Development of a framework and tool to assess on-farm energy uses of cotton production

Guangnan Chen* and Craig Baillie

National Centre for Engineering in Agriculture, Faculty of Engineering & Surveying, University of Southern Queensland, Toowoomba, Queensland 4350, Australia

Abstract

Within highly mechanised agricultural productions systems such as the Australian cotton industry, operational energy inputs represent a major cost to the growers. In this paper, a framework to assess the operational energy inputs of various production systems and the relative performance of a grower within an adopted system is developed. It divides energy usage of cotton production into six broadly distinct processes, including fallow, planting, in-crop, irrigation, harvesting and post harvest. This enables both the total energy inputs and the energy usage of each production processes to be assessed. This framework is later implemented and incorporated into an online energy assessment tool (EnergyCalc). Using the developed software, seven farm audits are conducted. It is found that overall, depending on the management and operation methods adopted, the total energy inputs for these farms range from 3.7-15.2 GJ/ha of primary energy, which corresponds to $80-310/ha and 275-1404 kg CO_2 equivalent/ha greenhouse gas emissions. Among all the farming practices, irrigation water energy use is found to be the highest and is typically 40-60% of total energy costs. Energy use of the harvesting operation is also significant, accounting for approximately 20% of overall direct energy use. If a farmer moves from conventional tillage to minimum tillage, there is a potential saving of around 10% of the overall fuel used on the farm. Compared with cotton, energy uses by other crops are generally much smaller, due to less intensive management practices, and reduced irrigation requirements.

Keywords: Cotton; Energy uses; Farming processes; Greenhouse gas emissions

1. Introduction

Cotton is a significant industry in Australia. Since 1987-88, the gross value of cotton production in Australia has more than tripled, while the value of exports has more

*Corresponding author: Ph: +61 7 4631 2518; Fax: +61 7 4631 2526; Email: chengn@usq.edu.au

than quadrupled. Australia is now the fourth largest cotton growing country in the world, valued at some $1.5 billion (Australian Dollar) per annum.

The Australian cotton growing industry is highly mechanised and heavily reliant on fossil fuels (electricity and diesel). Overall, it has been estimated that machinery related expenditure may consist of 40-50% of the cotton farm input costs. Given the major dependence on direct energy inputs and rising energy costs, energy use efficiency is becoming an emerging issue for the Australian cotton industry. Quantifying the operational energy costs for different cotton production systems through the development of an on-farm energy audit tool is fundamental in identifying strategies to reduce energy inputs.

Extensive research has been conducted on energy use and conservation both in agriculture [1-3] and in other industries [4]. Murray [5] showed that growing food and fibre accounts for approximately one fifth of total energy use in the U.S. food system. Pellizzi et al. [1] discussed the energy saving potential of various agricultural machinery and farming practices. Stout [2] reviewed much of the early research on energy use in agriculture, both for developing and developed countries. Tullburg and Wylie [3] provided a comprehensive review of energy use in agriculture in Australia. Brown and Elliot [6] found that overall, although the currently available agriculture data may be sufficient for general policy development, the quality of existing energy end-use data is often unsatisfactory, therefore making it difficult to predict where the largest opportunities for energy efficiency are.

Overall, it is found that energy saving in cotton industry received relatively little attention. Singh [7] found that cotton has highest energy usage among wheat, mustard, maize and cluster bean. Singh et al. [8] also reported that the cost of energy use per unit area decrease with the farm size, because large farms may have better capacity to manage energy use. Yaldiz et al. [9] reported that fertilizers and irrigation energy dominate the total energy consumption in Turkish cotton production. Yilmaz et al. [10] showed that the energy intensity in agricultural production is closely related with production techniques. They 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.

Four separate energy calculators were developed by United States Department of Agriculture (USDA) for estimating the energy uses in animal housing, irrigation, nitrogen, and tillage [11]. In this way, the average diesel fuel use and costs in the production of key crops in different parts of USA can be estimated and compared. These calculators however do not explicitly relate the energy use to the particular farming methods or per unit of work. It can therefore only estimate the average energy use for a given region.

