0 MJ) than organic production (110.6 MJ) (Figure 2). For spring wheat systems, energy per bushel produced is approximately 375MJ (National Nutrient Database for Standard Reference

That being said, certain aspects of production in the organic system are relatively energy intense (Figure 2; Table 3). The production of synthetically derived fertilizers and herbicides accounted for 26% and 16% of total conventional energy use, respectively. Due to differing inputs in organic systems, machinery accounted for



73% of total energy, while it only accounted for 32% in the conventional system.

Table 3: Energy inputs in MJ/bushel for sections covered in results.

	Inputs MJ/bushel	
	Organic	Conventional
N Fertilizer	0	21.5
P Fertilizer	0	4.2
K Fertilizer	0	4.1
Total Fertilizer	0	29.8
Glyphosate	0	18.3
Total Herbicides	0	18.3
Tiller	26.9	0
Air Seeder	29.2	13.2
Harvester	12.5	11.3
Overhead	11.6	11
Sprayer	0	2
Total Fuel/Machinery	80.2	37.5
Transportation (to mill)	8.6	8.6
Transportation (to plant)	21.8	21.8
Total Transport	30.4	30.4
System Total	110.6	116

Transportation inputs were the same across systems (30.4 MJ/bushel) and accounted for 27% of organic energy inputs and 26% of conventional inputs.

required to produce wheat are less in organic systems. The second standpoint is value.

Table 4: Economics Calculations: Please see references: Seeds (WestBred 2014), Weed and Fertilizer (Agronomy in Montana 2014), Planting and Harvesting (Aakre 2013)

(Aller 2014). While

Profit Comparison

Organic Inputs		Conventional Inputs	
Seeds	$40/ac (untreated)	Seeds	$26/ac (treated)
Weed Control	$40 (plowing)	Weed Control	$10.6 (Herbicide)
Fertilizer	$45 (green manure)	Fertilizer	$48.1 (Synthetic)
Planting	$30 (Air Seeder)	Planting	$30 (Air Seeder)
Harvest	$40 (custom combine)	Harvest	$40 (custom combine)
Total Cost/ac	$195	Total Cost/ac	$154.7
Profit/ac	28 bu*$18 = $504 --> $504-$195= **$309/ac**	Profit/ac	31 bu*$6.5 = $201.5 $201.5-$154.7= **$46.8/ac**

acre profit in the organic production system due to the similar yields per acre and

Discussion

The high-energy cost of nitrogen fertilizer production is due to the energy intensive process where nitrogen gas (N_2) is converted to ammonia (NH_3). Methane is intensively used in this process to produce energy and provide hydrogen (Equation 1) for the Haber-Bosch process (Equation 2).

Equation 1

$$4CH_4 + O_2 + 2H_2O \rightarrow 10H_2 + 4CO$$

Equation 2

$$N_2 + 3H_2 \rightarrow 2NH_3 \qquad \Delta H = -92.4 kJ/mol$$

The variation in nitrogen fertilizer production, as noted in Table 2, results from increases in efficiency in Haber Bosch nitrogen fixation processes over the last 100 years (Burgess et al. 2012). Along with variable coefficients in nitrogen fertilizer production, phosphorus and potassium production have variable coefficients due to different mining and ore extraction practices (Piringer 2006). Variation in these energy coefficients leads to uncertainty in calculations.

The only nutrient input in the organic system is nitrogen from a legume crop. As mentioned in the methods section, it is assumed that the legume crop will fix 95 lbs N/acre, which is adequate nitrogen for the wheat crop when background soil nitrogen levels are included (McCauley 2011). There are no phosphorus or potassium inputs to the soil in the organic system. This makes proper soil management and land use decisions essential in maintaining viable pools of these nutrients in the soils.

Variable soil nutrient levels and fertilizer application rates can highly influence overall energy input into the system. If values of nationwide average fertilizer application in conventional wheat systems were applied to this system, the conventional fertilizer energy inputs would almost double. The background levels used for NPK in this study indicate potassium limitation and excess nitrogen, which is not representative of other areas. Montana soils are extremely variable in nutrient content and seemingly small changes in inputs to the system can result in drastically larger outputs.

