Deteremination of Energy consumption in Pest Control Using pesticides in New Zealand

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Abstract

This study examines the energy consumption of pesticide applications in New Zealand. Energy use in pest control using pesticides is investigated in the horticultural, arable, pastoral and forestry sectors, based on 30 different groups of farm products.

On average, total energy consumption in pesticide applications in New Zealand was estimated at about 2,350,757 GJ. Energy use in pesticide applications was about 160 MJ/ha. The pastoral and horticultural sectors are ranked first and second in terms of total energy usage for pesticide applications, at about 1,109,389 GJ and 704,511 GJ, respectively. The horticultural sector has the most intensive pesticide consumption at around 5,855 MJ/ha.

The total operational energy was about 20% of total energy use in pest control of which 90% was for fuel. Herbicides are applied more than other pesticides in most agricultural sectors; therefore, energy equivalent of herbicides is ranked first with 1,353,503 GJ and 58% of total energy use. Fungicides and insecticides are mostly used in the horticultural sector.

Keywords: Energy inputs, Farm Operation, Pest Control, New Zealand

Introduction

New Zealand's economy is heavily dependent on exports from agricultural production, accounting for nearly 51% of New Zealand's exports by value (Statistics New Zealand, 2008). Farms cover about 50% of New Zealand's land area (Ministry of the Environment, 2006). In general, New Zealand farmers practice a form of 'industrialized' agriculture that relies on relatively high inputs of fossil fuels, not only to power machinery and irrigation directly but also embedded in artificial fertilizers and agrichemicals from their manufacture (Wells, C., 2001, Safa, M. and Samarasinghe, S., 2011). Consequently, New Zealand is one of the countries with the highest energy input per unit weight of agricultural output in the world (Conforti, P. and Giampietro, M., 1997). In New Zealand, the agricultural sector produces about 4.6% of total GDP, while its proportion of greenhouse gas (GHG) emissions is, surprisingly, over 54% of total national emissions (Kelly, G., 2007, Energy & Environment, 2009).

New Zealand's climate is not extremely cold or hot; therefore, high energy modifications are not widely used in agriculture, such as animal housing or heating. Moreover, 99% of cows and sheep graze directly on pasture and farmers don't need to spend energy on harvesting this land. Pigs and poultry are often intensively housed, but these are relatively small sectors of New Zealand's livestock industries. Other high intensive energy use farming activities, such as greenhouses production, are not very significant.

The relative proportion of different types of production in New Zealand varies with technical and financial factors. Following increases in the prices of dairy products in 2007 and 2008, many farms were converted from arable to dairy production and some existing dairy farmers increased their stocking rates. However, the high exchange rate for the New Zealand dollar and increasing oil prices are also likely to affect farming patterns. In addition, investigation into the effects of economic changes on farm production in the short term is difficult and farmers' reactions to price changes are always slower than those in other sectors. They cannot easily change capital equipment, establish orchard trees, or change crops after sowing, and they cannot convert their farms from dairy to arable use quickly. According to Statistics New Zealand (2007), 12,279,599 ha (82%) of farm land is in pastoral farms used for livestock and dairy production. Forestry ranks second with 13% of land, and horticulture and arable farms have similar proportions at 2% of total land.

Pests destroy an estimated 37% (insects 13%, plant pathogens 12%, and weeds 12%) of all potential agricultural production every year. When the post-harvest losses are added to the pre-harvest losses, total agricultural production losses due to pests increase to 52% (Pimentel, D. and Pimentel, M., 2008). Three different methods of pest control - chemical, mechanical and biological - are usually applied to control or eliminate fungi, insects and weeds on modern farms. On small farms, organic farms, and in areas with cheap labor sources, farmers use more mechanical methods. Other pest controls methods used for specific crops or conditions include insect collectors, thermal weeding and soil disinfectors. However, most farmers choose chemical methods because they are perceived to be faster, cheaper and more effective than non-chemical methods.

The average worldwide growth in the use of agrichemicals is around 4.4% per year (Vlek, P.L.G. et al., 2004). The first recorded chemical use on farms was by the Sumerians who used sulfur compounds as insecticides, around 4500 years ago. However, chemical pest control did not become widespread until the 18th and 19th centuries. In modern farming systems most farmers choose chemical methods because they believe them to be faster, cheaper, and more effective than other pest control methods. Global pesticides use is about 3 billion kg, costing nearly 40 billion US$ per year (Pimentel, D. and Pimentel, M., 2008). Significant challenges to plant protection by chemical pest control methods include pesticide resistance, pest resurgence, new pests and diseases, cost, and environmental and health issues.