The aim of this paper is to determine and compare the operational energy costs for different cotton production systems through the development of an on-farm energy audit tool. The specific objectives of this work are:

- Develop a framework and a tool to conduct operational energy audits;
- Evaluate energy use for alternative production systems and impacts on greenhouse gas emissions;
- Identify opportunities to reduce operational energy inputs and impacts on greenhouse gas emissions**.**

2. Cotton Production Systems in Australia

Australia currently has about 1500 cotton farms, with a cotton growing area of 536,000 hectares [12]. In addition to the cotton production, depending on the prevailing market and soil conditions, cotton growers in Australia may intensify the cropping system by adding a winter crop in rotation with cotton (i.e. double-cropping system), fallowing certain paddocks for moisture conservation, or replacing cotton with another summer crop [13]. In essence, a "typical" cotton grower in Australia will most likely have other crops (grains) incorporated into the farming system and the crop rotation. With the advance of biotechnology and increasing awareness of water and energy conservation, conservation farming practice with reduced or zero tillage is also becoming widely adopted.

Following the seedbed preparation, cotton is planted in spring (late September to mid November, because Australia is in the Southern Hemisphere). Herbicide and other chemicals may be applied before planting and may be repeated several times after that. Irrigation may also be continuously applied between the hot months of December and February, depending on available rainfall and soil moisture levels. Cotton is harvested in late March/early April. The total cotton growing period is about 180 days. The main cotton farming activities for a "typical" cotton farm in different months in Australia are summarized in Table 1.

3. A Framework to Assess On-farm Energy Use

A significant objective of this project is to develop a framework to assess on-farm operational energy inputs in cotton production. This will involve setting up a farm model for estimating energy inputs by all major machinery for use on the farms. In line with farmers' experience and common farming procedures, it may be reasonable (Table 1) to conceptualize the typical cotton farming processes as:

1. Fallow
2. Planting
3. In-crop
4. Irrigation
5. Harvesting

6. Post-harvest

Depending on the machinery being used, each of the above farming processes may be further divided into a number of common farming practices/operations such as tillage, harrowing, spraying, fertilizing, and irrigation type etc. Each of these farming practices / operations may also appear in several farming processes (Figure 1).

4. Estimation of On-farm Energy Use

4.1 Fallow

Fallow operations are normally weighted towards tillage. However, recent implementation of minimum tillage farming practices has placed greater emphasis on spraying (to conserve soil moisture and reduce fuel costs. Fallow tillage operations may include subsoiling, discing, chisel ploughing, or harrowing etc. Tillage operations performed prior to planting cotton is aimed to make a firm, well-drained seedbed that will provide a warm environment for seed germination and vigorous seedling growth. These tillage operations represent not only high energy, equipment and labour costs, but also can reduce soil organic matter, and contribute to environmental pollutions and soil erosion. Tillage operations can account for a significant proportion of overall cotton production costs and is one of the important management variables that growers can directly control.

From the literatures [3, 14], the average fuel use for various tillage methods in Australia is estimated as (Table 2):

It is noted that these figures assume typical conditions and average working depths. For some very heavy or light soils, these values may vary by up to 25% or more [15].

For some operations such as hilling (bed forming), there is currently no fuel use data available in the literature. In this case, the energy use may be estimated using the data of “similar” operations or based on the power (size) of the tractor engine, loading conditions (heavy, normal or light duty), and tractor work rate etc. This (alternative) method is discussed later in Section 4.7 of this paper.

4.2 Planting

For cotton production, there are essentially two methods of planting: conventional drilling (multiple passes) or direct drilling (single pass).

Table 3 shows the estimated average energy uses for one pass of these two methods [3, 14].

By adopting the minimum tillage and direct drilling method, the total number of tractor uses (passes) will be significantly reduced. This can therefore lead to a significant reduction of fuel uses in the overall farming operation.

4.3 In-crop operations

After planting, various in-crop operations will be performed to maintain the crop. These include weed control, and applications of various fertilizers and pesticides. Depending on the height of the crop, weed control may be carried out by either inter-row cultivation or shielded / boom spraying. Farm chemicals (herbicides and insecticides) may also be applied using tractors on the ground, or by an aircraft. With the advance of biotechnology and development of new crop varieties, the number of crop spraying operations (insecticides) has been reduced from as much as 16 to 3 to 4 times on average now. Similarly, the number of inter row cultivation has also been reduced. Table 4 presents the average fuel uses for each of these field operations [3, 14].

From the above table, it can be seen that the (direct) fuel use for spraying is significantly lower than that used for cultivation. The energy use for manufacturing the pesticides has however not been included in the above table. For these in-crop operations, the range of variation of energy use is typically around 10% [15].

4.4 Irrigation

Cotton may be rain-grown (dryland farming) or watered by irrigation. Farm irrigation systems include surface irrigation, sprinkler systems, and drip (trickle) systems.