The use of glyphosate serves to inhibit EPSP synthase, an enzyme needed by weeds to produce proteins that are essential to growth (Pike and Hager 2010). In the organic system, tilling and a cover crop are used to mitigate weeds. Tilling incorporates crop stubble into the soil, uprooting and killing any existing weeds. Similarly, crop rotation disrupts the weed's life cycle (Cavigelli 2000). The extra machinery use associated with these practices makes up roughly 60% of the organic machinery input.

Fuel constitutes a significant energy requirement to the wheat production process. The biggest variation in fuel expenditures between organic and conventional systems is the difference in pest management and fertilizer application. Cultivation for weed control in organic wheat production increases the fuel costs significantly. However, after considering production costs of fertilizers and conventional pest controls, the higher energy cost shifts in favor of organic production. About 72% (80.2 MJ/bushel) of the total energy inputs for organic spring wheat production come from fuel requirements, compared to roughly 32% (37.5 MJ/bushel) for conventional production.

Different from fuel production inputs, transportation inputs do not vary across systems, but still make up a large percentage of total energy inputs. Train transport is 10 times more energy efficient than truck transport (Vanek and Morlock, 2000). In some situations outdated infrastructure may limit train use, but if train transport is available, it should be used over trucks due to its greater energy efficiency. Wheat transportation methods are often not the farmer's decision due to geographic and infrastructure constraints.

This study indicates that that the organic system of raising wheat is less energy intensive, though more costly per acre as labor is more expensive than chemical agents. However based on current wheat prices as well as input costs, this analysis suggests that organic wheat farming is more profitable per acre than conventional wheat farming. The overall input costs for organic production are more expensive. It should be noted again that the estimated costs for organic production are based on hired custom farming rates.

The difference between the two input regimes is due to the expense of labor and equipment being more expensive when compared to synthetic chemical inputs. Specifically weed control in organic production is nearly four times that of conventional production because tillage as a means of weed control is a more expensive process than spraying glyphosate (NDSU 2013). Despite the fact that total inputs are more expensive under organic regimes due to the significant difference in wheat prices, the organic system is nearly six times more profitable. As of October 1, 2014 organic wheat was selling for $18/bu while conventional wheat was listed at $6.50/bu. Based on labor availability on a given farm, the inputs cost for organic production may be significantly lower if no outside operators are hired to perform custom work.

Mačkić and Ahmetović 2011

organic farming is slightly less energy intensive. The energy required to produce wheat,

Works Cited

Aakre, D. (2013) Custom Farm Work Rates on North Dakota Farms. by NorthDakota Farming Regions. *NDSU Extension Service*. Retrieved from http://www.ag.ndsu.edu/pubs/agecon/market/ec499.pdf

Agronomy in Montana. (2014) Retrieved fromhttp://www.rmsi.coop/agronomy

Aller, Lakisha. "National Organic Grain and Feedstuffs - Bi-Weekly." *USDA Livestock, Poultry and Grain Market News*. USDA Agriculture Marketing Services, 28 Nov. 2014. Web. 10 Dec. 2014. <http://www.ams.usda.gov/mnreports/lsbnof.pdf>.

Burgess, M., Miller, P., Jones, C. (2012) Pulse Crops Improve Energy Intensity and Productivity of Cereal Production in Montana, USAJournal of Sustainable Agriculture. Vol. 36, Issue 6,

Cavigelli, Michel. (2000) Organic Cropping Systems to Enhance Ecosystem Services.

Census of Agriculture. (2012) United States Department of Agriculture, 2012 Census Volume 1, Chapter 1: State Level Data, Montana. http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Montana/

Dinkins, C., Jones, C. (2013) Interpretation of Soil Test Reports for Agriculture. Montana State University Extensions.