In agriculture, a wide range of pesticides are used for a variety of purposes. Pesticides should control weeds, insects and fungi without causing serious harm to the crops (Smil, V., 2008). Their responsibilities are prevention, avoidance, monitoring, and suppression of weeds, insects, diseases and other pests. Pesticide use generally reduces crop losses. However pesticide use creates a number of adverse effects, including human and animal poisoning, cancer and other chronic health effects, reduced biological diversity, and soil and water contamination. These adverse effects should be a balanced against the benefits from pesticides. Some studies show that through appropriate management, it is possible to reduce pesticide use without reducing crop yields (Pimentel, D. and Pimentel, M., 2008).

Nevertheless, the use of pesticides is increasing rapidly in some countries. Pesticides have become a major environmental hazard, the main source of pollution in agriculture (Lal, R., 2004), and a major hazard to health in some countries.

Because of public and scientific concern about the environmental effects of agrichemical use, new components have been introduced into spray programs to reduce pesticide losses from runoff and leaching and reduce pesticide residues in crops. Research is being carried out to introduce new natural methods and to improve traditional methods. Several studies have been undertaken to improve the genetic resistance of crops to pests, encourage pests' biological enemies, employ crop rotation, combinations with conservation tillage and the use of natural forages and trees (CIGR, 1999, Lal, R., 2004, Pimentel, D. and Pimentel, M., 2008). Some government programs in Canada, Sweden, Denmark and Indonesia have reduced pesticide use in some crops by 50% to 65% with minimum impact on yields and quality (Pimentel, D. et al., 2005). There is now also high-level support for the replacement of pesticides with what is increasingly known as agroecological methods that use pesticides only as a last resort when other approaches are not sufficient. For example, the International Code of Conduct on the Distribution and Use of Pesticides (the Code), a global guidance document on pesticide management for all public and private entities associated with the distribution and use of pesticides was adopted by the FAO in 1985, has a guidance document on Pest and Pesticide Management Policy Development (2010) that promotes the adoption of integrated pest management (IPM). Its definition of IPM involves an ecosystem approach to pest management and states that "Pesticides are only used in those cases where there are no effective or economically viable alternatives" (FAO, 2010).

1. Pesticide Consumption in New Zealand

Comparing pesticide consumption in different years is not easy. Because of the wide range of companies and products, and the broad classifications of the later, together with the lack of government collection of usage figures, and the difficulty in obtaining data from the companies, comprehensive and reliable data on the use of agrichemicals in New Zealand was difficult to obtain. Also, every year new, more concentrated products are introduced that can reduce later sales volume without reducing pesticidal activity (Ministry of the Environment, 2006). The value of pesticide products, moreover, depends on several financial factors that make the analyses more difficult. Non-agricultural use is one of the major limitations in estimating usage figures. There are few records available of this kind of use in New Zealand, but it can be substantial. For example, some estimations show the annual use of glyphosate to manage roadside weeds in the Auckland region alone to be about 25,000 liters of formulated product (pers. Comm. Burton, Biothermal, 2012)[1]. There is no information available on home use, but this can also be substantial, especially the use of herbicides.

Agcarm (the agrichemical industry's organization in New Zealand) provides a report from members only, which is estimated to cover about 80% of agrichemical sales (Manktelow, D. et al., 2005). Over the last ten years (2000-2010), according to FAOSTAT, the value of imported agrichemicals in New Zealand has increased by approximately 62%. Between 2000 and 2006 the value of imported herbicides, fungicides and insecticides increased 61%, 50%, and 42%, respectively (Manktelow, D. et al., 2005). Unfortunately, data for these individual categories were not available after 2006. Most herbicides are used in the pastoral and forestry sectors, and the horticulture sector accounts for the largest volume of fungicides and insecticides.

Total pesticide consumption for each farming sector depends on the total land area cropped and the sum of diseases, pests and weeds for a particular farm production system. There is no recent reliable data on the total pesticide consumption in New Zealand. It is estimated that the value of agrichemical sales in New Zealand is around $200 million NZ$ (too difficult to verify) (Ministry of the Environment, 2006). Compared with world standards, the pesticides market in New Zealand is very small, which reduces opportunities for establishing new products because of the high cost of development and registration relative to sales.

Over the last few years new and more effective pesticides have been introduced and the pesticide products being used have been changed considerably. For example, the quantity of biological materials sold has increased and there has been a decrease in the quantities of miticides sold (Manktelow, D. et al., 2005). The fluctuating trends of herbicide, fungicide and insecticide use during the last few years would be mostly because of major changes in the pesticide types used. Because of new pesticides and fluctuating prices of most pesticides (mostly downwards), neither the value nor the quantity are good indicators of pesticide consumption.