It is estimated that in Australia, about 92% of total agricultural production and 85% of total area is under surface irrigation [16]. Sprinkler irrigation (6-7%) consists of either Centre Pivot or Lateral Moves. These pressured irrigation systems are often powered by diesel engines or electric motor (when the electricity is readily available). The occurrence of drip irrigation is relatively infrequent, covering only 1-2% of the irrigated area in Australia.

Compared with other on-farm operations, pumping energy use is highly variable. Wells [14] found that energy use for irrigation is highly correlated to choice of irrigation system, and total pumping head pressure, which includes the energy required for both lifting water several meters higher and pushing against the pressure of the sprinklers and friction loss.

The energy consumed by pumping system is determined by:

Flow rate × Pressure head/ Pump efficiency

This may be represented by the following equation (for electric pump):

$$\text{Pumping Electricity Use (kWh/ha)} = (g/3.6)\ V\ H\ /\eta \qquad (1)$$

Where: g = gravity acceleration constant = 9.81 (m/s^2)
η = pump efficiency %
V = volume of water pumped (ML/ha)
H = head pressure (m)

Typical electric pump efficiency is between 50-70%. When diesel engine is used, the pump efficiency would be lowered to 25-30% [2]. Because the energy content of diesel is taken as 38 MJ/L, and 1 kWh is equal to 36 MJ, the corresponding equation for diesel pump is:

$$\text{Pumping Diesel Use (Litre/ha)} = g\ V\ H\ /\ (\ 38\ \eta\ ) \qquad (2)$$

Irrigation may have 10-40 m head pressure, with the "typical" values for various systems as (Table 5):

Whatever possible, farmers should conserve water because this saves both energy and water.

4.5 Harvesting

Several units of work are involved in mechanical harvesting of cotton: harvesting, module building, trailer loading and basket dumping, and road cartage. Table 6 presents the average fuel uses for these operations [3, 14].

It can be seen here that a cotton picker uses about four times of the energy that is used by a cotton stripper.

4.6 Post-harvesting

After the harvesting, the paddy and stubble will need to be removed to prepare for next season's crop. This usually involves the actions of slashing, stalk pulling and mulching etc. Table 7 presents the average fuel uses for these operations [3, 14].

4.7 Others

From time to time, farmers may also need to carry out certain tasks that are not discussed above. For these unspecified "others" operations, their energy uses may have to be estimated based on the power (size) of the tractor engine, loading conditions (heavy, normal or light duty), and tractor work rate. For this paper, the rule of thumb as suggested by Harris [17] is adopted:

$$\text{Average tractor fuel usage (L/hr)} = \text{PTO power rating (kW)}/4 \qquad (3)$$

Note that the above equation is only applicable for normal (medium) loading conditions. For either heavy or light condition, adding or subtracting 20% fuel use may be appropriate.

4.8 Total energy use and greenhouse gas emissions

By adding up all the energy uses discussed above, we are able to determine the total (primary) energy use of the farming operation as

$$\text{Total (primary) energy use of the farm (GJ)} = 0.0386 * \text{Total diesel use (Litre)} + 0.0036 * \text{Total electricity use (kWh)}/0.35 \qquad (4)$$

Here we have assumed that the diesel heat content is 38.6 MJ/L, and the electricity generation efficiency is 35%. In the current market condition, 1 GJ of fuel energy would cost around $25-30 Australian Dollar.

With the increased community concern on global warming and climate change, the greenhouse gas emissions from the cotton production will also be important. In this paper, the following equation will be used [18]:

$$\text{GHG Emissions due to energy use (kg } CO_2 \text{ equivalent)} = Q \times EF \qquad (5)$$

in which Q is the quantity of fuel (L) or electricity (kWh) used. EF is the relevant emission factor given in Table 8 (assuming the emission factor for diesel is 74.9 kg CO_2 /GJ):

Therefore,

$$\text{Total greenhouse gas emissions of the farm due to energy use (kg } CO_2 \text{ equivalent)} = 2.89 * \text{Total diesel use (Litre)} + 1.051 * \text{Total electricity use (kWh)} \qquad (6)$$

Note that the above calculation has only included the direct greenhouse gas emissions from the energy use, and has not included the effect due to soil tillage/disturbance and nitrogen fertilizer applications. The latter may change significantly with both time and locations.

5. Software design and implementations

A significant objective of this project is to develop a framework and a software tool to assess on-farm operational energy uses. As outlined previously, the calculation will be based on the energy use by units of activities. The software (EnergyCalc) will therefore have a hierarchal structure as shown in Figure 2, which assumes that the faming activities will be arranged in the order of six farming processes of fallow, planting, in-crop, irrigation, harvesting and post harvest.

