Improving energy efficiency in agriculture

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Abstract: Agriculture and the related primary industry is an increasingly energy demanding sector. Energy is needed to different extent in all the stages of the agri-food chain. In many cases, energy cost may represent up to 20-50% of the total agricultural production cost, including the cost of manufacturing and transportation of various chemicals and fertilisers. Australia's electricity costs have already increased by 80% in the last 5 years, and are expecting a further increase of 20% or more in the next few years. It is shown that energy use in agriculture varies considerably, depending on the cropping enterprise and the farming systems. There are significant opportunities to reduce energy, costs and greenhouse gas emissions. There are also significant inconsistences and access issues for the on-farm energy use data in and between different industries. Standardised energy analysis and benchmarking process is developed. The implications of changing energy sources and practices on future GHG emissions and economic impacts are discussed.

Keywords: Energy, energy benchmarking, farming systems, greenhouse gas emissions

INTRODUCTION

Farming is often an energy intensive operation (Table 1). Within highly mechanised agricultural productions systems such as the Australian cotton industry, energy inputs represent a significant cost (20-50% of the total operating cost) to growers. Energy cost is also a significant component of the cost of manufacturing nitrogen fertilizer and other chemicals. In the United States, it has been estimated that the operations of food systems, including agricultural production, food processing, packaging, and distribution, accounted for approximately 19% of America's national fossil fuel energy use (Pimentel, 2006). In another study, it was found that in the United States, about 1500 litres of oil equivalents are expended annually to feed each American (as of data provided in 1994). In many developed countries, fossil fuel consumption by food systems often rivals that of transport systems.

Energy efficiency is an important consideration for agriculture both in terms of rising energy costs and greenhouse gas (GHG) emissions. Overall, Australia's electricity prices have increased by 80% in the last 5 years, which has far exceeded the increases in consumer price index (CPI) changes over the same period (Fig.1). It is projected that electricity prices in Australia will further increase by another 20% in the next 2 years. Hence, there is increased importance in quantifying energy use, as an essential step toward encouraging efficient energy use on the farm. It is likely that farmers in Australia may face either an energy, water or carbon constrained future.

Table 1: Examples of average fuel use for different tillage methods. A ratio of up to 4:1 from the highest to the lowest energy use may be found in different tillage methods.

Soil tillage methods	Average fuel use
Subsoiling	18 Litre/ha diesel use
Discing	12 Litre/ha diesel use
Chisel ploughing	7 Litre/ha diesel use
Power Harrowing	8 Litre/ha diesel use
Light Harrowing/rolling	4 Litre/ha diesel use

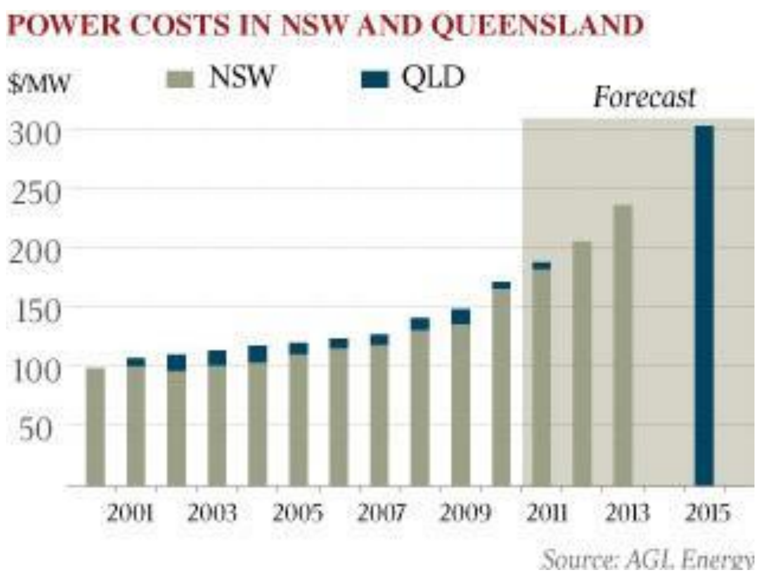

Fig.1: Electricity price increases in NSW and Queensland, Australia, since 2004

ENERGY AUDITS

Energy audits are a crucial part of farm energy management. Energy audits refer to the systematic examination of an entity, such as a firm, organisation, facility or site, to determine whether, and to what extent, it has used energy efficiently. An energy audit determines how efficiently energy is being used, identify energy and cost saving opportunities and highlight potential improvements in productivity and quality. An energy audit may also assess potential energy savings through strategies such as fuel switching, tariff negotiation and demand-side management (eg, by changing to alternative farming systems and farm layouts).