The wet maritime climate of New Zealand creates suitable conditions for disease development, which affects fungicide use in New Zealand. As shown in Table 1, based on pesticides loading (Manktelow, D. et al., 2005) and area of agriculture

[1] Biothermal is a roadside weed maintenance contractor in Auckland.

sectors (Statistics New Zealand, 2007), horticulture is the most intensive pesticide using sector, using 49% of total pesticides on about, 1.7% of land, and this must be taken into consideration.

Table 1 Areas and pesticide used in sector group (Manktelow, D. et al., 2005, Statistics New Zealand, 2007)

Sector group	Total New Zealand Area (ha) (2007)	Areas as % of Total	Total Tonnes (a.i/yr)	Mean Pesticide Loading (kg a.i./ha/yr) (2005)	Percentage of Total Use
Horticulture	246,748	1.7%	3,254,606	13.19	49%
Arable	318,416	2.2%	773,751	2.43	12%
Pastoral Farming	12,279,599	84%	2,087,532	0.17	32%
Forestry	1,849,897	13%	499,472	0.27	8%

Manktelow et al (2005) estimated the proportion of herbicide, insecticide and fungicide use in each agricultural sector. Table 2 shows herbicides are applied mostly on pastoral farms and the horticulture sector ranked the highest for insecticide and fungicide consumption at 88.6% and 61.9 %, respectively.

Table.2 The percentage of pesticide use by agricultural sector (Manktelow, D. et al., 2005)

Sector group	Herbicides (%)	Insecticides (%)	Fungicides (%)
Horticulture	13.2	88.6	61.9
Arable	12.3	3.5	3.7
Pastoral Farming	55.5	6.3	34.4
Forestry	19	1.8	0

2. Spraying Systems and Technologies

There are several techniques and technologies for applying pesticides on farms, including aerial spraying, air-blast spraying, boom spraying, in-furrow spraying, soil injection, dust and granular application. It appears the technology of farm spraying has not significantly changed during the last few decades. However, the new large commercial sprayers use GPS guidance to prevent overlap, misses and reduce drift (Kubik, R., 2005, Kondo, N. et al., 2011).

Spraying liquid is more common than dust and granular applications. Sprayed chemicals are mixed with water and broken down into droplets by forcing the liquid under pressure through an orifice, injecting the liquid into a fast moving air stream, or spraying the liquid off the surface of a rapidly rotating disc (Hawker, M.F.J. and Keenlyside, J.F., 1985, Culpin, C., 1986). Tank, pump, filter, spraybar (boom), nozzles and mixing devices are the most important parts of liquid sprayers. Selecting appropriate spraying size, selecting right tractor speed, spraying pressure, nozzle size, and spraying boom height can increase the efficiency of pesticide use (Bell, B.J. and Cousins, S., 1991, CIGR, 1999, Hunt, D., 2001, Bell, B.J., 2005, Kubik, R., 2005). Furthermore, the shape and size of paddocks, barriers in borders, environmental condition, availability of clean water and fuel, and driving skill can influence field efficiency by sprayers.

Spraying techniques and technologies can be categorized based on pesticides properties, injection system, amount of liquid applied per hectare, power sources, targeted pests and targeted species. In this study, to analyze energy use in pesticide application, the applications are categorized into ground and aerial spraying.

3. Main Energy Inputs in Spraying

Studies by McChesney et al. (1982), Nguyen and Hignett (1995), Wells (2001), Barber (2004), Barber and Glenys (2005) and Saunders et al. (2006)have estimated energy consumption in different farming systems and farm productions.,. Most of these studies are interesting and provide useful information; however, agriculture is a complex system and it is not easy to estimate the average energy use for the whole country from a limited number of farms. Many energy studies in New Zealand use a small number of farms or do not mention the sample size. Also, some of them do not indicate the location of the farms on which they estimated energy use. Moreover, most studies only estimated energy consumption in a particular agricultural system while some compared energy use of different methods and in different countries.

Due to different farming systems, spraying techniques and agricultural products, it is very difficult to have definite energy consumption figures for pesticide applications. Main energy inputs in pesticide applications include fuel, labor, machinery and pesticides. Farmers use knapsacks (which do not consume significant amounts of fuel and machinery energy) in many greenhouses and small nurseries, but the labor costs per hectare for knapsacks are much higher than for boom sprayers. Many factors, such as environmental and soil conditions, driving skill, shape and size of paddocks also affect energy use in pesticide applications.