To enter the data into the software (online), the user will need to select the appropriate farming and sub-farming actions such as subsoiling, discing, chisel ploughing, or harrowing etc, and then enter the specific number of operations (passes) performed (Figures 3 and 4). The calculator will then be able to (automatically) convert these input data into estimated energy use based on the data shown in Tables 2-8 and Equations (1)-(6). To allow for flexibility, the software has also given the user the option to override these values using his own site-specific data. This may be obtained for example by measuring the amount of fuel used and the area of crop covered for specific operations over a specific time, such as two or three days. This will allow a grower to benchmark his real performance and identify opportunities to reduce costs.

EnergyCalc is also able to give detailed feedback on the estimated total energy use for both the whole production system, as well as the individual farming processes. For this purpose, the software outputs are grouped into four broad categories related to fuel use, electricity use, total on-farm energy use and greenhouse gas carbon emissions (Fig.5). A number of normalised energy use indices such as GJ/ha or $/ha are also included to allow farmers to directly compare and benchmark his energy performance.

All the input and output data in EnergyCalc will be automatically stored in a central location (web server) for later retrieval if necessary. This accumulation of data will eventually provide a wealthy source of data for the industry, and may be used for industry-wide energy use benchmarking and policy development.

6. Examples of case studies

In the following, EnergyCalc will be used to examine the energy use in seven simplified case studies (Farms A to G). The data for cotton farms A and B are extracted from the report of Chudleigh et al [13], while the data for Farms C to G came from farmer interviews [19]. These examples cover a range of farming regions and farming practices (eg, conventional tillage, minimum tillage, dryland farming, and irrigation). The details of farming practices for each of these properties are described in the report by Chen and Baillie [19]. For some of the case studies, basic farm data (eg, irrigation head pressure) was estimated to reflect the operating costs recorded by the growers and may therefore not reflect the true physical setup on the farm.

Key farming methods of each farm are (Table 9):

- Farm C: entirely gravity fed surface irrigation (no pumping cost)
- Farms F and G: utilised electric power plants for pumping irrigation

- Farms A, B, D and E: utilised diesel power plants for pumping irrigation
- Farm B: used sprinkler irrigation
- Farms D, E and G: sourced ground water (high pumping costs) and
- Farms C, E and G: practiced minimum tillage (low tillage costs).

To demonstrate and compare the relative energy uses for different crop rotation practices, three case studies (Farms E, F, G) of mixed farms (producing cotton and other crops such as wheat, sorghum and chickpeas) are also included. Dryland farming is also practiced in farms B, E and G (for other crops only, not for cotton).

7. Results and Discussions

The details of calculation results for each of the case studies are described by Chen and Baillie [19]. Based on the EnergyCalc calculation results, it is found (Fig.6) that overall, for the cotton production, depending on the management and operation methods adopted, the total on-farm energy inputs for these farms may range from 3.7 to15.2 GJ/ha of primary energy, corresponding to 275-1404 kg CO_2 equivalent greenhouse gas emissions per hectare. Diesel energy inputs range from 95 to 365 liters/ha diesel use. For “most” farms relying on surface irrigation, the “medium” diesel use is around 120-180 liters/ha. These results are broadly consistent with that is reported in the literature [10] and the experience of the farmers.

Fig.6 also shows that values of the energy inputs vary widely between individual farms, by as much as 300%. Farm C uses the smallest amount of diesel energy (95 L/ha, or 3.7 GJ/ha) due to the adoption of gravity fed surface irrigation and minimum tillage. Farm D uses the largest amount of diesel energy (365 L/ha) due to irrigation water which is double pumped. That is, the water is first pumped out of a bore and into an on-farm storage and then pumped out and onto the field. This significantly increases the irrigation energy use (70% of the total energy cost) for this farm (Table 10). A similar situation also occurs for farms E (62%) and G (51%). The total energy costs for different farms for cotton production are shown in Figure 7.

Compared with cotton, the calculation results for Farms E, F, G indicate the total energy use by other crops are generally much smaller (wheat $42-130/ha, sorghum $60-130/ha, chickpeas $50-130/ha). Part of the reason for this lower energy use is the lower number of farming operations (passes) carried out for these crops which is generally 10, compared to 17-18 for cotton. The energy use by the cotton harvester (45 L/ha) may be another factor [3], as it uses much more energy than other types of crop harvesters (typically, 10-15 L/ha of diesel use). As a result, obtaining accurate measurements for harvesting energy use becomes important in the context of the cotton production system [19].