Economic Research Service. (2013) United States Department of Agriculture, Wheat, Background, http://www.ers.usda.gov/topics/crops/wheat/background.aspx#.VD39Ghb4KMI

Gellings, Clark W., and Kelly E. Parmenter. (2004) *"Energy efficiency in fertilizer production and use." Efficient Use and Conservation of Energy, Encyclopedia of Life Support Systems. Eolss Publishers, Oxford, UK. www. eolss. Net*,

Gittlein, Jonathan. "USDA-CO Dept of Ag Market News Service, Greeley, CO." *USDA-CO Dept of Ag Market News*. USDA Ag Market Services, 9 Dec. 2014. Web. 9 Dec. 2014. <http://www.ams.usda.gov/mnreports/gl_gr851.txt>.

Helsel, Zane. (2012) "Energy Use and Efficiency in Pest Control, Including Pesticide Production, Use, and Management Options - EXtension." *Energy Use and Efficiency in Pest Control, Including Pesticide Production, Use, and Management Options* - EXtension. N.p., n.d., Web. 25 Nov. 2014.

Henderson, A. M.; Gervais, J. A.; Luukinen, B.; Buhl, K.; Stone, D. (2010) Glyphosate Technical Fact Sheet; National Pesticide Information Center, Oregon State University Extension Services.

Jacobsen, J., Jackson, G., Jones, C. (2003) *Fertilizer Guidelines for Montana Crops.* Montana Fertilizer Research Extension Program.

Mačkić, S. and Ahmetović, N., (2011) *Toxicological Profiles of Highly Hazardous Herbicides With Special Reference to Carcinogenicity to Humans*. Herbologia. Vol. 12 No. 2.

Manual, J. (2014) *Nutrient Pollution*. Environmental Health Perspectives. Vol. 122 Issue 11.

McCauley, Ann Michelle. (2011) Nitrogen fixation by annual legume green manures in a semi-arid cropping system. Diss. Montana State University-Bozeman, College of Agriculture,.

NASS (National Agricultural Statistics Service). (2008) Certified Organic Production Survey. United States Department of Agriculture. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Organics/organics_1_07.pdf

NASS (National Agricultural Statistics Service). (2011) United States Department of Agriculture. Spring Wheat Acreage, Yield, and Production by Counties and Districts. http://www.nass.usda.gov/Statistics_by_State/Montana/Publications/Annual_Statistical_Bulletin/2012/CoEstSW11.pdf

NASS (National Agricultural Statistics Service). (2012) 2011 Certified Organic Production Survey. United States Department of Agriculture. pg. 108 http://usda.mannlib.cornell.edu/usda/current/OrganicProduction/OrganicProduction-10-04-2012.pd

National Association of Wheat Growers. Fast Facts. Wheat Info. http://www.wheatworld.org/wheat-info/fast-facts/

National Nutrient Database for Standard Reference. Agricultural Research Service. United States Department of Agriculture. Wheat, hard red spring. http://ndb.nal.usda.gov/ndb/foods/show/6481?fg=&man=&lfacet=&format=Full&count=&max=25&offset=&sort=&qlookup=red+wheat

NC State University. (2014) "Chemical Weed Control." *NC State Chemical Weed Control Manual*,

Olson-Rutz, K., Jones, C., Miller, P. *"Soil Nutrient Management on Organic Grain Farms in Montana."* Montana State University College of Agriculture Extensions.

Pike, David R., and Aaron Hager (2010)"A Short Course On How Herbicides Kill Weeds and Injure Crops." *Department of Crop Sciences, University of Illinois*

Piringer, G. and Steinberg, L. J. (2006) Reevaluation of Energy Use in Wheat Production in the United States. Journal of Industrial Ecology, 10: 149–167.

Smil, Vaclav. (2008) Energy in nature and society: general energetics of complex systems. MIT press..

WestBred Wheat Seed. *WB-PRESTEA*. Monsanto Corp., 1 May 2014. Web. 1 Oct. 2014.<http://www.westbred.com/Products/MT/pages/showpdf.aspx?product=WB-PRESTEA>.

Zentner RP, Lafond GP, Derksen DA, Nagy CN, Wall DD, May WE. (2004) *"Effects of tillage method and crop rotation on non-renewable energy use efficiency for a thin Black Chernozem in the Canadian Prairies"*. Soil Till Res.77(2):125–136.