In terms of energy, using pesticides is much more energy intensive than mechanical pest control methods. For example, in organic farms, energy used for weed control using cultivators takes half the energy used for herbicide weed control (Pimentel, D., 2009). The energy component in agrichemicals comes mainly from its manufacture, packaging and transport (Stout, B.A., 1990, CIGR, 1999). Fuel consumption and machinery use depend on the number of applications, farm production and farming system. The number of applications would be increased in high pest or disease pressure situations. Due to large potential variations in the number of applications, finding actual use patterns is extremely difficult. For example, in the pastoral and forestry sectors, only some farms are usually sprayed and it varies with area and farming system.

3.1 Fuel

Fuel consumption in specific operations depends on soil conditions, crop type, ground speed and rolling resistance (Smil, V., 1991). Also, fuel consumption in spraying depends on the tractor, sprayer, shape and size of farm, and driver skill. The energy component in fuel comes mainly from the heat of combustion; furthermore, the energy required to drill, transport and refine the petroleum should be added to this figure (Stout, B.A., 1990).

There are several methods to estimate the fuel consumption of tractors based on the power of the tractors; nevertheless, due to the effect of parameters such as altitude above sea level, soil conditions (soil type, moisture, density and residue cover), barometric pressure, humidity and temperature on tractor power and fuel consumption, most of these methods work only in specific areas (McLaughlin, N.B. et al., 2002, Serrano, J.M. et al., 2007, Bertocco, M. et al., 2008, Safa, M. et al., 2010). Furthermore, these methods can only predict fuel usage of diesel engines under full loads, but under partial loads and conditions when engine speeds are decreased from full throttle these methods do not work (Siemens, J. and Bowers, W., 1999, Safa, M. et al., 2010).

For an accurate estimation, fuel consumption is measured before and after any farm operation by filling the fuel tank of the equipment (tractor, combine, or pump) and recording the difference in volume. After sampling several different farms and conditions, a formula was arrived at using mathematical modelling methods (Safa, M. and Tabatabaeefar, A., 2002). The energy input is determined from fuel consumption per operation for one hectare times the fuel equivalent energy per litre, as shown in Equation 4-1.

$$\text{Energy (input)/hectare} = \text{Operation fuel consumption (L/ha)} \times \text{Fuel energy (MJ/L)} \qquad (4\text{-}1)$$

The formula for fuel consumption depends significantly on field efficiency of farm machinery. The efficiency of tractors and self-propelled sprayers is analyzed with respect to engine, power transmission and wheel soil system (Pellizzi, G. et al., 1988, Serrano, J.M. et al., 2007, Safa, M. et al., 2010). Matching of tractor and implement, using hydraulic 3-point linkage equipment, using Power-Take-Off (PTO) equipment, selecting the right travel pattern, having large paddocks, regular servicing, adjusting tyre inflation pressure, matching engine speed and gear selection, improving traction efficiency, using turbochargers and improving farmers' awareness, are all methods that could reduce fuel usage and improve field efficiency (Barber, A., 2004, Grisso, R.D. et al., 2004, Safa, M. et al., 2010) and can reduce fuel consumption around 10% in crop production (Pimentel, D., 2009).

Diesel is the main fuel for tractors and other agricultural machinery because diesel engines are stronger, and have a higher efficiency and longer life than gasoline-powered engines (Safa, M. et al., 2010). McChesney (1981) estimated diesel consumption for spraying at approximately 3 l/ha in New Zealand. However, because of developing technology and the use of more efficient machines and methods, the current rate is much lower than his estimation. There are large differences between different estimations of diesel consumption in ground spraying: Witney (1988): 1 L/ha, Dalgaard (2001): 1.2 L/ha, CIGR (1999) 1.5 L/ha to 3 L/ha, and Wells (2001): 3 L/ha.

Estimations of fuel consumption for aerial spraying range from 0.035 L/ha in New Zealand (Barber, A., 2004) to 1.85 L/ha in southern Queensland, Australia (Ghareei Khabbaz, B., 2010). Comparing catalogs of helicopters and aircraft and data collection from contractors shows that fuel consumption for most aircraft and helicopters ranges from 58 L/h to 200 L/h, which means that due to high field capacity, fuel consumption per hectare is much lower and per hour is much higher than ground applications.

According to Saunders et al. (2006), an extra 23% of energy consumption beyond the energy contents of diesel fuel and gasoline consumed accounts for processing, refining, and transport of crude oil and final products to, and within, New Zealand. Thus the total energy consumption for diesel and gasoline were taken to be 43.6 MJ/ha and 39.9 MJ/ha, respectively.

3.2 Tractors and Field Machines

Most commercial energy in agriculture is used in agricultural machinery manufacture and operation (Stout, B.A., 1990). This energy can be categorized into energy required for manufacturing, maintenance and repair (Fluck, R.C. and Baird, C.D., 1980). Estimating the energy consumption of field machinery is much more complicated than determining energy consumption of other farm inputs (Smil, V., 2008) because of the wide range of different tractors and sprayers and also different companies use different processes for producing machinery.