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The calculated results also indicate that the energy use by tillage and other on-farm operations change considerably, mainly because the number of tillage operations varies significantly between different growers (depending on if minimum tillage is practiced). It is shown that if a grower moves from conventional tillage to minimum tillage (eg Farms C and E), there is a potential saving of around 10% of the overall fuel used on the farm. This can also be seen in the proportion of energy spent on fallow which reduces significantly from typically 12-15% to 4-5% of the total cost (Table 10). In comparison, Farm F spends the highest proportion of energy inputs (32%) on fallow operations due to the use of both a rotary hoe and ripper.

It can also be seen from Table 10 that values of the energy use by irrigation vary significantly between individual farms, with the "medium" value typically between 40-60% of total energy costs. Farm G produces the highest greenhouse gas emissions (1404 kg CO_2 equivalent /ha) because it uses electricity to pump ground water from a bore. These results show that effective water management is critically important, particularly when pumping costs are quite high (i.e. extracting water from bores).

8. Conclusion

With increasing concern for fuel cost and energy conservation, there is an increasing need for cotton farmers in Australia and around the world to be able to understand and calculate the amount of fuel used to perform farming operations. By knowing the amount of fuel and electricity used, farmers are empowered the capacity to fine-tune and select the best farming practices for them.

In this paper, a framework to assess the on-farm operational energy inputs of various production systems and the relative performance of a grower within an adopted system has been developed. It divides energy usage of cotton production into six broadly distinct processes, including fallow, planting, in-crop, irrigation, harvesting and post harvest. This enables both the total energy inputs and the energy usage of each production processes to be assessed. This framework has also been implemented and incorporated into an online energy assessment tool (EnergyCalc). All the input and output data to EnergyCalc are also automatically stored in a central location (web server).

Seven simplified case studies have been presented. It has been found that overall, depending on the management and operation methods adopted, the total on-farm energy inputs for these farms range from 3.7-15.2 GJ/ha of primary energy, corresponding to $80-310/ha and 275-1404 kg CO_2 equivalent/ha greenhouse gas emissions. It has also been found that energy use of harvesting is significant, because it usually contributes around 20% of overall direct energy use. If a farmer moves from conventional tillage to minimum tillage, there is a potential saving of around 10% of the overall fuel used on the farm. Compared with cotton, the energy use by other crops are generally much smaller (approximately half).

The model has also shown that water management on irrigated cotton properties is critically important, particularly for those with high pressure spray irrigation. For surface furrow irrigation, the “medium” energy use by irrigation may vary between 40-60% of total energy costs.

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Spraying
Others

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Sprinkler spraying
Drip irrigation

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Infield operation
Others

Post Harvest

Crop destruction
Others

Figure 1 Farming processes (stages) in cotton production. Each of the farming processes may contain a number of different farming practices/operations such as tillage, harrowing, spraying, fertilizing, and irrigation etc.