An energy audit may be undertaken as part of a broader plan to manage energy inputs on farm (Chen and Baillie, 2009a). The objectives of energy management include:

- conserve energy inputs;
- reduce greenhouse gas emissions;
- achieve operational and cost efficiencies with improved productivity and profitability.

Energy audits may be conducted with different levels of detail (Fig.2). The level 1 is the simplest and usually utility-bill based. A level 2 audit is referred to as a standard / general audit and is effectively process-based, and provided an itemised account of energy usage across the farm so that energy saving opportunities can be prioritised. The level 3 audit is the highest and is an investment-grade audit for detailed study carried out by specialists.

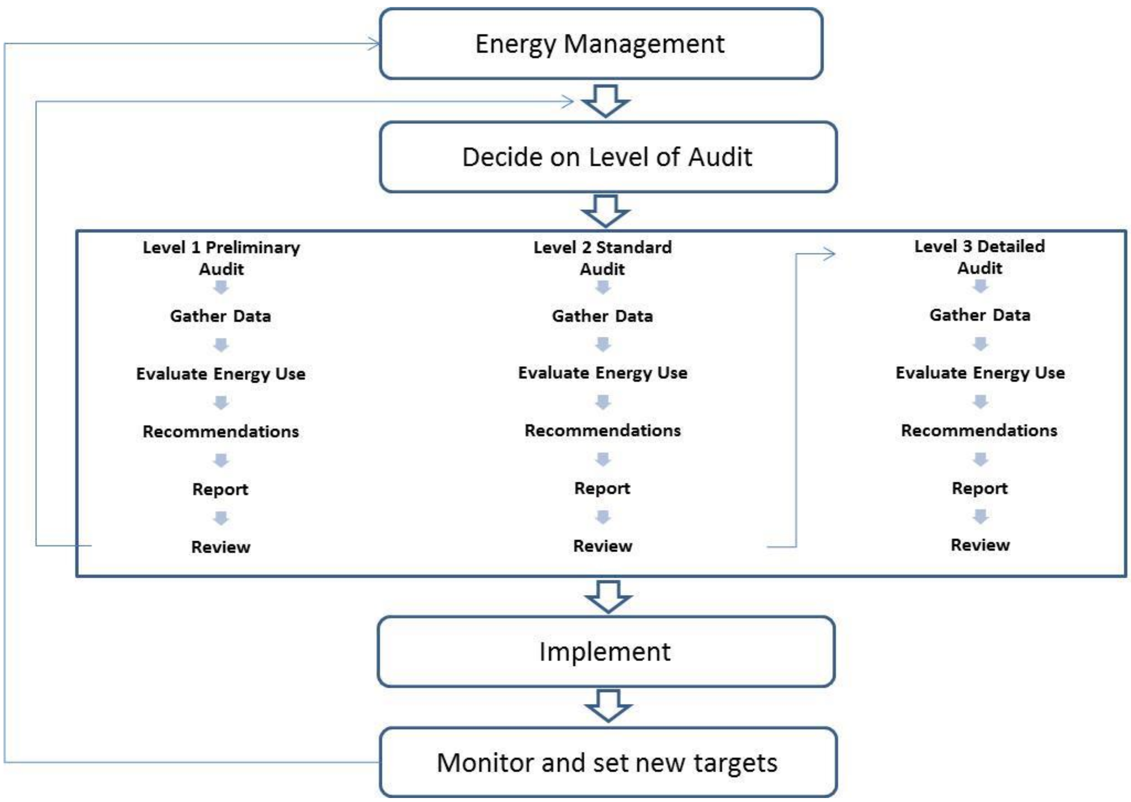

Fig. 2: Energy assessment and management process (Baillie and Chen 2012)

A user may decide to conduct any single level of audit or may conduct a level one audit and then progress to a level two audit and possibly to a level three audit. Each level of audit has its own time and monetary cost.