To compare energy use for producing and repairing tractors and equipment, energy use per kg has usually been used. Due to different technologies and different components, weight is not a good estimation index to compare energy consumption in producing machinery. There are large differences between different estimations: 75 MJ/kg (Roller, W.L. et al., 1975), 90 MJ/kg (McChesney, I.G. et al., 1978), 80.23 MJ/kg (Hornacek, M., 1979), 27 MJ/kg (Fluck, R.C. and Baird, C.D., 1980), 85 MJ/kg (Stout, B.A., 1990), 129 MJ/kg for sprayers and 138 MJ/ha for tractors (CIGR, 1999), 132 MJ/kg for sprayers and 144 MJ/ha for tractors (Lague, C. and Khelifi, M., 2001), and 80 MJ/kg for sprayers and 160 MJ/kg for tractors (Wells, C., 2001). Comparing the above rates, it appears that improving technology does not change the energy consumption for producing agricultural machinery. CIGR (1999) considered several steps in calculating these energy coefficients: first, the energy required for producing the raw materials; second, the energy used in the manufacturing process; third, the energy consumption for transporting the machine to the consumer; and fourth, the energy used in repairs and maintenance.

To calculate the energy input of tractors and other field equipment, it was necessary to know the weight, working life span, and the average surface area on which they were used annually (Safa, M. et al., 2011). The estimated life can be taken from the ASAE Standard D497.6 (2009) and the estimated weight of different machines and equipment can be taken from companies' catalogues.

To calculate the energy used in producing and repairing agricultural machinery, the following formula was used:

$$ME = (G \times E)/ (T \times Ca) \qquad (4\text{-}2)$$

where ME is machine energy (MJ/ha); G is the weight of the implement (kg); E is the energy sequestered in agricultural machinery (MJ/kg); T is the economic life of the machine (h) and; Ca was effective field capacity (ha/h).

For calculation of Ca, the following equation was used:

$$Ca = (s \times w) \times FE / 10 \qquad (4\text{-}3)$$

where *s* is ground speed (km/h); *w* is the width of the machine (m) and; FE is field efficiency (%), which was taken from the ASAE Standard D497.6 (2009).

3.3 Labor

Before the invention of the tractor, hand and draught domestic animals were the only choices for power generation needed for agricultural operations. Even now, human power is the main source (73%) of energy in agricultural operations in many developing countries (Stout, B.A., 1990). In the future, human labor on fully mechanized (mechatronic) farms could be reduced to almost nil. Nevertheless, some scientists believe that organic agriculture, one of the important choices for future farming, needs more manual work for harvesting and weeding (WCED, 1987, Pimentel, D. et al., 2005, Wallgren, C. and Höjer, M., 2009) and, in some crops, this could be up to 35% (WCED, 1987, Pimentel, D. et al., 2005, Wallgren, C. and Höjer, M., 2009).

Human energy is used less than other energy inputs in modern agriculture (sometimes less than 1% of all energy inputs) so it has not been calculated in many recent agricultural energy studies. The energy output for a male worker is 1.96 MJ/hr and 0.98 MJ/hr for a female worker (Singh, S. and Mittal, J., 1992, Mani, I. et al., 2007). Most physical activities in pesticide application involved driving, adjusting, and servicing tractors and sprayers, which consumed significantly less energy than physical weed control. However, estimating human energy use in operations such as tractor servicing is difficult as this also contributes to other farm products. Farmers clearly expended different amounts of energy per hour for each operation and several factors, such as gender, weight and age can influence their energy use.

3.4 Pesticides

Pesticides are the most energy intensive of all farm inputs (Stout, B.A., 1990). Most ingredients used in pesticide production come from petrochemical products such as ethylene, methane and propylene (Safa, M. et al., 2011). Energy used in formulation, packaging and transport, as well as manufacturing active ingredients, inert ingredients and adjuvants should be considered as a part of pesticide energy equivalents.

Studies such as Helsel (1992) and CIGR (1999) estimated energy use of some pesticides, but these studies did not cover all products, especially new ones. Pesticide products vary between brands and, because of patent and commercial issues, it is impossible to access the details of active ingredients, inert ingredients, and manufacturing processes. Exact documented energy consumption in manufacturing is not available and would be very difficult to estimate, especially for newer pesticides which are introduced continuously and labelled for use at very low rates. In this study, the energy coefficients for herbicides, insecticides and fungicides were taken from Saunders et al.'s (2006) report and these were 310, 315, and 210 MJ/kg, respectively.