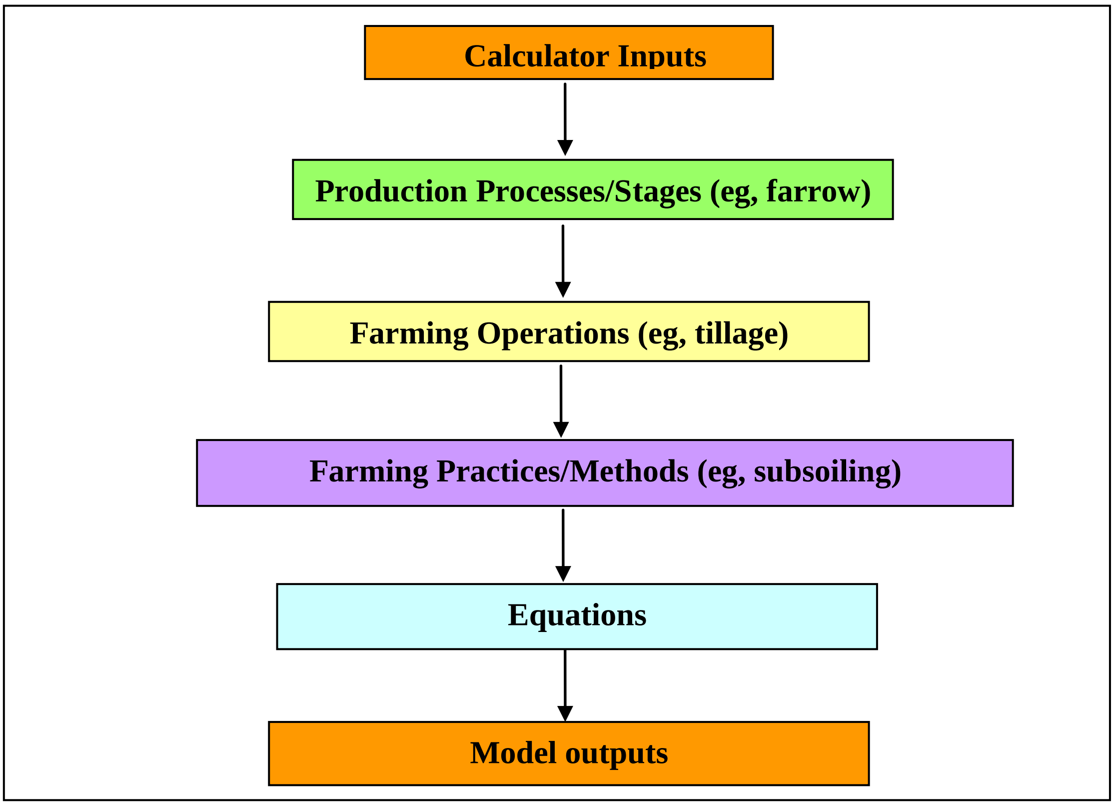
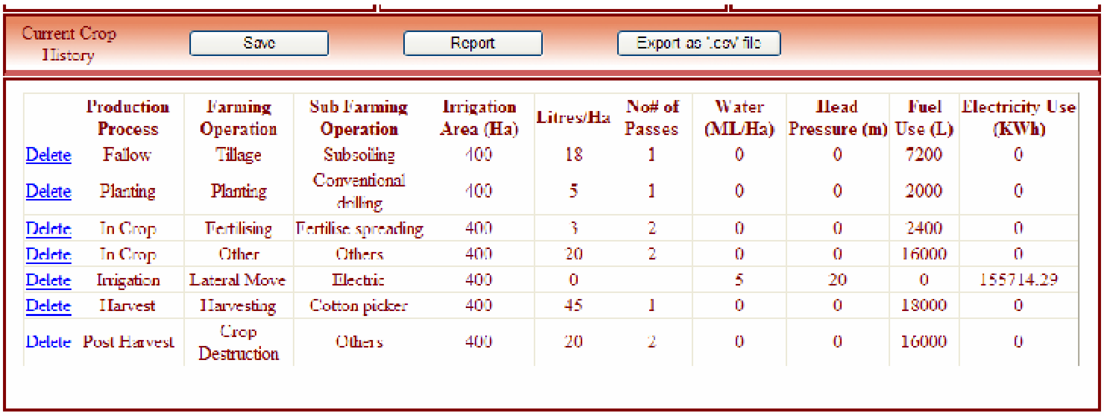