The level of audit will depend on factors such as:

- The potential energy or energy cost saving strategies,
- The level of detail and accuracy required to evaluate proposed changes,
- The total annual energy cost,
- Size of the site.

ENERGY USE AND LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is an internationally recognised approach for evaluating the environmental impacts of products and services. LCA is often used to compare the environmental damages assignable to products and services, and further to choose the least burdensome one (Chen et al, 2010).

The quality of a LCA project is strongly dependent on the quality of inventory data. A simple LCA analysis may be performed manually. But when the complexity of the analysis increases, a computer based tool with a comprehensive data library may be required.

Energy data for LCA may include direct measurement of actual performances in the field, or alternatively by a proxy based protocol and / or a combination of both methods. A proxy based protocol is where energy inputs are assumed or estimated based on practices or tools as opposed to direct measurement. A proxy based protocol is generally more economic, but its accuracy may be lower. Research is currently being conducted to compare the values of energy use in different operations and different regions between default values and direct measurements. Preliminary research results also indicated that the percentage difference between measured results and practice-based (default) results for tractor operations may often be within 10-20%. This suggests that default and calculation based techniques were found to be an acceptable method of performing an energy and LCA analysis. It is also found that there is less variation in fuel use of in-field operations and pumping has the most potential for saving energy and money.

OPPORTUNITIES OF IMPROVING ENERGY EFFICIENCY IN AGRICULTURE

Extensive research has been conducted on both energy use and conservation in agriculture. The library of energy use benchmarks provides a foundation to perform energy audits and also life cycle assessments. Recent results of energy efficiency programs have shown considerable variation in energy use between different farms of similar production types.

Table 2: Energy performance data from published literature

Crops	Total Energy Input (GJ/ha)	Direct Energy Input (GJ/ha)	Indirect Energy Input (GJ/ha)	Researchers	Country
Wheat	-	2.5 ~ 4.3	-	Pellizzi et al (1988)	Europe
Cotton	82.6	-	-	Tsatsarelis (1991)	Greece
Cotton	49.73	21.14	28.59	Yilmaz et al (2005)	Turkey
Cotton	-	3.7 ~ 15.2	-	Chen & Baillie (2009b)	Australia
Cotton	-	5.5~20.5	1.6~ 7.9	Nelson et al (2009)	USA
Cotton	47~128	11.5~13.2	21.9~112.2	Khabbaz (2010)	Australia
Sugarcane	148.0	100.6	47.4	Karimi et al (2008)	Iran
Sugarcane	35.7	2.48 (onfarm)	-	Mashoko et al (2010)	South Africa
Rice	64.89	-	-	Pretty (1995)	USA
Pea	2.5 ~5.4	-	-	Gulden & Entz (2005)	Canada
Dairy pasture	18.2	14.56	3.63	Wells (2001)	NZ

Table 2 summarizes energy performance data for several different crops. Pellizzi et al (1988) found that in Europe, the range of field energy consumption for wheat-like cereals varied from 2.5 GJ/ha to 4.3 GJ/ha. For cotton, a recent study by Chen & Baillie (2007) showed that the direct energy inputs for cotton production in Australia ranged from 3.7 to 15.2 GJ/ha (Figure 3). Diesel energy inputs ranged from 95 to 365 liters/ha, with most farms using 120 to 180 liters/ha. Dryland cotton was at the lower end of this range. Results by Nelson et al (2009) also indicated that on-site energy use and total energy use for US cotton in 2004 ranged from 1.6 to 7.9 GJ /ha and from 5.5 to 20.5 GJ/ha respectively. It is also noted that in 2006/07, Australia yielded an average 1,792 kg/ha (7.89 cotton bales per hectare). This figure was almost two and a half times the world average of 747 kg/ha. In Australia, 1 GJ of energy is worth $10~40, depending on the fuel type being used (Table 2).