4. Results

Herbicides are the main pesticide energy use with 1,353,502 GJ. As shown in Table 3 and Figure 1, the intensive use of pesticides in the horticultural sector affects energy consumption as well. However, pastoral farming, because of the size and high herbicide use, has the highest proportion of total pesticide use.

The high energy intensity in the horticulture sector was expected; it is four times more than the arable sector and around 35 times more than pastoral farming per hectare. The average energy use per hectare of all pesticides was estimated at around 128 MJ/ha, which is around five times more than operational energy.

The total energy use for pesticide applications in New Zealand was estimated at around 2,350,757 GJ. As expected, pastoral farming has the highest proportion of total energy use for pesticide applications, with 1,109,389 GJ, due to the large area; and the horticultural sector ranked second due to intensive pesticide applications, with 704,511 GJ (Table 3). As Table 3 shows, horticultural and arable farming have the most intensive energy use per hectare with 2,855 and 792 MJ/ha, respectively. Average total energy use per hectare was estimated to be 160 MJ/ha. Table 3 shows that operational energy in arable and pastoral farming is higher than other sectors, at 27% and 25%, respectively. The percentage of operational energy to total energy in orchard and vegetable production is higher than for other groups but is very low in nurseries and greenhouses, which are estimated to be around 16% of the horticultural sector. The percentage of operational energy, mostly from aerial applications, of total energy use in forestry sector was estimated at only 2.5%.

As shown in Table 3, energy use in each farming sector depends on pesticide use, the area of that sector, type of pesticide application and spraying frequency. For example, fungicides and most herbicides are applied by aerial application in only some forests; therefore, the proportion of insecticide and operational applications per hectare are lower than in other sectors. Another example is the high usage of fungicides in vegetable farms, nurseries and orchards in humid areas of the North Island.

Table. 3 Total energy use (GJ) and energy use per hectare of pesticides and operational energy inputs in New Zealand

	Herbicides	Insecticides	Fungicides	Operational Energy	Total Energy (%)	Energy use per hectare (MJ/ha)
Horticulture	178662	128990	282138	114721	704511 (30%)	2855
Arable	166481	7710	11183	66946	252320 (11%)	792
Pastoral	751194	71684	5751	280759	1109389(47%)	90
Forestry	257166	0	20130	7241	284537(12%)	154
Total (%)	1353503(58%)	208384(9%)	319202(14%)	469667(20%)	2350757	160