Figure 2 EnergyCalc software flow chart

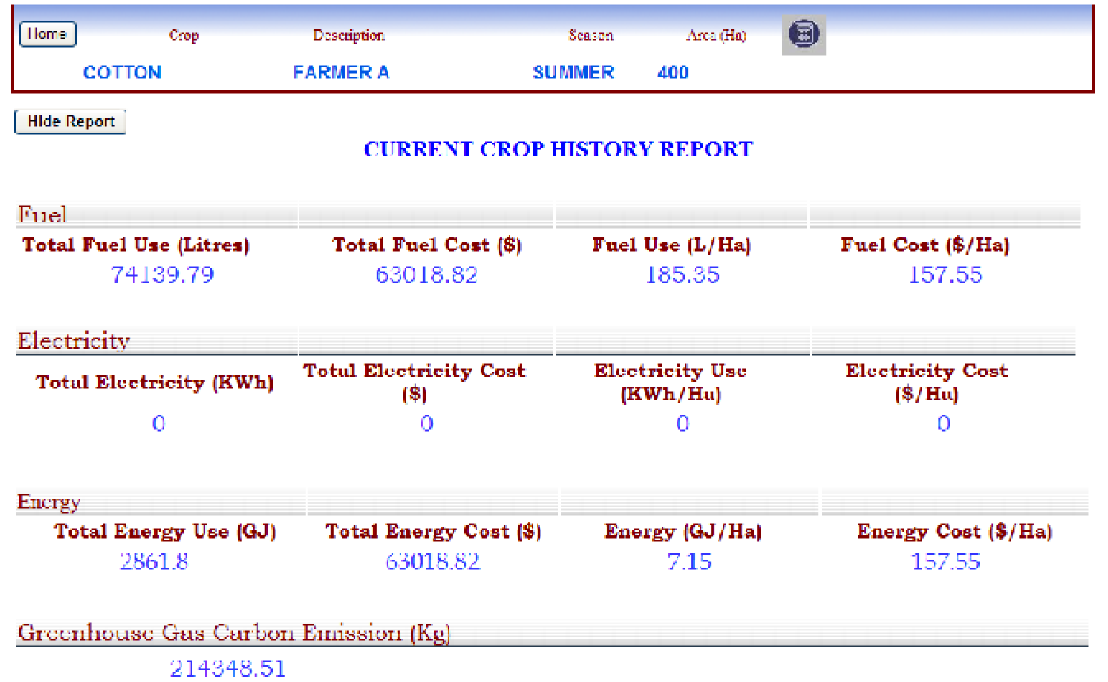
Figure 3 An input page of EnergyCalc



Current Crop History | Save | Report | Export as '.csv' file

	Production Process	Farming Operation	Sub Farming Operation	Irrigation Area (Ha)	Litres/Ha	No# of Passes	Water (ML/Ha)	Head Pressure (m)	Fuel Use (L)	Electricity Use (KWh)
Delete	Fallow	Tillage	Subsoiling	400	18	1	0	0	7200	0
Delete	Planting	Planting	Conventional drilling	400	5	1	0	0	2000	0
Delete	In Crop	Fertilising	Fertilise spreading	400	3	2	0	0	2400	0
Delete	In Crop	Other	Others	400	20	2	0	0	16000	0
Delete	Irrigation	Lateral Move	Electric	400	0		5	20	0	155714.29
Delete	Harvest	Harvesting	Cotton picker	400	45	1	0	0	18000	0
Delete	Post Harvest	Crop Destruction	Others	400	20	2	0	0	16000	0

Figure 4 Saved crop data in EnergyCalc



Home | Crop: COTTON | Description: FARMER A | Season: SUMMER | Area (Ha): 400

Hide Report

CURRENT CROP HISTORY REPORT

Fuel

Total Fuel Use (Litres)	Total Fuel Cost ($)	Fuel Use (L/Ha)	Fuel Cost ($/Ha)
74139.79	63018.82	185.35	157.55

Electricity

Total Electricity (KWh)	Total Electricity Cost ($)	Electricity Use (KWh/Ha)	Electricity Cost ($/Ha)
0	0	0	0

Energy

Total Energy Use (GJ)	Total Energy Cost ($)	Energy (GJ/Ha)	Energy Cost ($/Ha)
2861.8	63018.82	7.15	157.55

Greenhouse Gas Carbon Emission (Kg)

214348.51

Figure 5 Output page of EnergyCalc

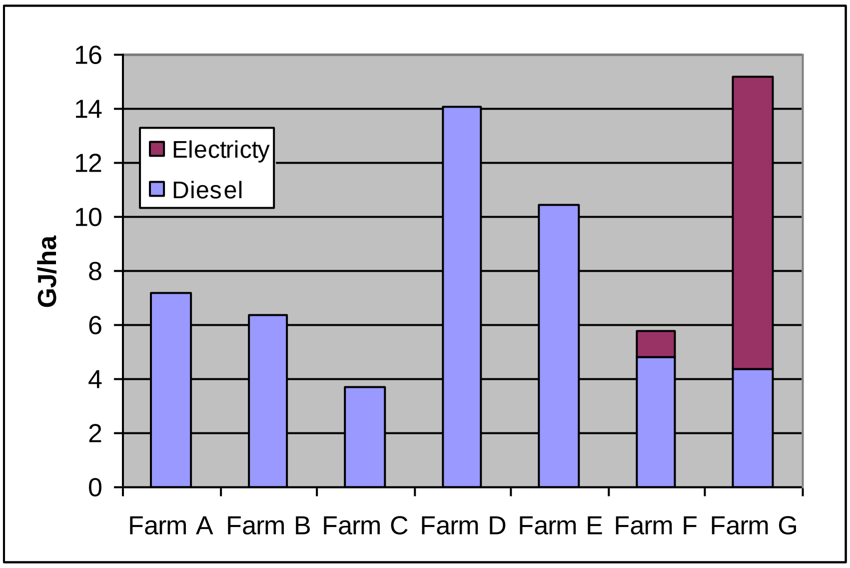


Figure 6 (Primary) energy inputs of the farms (cotton production only)