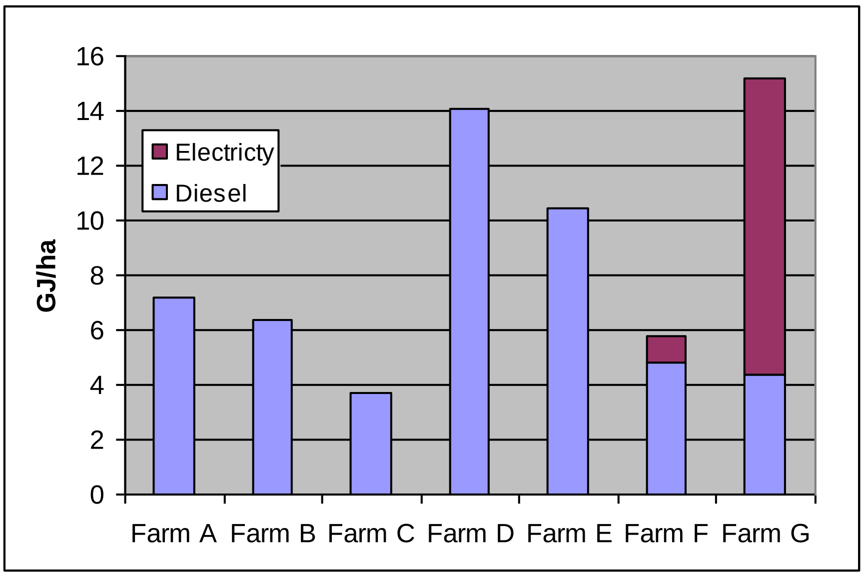

Figure 3: Direct on-farm energy inputs of seven cotton farms in Australia. Electricity in Farm F and G was used for irrigation water pumping.

Singh (2002) found that cotton has the highest energy usage among wheat, mustard, maize and cluster bean. Compared with cotton, Baillie & Chen (2011) also suggested that the energy use of other rotational crops (grain) is usually lower, because cotton generally has a greater number of farming operations, more intensive energy use associated with harvest (i.e. picking) and higher irrigation demands. Yaldiz et al. (1993) reported that fertilizers and irrigation energy dominate the total energy consumption in Turkish cotton production. Yilmaz et al (2005) showed that the energy intensity in agricultural production was closely related with production techniques. He estimated that cotton production in Turkey consumed a total of 49.73 GJ/ha energy, consisting of 21.14 GJ/ha (42.5%) direct energy input and 28.59 GJ/ha (57.5%) indirect energy input. Total sequestered energy in Greece was found to be 82.6 GJ/ha with irrigation and fertilizers as major inputs. Cotton yield was 1024 kg/ha lint and 2176 kg/ha seed.

Significant analyses (eg, Table 2) also indicate that in many cases, the embodied energy of agricultural inputs can be equal to or substantially greater than the direct energy (Chen et al, 2013). The role of embodied energy and trade-offs between embodied and direct energy inputs are therefore important in discussing the impact of system change on overall energy budgets. Such examples include the trade-off between water (availability) and energy (price) resulting from irrigation system selection and performance, and trade-off between reduced on-farm energy by conservation farming practice and the increased indirect energy use by fertilizer and weed control. The increased water-use efficiency of pressured irrigation systems will need to be balanced against the higher cost of the energy needed.

Overall, Pimentel et al (2008) showed that fossil energy use in the US food system could be reduced by about 50% by appropriate technology changes. Using corn production as an example, they estimated that total energy in corn production could be reduced by more than 50% with the following changes of practices: (1) using smaller machinery and less fuel; (2) replacing commercial nitrogen applications with legume cover crops and livestock manure; and (3) adopting alternative tillage and conservation techniques.

For cotton operations, it is suggested that energy audits should first focus on high-energy use areas such as irrigation, heavy tillage operations and harvesting. Low-cost abatement methods (eg adopting more efficient machinery and switching to different mix of fuel) must be actively identified and encouraged. It is also important to further reduce the indirect embodied energy and post-harvest energy uses. Previous research shows that fertilizer and chemicals account for large amounts of energy and efficiency in these is to be improved (Chen et al, 2013). While minimum or no till systems can work and reduce in-field energy use, they on the other hand increase chemical use. Further research is required to determine the balance of this trade-off.

CONCLUSION

Energy in agriculture is becoming an increasingly important issue for both economic and environmental reasons. This paper has assessed the practices and opportunities in terms of energy efficiency in agricultural production. It has been shown that energy uses vary significantly between different farms and different practices. Considerable opportunities also exist for the improvement of energy efficiency.

To achieve best outcomes, it has been suggested that energy audits would need to be customer-focused and encourage implementation. The future of energy management may lie in offering a full service that makes recommendations much easier for clients.

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