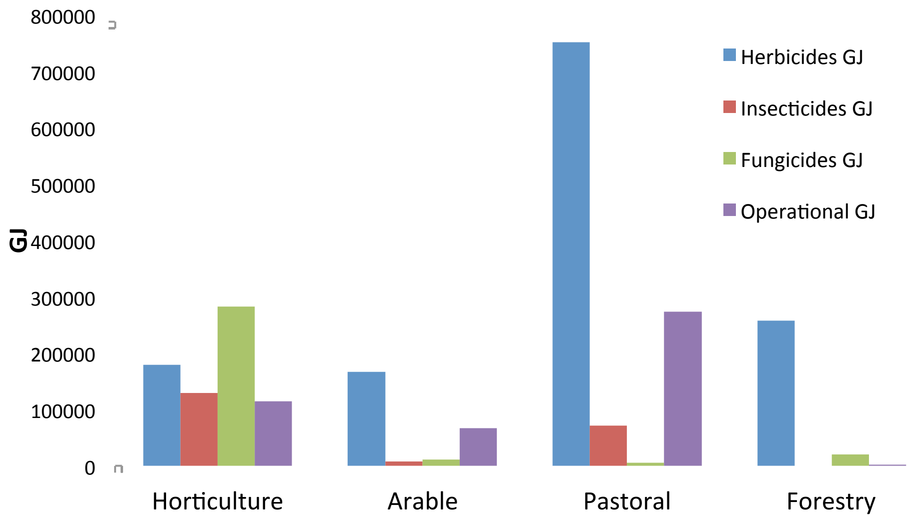

Figure. 1 Energy use (GJ) of farm inputs in agriculture sectors in New Zealand

References

ASAE (2009). ASAE D497.6, June 2009, Agricultural Machinery Managment Data. In (ed.), Vol. pp. St. Joseph, Mich.: American Society of Agricultural and Biological Engineers (ASAE),
Barber, A. (2004). Seven Case Study Farms: Total Energy & Carbon Indicators for New Zealand Arable & Outdoor Vegetable Production. In (ed.), Vol. pp. AgriLINK New Zealand Ltd,
Barber, A., Glenys, P. (2005). Energy Use and Efficiency Measures For the New Zealand Arable and Outdoor Vegetable Industry. In (ed.), Vol. pp. Climate Change Office and Energy Efficiency and Conservation Authority, Auckland.
Bell, B.J. (2005). *Farm machinery*. 5th (ed.), Old Pond Publishing, Ipswich [England].
Bell, B.J., Cousins, S. (1991). *Machinery for horticulture*. Farming Press Books, Ipswich, U.K.
Bertocco, M., Basso, B., Sartori, L., Martin, E.C. (2008). Evaluating energy efficiency of site-specific tillage in maize in NE Italy. *Bioresource Technology,* 99(15):6957-65.
CIGR (1999). *CIGR Handbook of Agricultural Engineering. International Commission of Agricultural Engineering*. American Society of Agricultural Engineers, St. Joseph, MI.
Conforti, P., Giampietro, M. (1997). Fossil energy use in agriculture: an international comparison. *Agriculture, Ecosystems & Environment,* 65(3):231-43.
Culpin, C. (1986). *Farm machinery*. 11th (ed.), Collins, London.
Dalgaard, T., Halberg, N., Porter, J.R. (2001). A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. *Agriculture,Ecosystems & Environment,* 87(1):51-65.
Energy & Environment (2009). New Zealand energy & environment business week. In (ed.), Vol. 6, pp. 1, Media Information, Christchurch, N.Z.
FAO (2010). International Code of Conduct on the Distribution and Use of Pesticides, Guidance on Pest and Pesticide Management Policy Development. In (ed.), Vol. pp. Food and Agriculture Organization of the United Nations,
Fluck, R.C., Baird, C.D. (1980). *Agricultural energetics*. AVI Pub. Co., Westport, Conn.
Ghareei Khabbaz, B. (2010). LIFE CYCLE ENERGY USE AND GREENHOUSE GAS EMISSIONS OF AUSTRALIAN COTTON: IMPACT OF FARMING SYSTEMS[Thesis]. Type, UNIVERSITY OF SOUTHERN QUEENSLAND, Toowoomba.
Grisso, R.D., Kocher, M.F., Vaughan, D.H. (2004). Predicting tractor fuel consumption. *Applied Engineering in Agriculture,* 20(5):553-61.
Hawker, M.F.J., Keenlyside, J.F. (1985). *Horticultural machinery*. 3rd (ed.), Longman, London ; New York.
Helsel, Z.R. (1992). *Energy and alternatives for fertilizer and pesticide use*.
Hornacek, M. (1979). Energetic analysis of 14 agricultural practices. *Etude du Centre National d'Etude et d'Expérimentation de Machinisme Agricole, France,* 457
Hunt, D. (2001). *Farm power and machinery management*. 10th (ed.), Iowa State University Press, Ames.
Kelly, G. (2007). Renewable energy strategies in England, Australia and New Zealand. *Geoforum,* 38(2):326-38.
Kondo, N., Monta, M., Noguchi, N. (2011). *Agricultural robots : mechanisms and practice*. English (ed.), Kyoto University Press & Trans Pacific Press, Sakyo-ku, Kyoto & Melbourne, Vic., Australia.
Kubik, R. (2005). *How to use implements on your small-scale farm*. Motorbooks, St. Paul, MN.
Lague, C., Khelifi, M. (2001). Energy use and time requirements for different weeding strategies in grain corn. *Canadian Biosystems Engineering,* 43
Lal, R. (2004). Carbon emission from farm operations. *Environment International,* 30(7):981-90.
Mani, I., Kumar, P., Panwara , S.G., Kanta, K. (2007). Variation in energy consumption in production of wheat–maize with varying altitudes in hilly regions of Himachal Pradesh, India *energy,* 32(12):2336-9.
Manktelow, D., Stevens, P., Zabkiewicz, J., Walker, J., Gurnsey, S., Park, N. et al. (2005). Trends in Pesticide Use in New Zealand: 2004. In (ed.), Vol. pp. Ministry for the Environment, Auckland, New Zealand.
McChesney, I.G. (1981). Field Fuel Consumption of Tractors. In *Internal Report 3, Joint Centre for Environmental Sciences, Lincoln College*. (ed.), Vol. pp. University ofCanterbury,
McChesney, I.G., Pearson, R.G., Bubb, J.W., Joint Centre for Environmental Sciences (N.Z.) (1978). *Energy use on Canterbury mixed cropping farms : a pilot survey*. Joint Centre for Environmental Sciences, Lincoln College.
McChesney, I.G., Sharp, B.H.M., Hayward, J.A. (1982). Energy in New Zealand Agriculture: Current Use and Future Trends. *Energy in Agriculture,* 1:141-53.