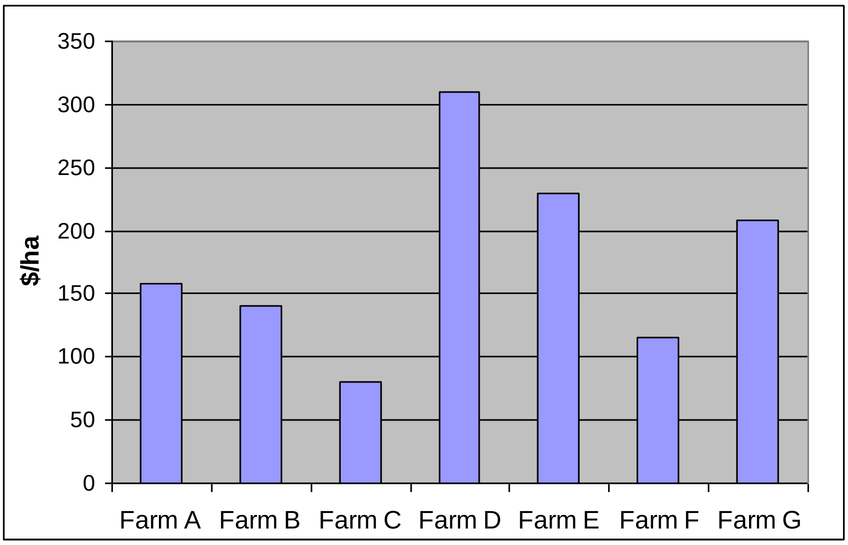


Figure 7 Total direct energy costs of the farms (cotton production only)

Table 1: Calendar of cotton operation in Australia

Month	Farming operations	Farming processes
May	Soil deep ripping	Fallow
June	Hilling (bed forming)	
July	Fertilising and hilling up (bed refining)	
August	Fertilising	
September	Pre-planting spraying and irrigation	Planting
October	Planting	
November	Inter-row cultivation	In-crop operation
December	Inter-row cultivation, Fertilising	
January	Inter-row cultivation	
February	Defoliation	
March	Harvesting	Harvesting
April	Munching	Post-harvesting

Table 2: Average fuel use for 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
Hilling (bed forming)	No data currently available

Table 3: Average fuel use for planting

Planting methods	Average fuel use
Conventional drilling	5 Litre/ha diesel use
Direct drilling	10 Litre/ha diesel use

Table 4: Average fuel use for in crop operations

In-crop operations	Average fuel use
Fertiliser spreading	3 Litre/ha diesel use
Spraying (by aircraft)	0.035 Litre/ha diesel use
Boom spraying (by tractor)	1.5-3 Litre/ha diesel use
Inter-row cultivation	4-6 Litre/ha diesel use
Cotton chippers	0

Table 5: Head pressures for various irrigation systems

Irrigation method	Typical head pressure (meter)
Furrow irrigation	8
Sprinkler spraying	20
Trickle irrigation	35

Table 6: Average fuel use for harvesting operations

Machinery	Average fuel use
Cotton picker	45 Litre/ha diesel use
Cotton stripper	11 Litre/ha diesel use
Module builder	No data currently available
Infield trailers	3 Litre/km
Road cartage	0.08 Litre/km*tonne

Table 7: Average fuel use for post-harvesting operations

Crop destruction action	Average fuel use

Slashing	10 Litre/ha diesel use
Stalk pulling	5 Litre/ha diesel use
Munching	No data currently available

Table 8: CO2 Emission factor for diesel and electricity

Energy sources	Emission Factor kg CO_2 equivalent per litre diesel or per kWh electricity
Diesel	2.89
Electricity	1.051

Table 9 Key farming methods in the different farms (cotton production only)

	Tillage method	Irrigation method	Water Sources
Farm A	Conventional tillage	Diesel pump	Surface water
Farm B	Conventional tillage	Diesel pump	Surface water
Farm C	Minimum tillage	Gravity feed	Surface water
Farm D	Conventional tillage	Diesel pump	Ground water
Farm E	Minimum tillage	Diesel pump	Ground water
Farm F	Conventional tillage	Electric pump	Surface water
Farm G	Minimum tillage	Electric pump	Ground water

Table 10: Percentage of total energy costs for different cotton farming processes

	Fallow	Harvest	In Crop	Irrigation	Planting	Post Harvest
Farm A	15%	24%	8%	40%	4%	9%
Farm B	14%	27%	3%	39%	7%	10%
Farm C	4%	54%	21%	0%	5%	16%
Farm D	7%	14%	4%	70%	1%	3%
Farm E	5%	19%	4%	62%	2%	7%
Farm F	32%	38%	7%	9%	7%	7%
Farm G	12%	21%	4%	51%	4%	8%
All farm average	8%	20%	5%	57%	3%	7%