McLaughlin, N.B., Gregorich, E.G., Dwyer, L.M., Ma, B.L. (2002). Effect of organic and inorganic soil nitrogen amendments on mouldboard plow draft. *Soil and Tillage Research,* 64(3-4):211-9.
Ministry of the Environment (2006). Study of the New Zealand Product Stewardship Scheme for Agrichemical Containers. In (ed.), Vol. pp. Ministry of the Environment, Wellington.
Nguyen, M.L., Hignett, T.P. (1995). Energy and labour efficiency for three pairs of conventional and alternative mixed cropping (pasture-arable) farms in Canterbury, New Zealand. *Agriculture, Ecosystems and Environment,* 52:163-72.
Pellizzi, G., Guidobono Cavalchini, A., Lazzari, M., Commission of the European Communities. (1988). *Energy savings in agricultural machinery and mechanization*. Elsevier Applied Science, London ; New York.
Pimentel, D. (2009). Reducing Energy Inputs in the Agricultural Production System. *Monthly Review,* 61(3):92.
Pimentel, D., Hepperly, P., Seidel, R., Hanson, J., Douds, D. (2005). Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems. *Bioscience,* 55(7):573.
Pimentel, D., Pimentel, M. (2008). *Food, energy, and society*. 3rd (ed.), CRC Press, Boca Raton, FL.
Roller, W.L., Keener, H.M., Kline, R.D., Mederski, H.J., Curry, R.B. (1975). Grown organic matter as a fuel raw material resource. In *Report No NASA CR-2608* (ed.), Vol. pp. Ohio Agricultural Research and Development Center, Wooster.
Safa, M., Samarasinghe, S. (2011). Determination and modelling of energy consumption in wheat production using neural networks: "A case study in Canterbury province, New Zealand". *Energy,* 36(8):5140-7.
Safa, M., Samarasinghe, S., Mohssen, M. (2010). Determination of fuel consumption and indirect factors affecting it in wheat production in Canterbury, New Zealand. *Energy,* 35(12):5400-5.
Safa, M., Samarasinghe, S., Mohssen, M. (2011). A field study of energy consumption in wheat production in Canterbury, New Zealand. *Energy Conversion and Management,* 52(7):2526-32.
Safa, M., Tabatabaeefar, A. (2002). Energy Consumption in Wheat Production, IACE 2002,Wuxi, China. In *IACE 2002*. (ed.), Vol. pp. Wuxi, China.
Saunders, C., Barber, A., Taylor, G. (2006). *Food miles : comparative energy/emissions performance of New Zealand's agriculture industry*. Agribusiness & Economics Research Unit, Lincoln University, [Lincoln] N.Z.
Serrano, J.M., Peça, J.O., Marques da Silva, J., Pinheiro, A., Carvalho, M. (2007). Tractor energy requirements in disc harrow systems. *Biosystems Engineering,* 98(3):286-96.
Siemens, J., Bowers, W. (1999). Machinery management: how to select machinery to fit the real needs of farm managers. In *Farm Business Management (FMB) series*. (ed.), Vol. pp. John Deere Publishing, East Moline, IL.
Singh, S., Mittal, J. (1992). *Energy in Production Agriculture*. Mittal Publishing Company, Mittal Publishing Company.
Smil, V. (2008). *Energy in nature and society : general energetics of complex systems*. The MIT Press, Cambridge, Mass.
Smil, V. (1991). *General energetics : energy in the biosphere and civilization*. Wiley, New York.
Statistics New Zealand (2007). Agricultural Areas in Hectares by Farm Type (ANZSIC06). In (ed.), Vol. pp. Statistics New Zealand,
Statistics New Zealand (2008). Agricultural Production Statistics (Final): June 2007. In (ed.), Vol. pp. Statistics New Zealand, Wellington.
Stout, B.A. (1990). *Handbook of energy for world agriculture*. Elsevier Science Pub. Co., London; New York.
Vlek, P.L.G., Rodríguez-Kuhl, G., Sommer, R. (2004). Energy Use and CO2 Production in Tropical Agriculture and Means and Strategies for Reduction or Mitigation *Environment, Development and Sustainability,* 6
Wallgren, C., Höjer, M. (2009). Eating energy--Identifying possibilities for reduced energy use in the future food supply system. *Energy Policy,* 37(12):5803-13.
WCED (1987). Our Common Future. In *Oxford University Press, Oxford (1987)*. (ed.), Vol. pp. World Commission on Environment and Development,
Wells, C. (2001). Total energy indicators of agricultural sustainability : dairy farming case study. In (ed.), Vol. pp. vii, 81 p., Ministry of Agriculture and Forestry, Wellington [N.Z.].
Witney, B. (1988). *Choosing and using farm machines*. Longman Scientific & Technical ; Wiley, Harlow, Essex, England, New York.

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