Determination and Modelling of Energy Consumption in Wheat Production Using Neural Networks

"A Case study in Canterbury Province, New Zealand"

A thesis

submitted in partial fulfilment of

the requirements for the Degree of

Doctor of Philosophy

in

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at

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by
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Lincoln University

2011

To Maryam

and

To those affected by the life changing earthquake of Tuesday 22nd February

Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy

Determination and Modelling of Energy Consumption in Wheat Production using Neural Networks

"A Case Study in Canterbury Province, New Zealand"

By

M. Safa

New Zealand farmers practice a form of 'industrialised' agriculture that relies on relatively high inputs of fossil fuels, not only to power machinery directly but also for manufacturing artificial fertilizers and agrichemicals (Wells, 2001). Consequently, New Zealand is one of the countries with the highest energy input per unit weight (in agriculture) in the world (Conforti & Giampietro, 1997). Furthermore, in terms of shipping, the influence of increasing global fuel costs is greater on New Zealand farming than in other countries. The main aim of this study was to estimate energy consumption in wheat production. Energy determination can give a clear picture of farms in order to compare different farming systems and energy inputs. The second main target of this study was to develop a neural network model to simulate and predict energy use in wheat production under different conditions incorporating social, geographical, and technical factors. Additionally, the interaction effects between different factors were examined in this study.

This study was conducted on irrigated and dryland wheat fields in Canterbury, New Zealand, in the 2007-2008 harvest year. Canterbury represents 87% of the wheat area and 66% of the arable area harvested in New Zealand.

Energy consumption here is defined as the energy used for the production of wheat until it leaves the farm. The data were collected from three different sources: questionnaire, literature review, and field measurements. The energy inputs estimated in this study are those that go into on-farm production systems before the post-harvest processes. The study considered only the energy used in wheat production, without taking into account the natural sources of energy (radiation, wind, rain, etc).

A survey was conducted to collect the most important data and to identify farmers' attitudes and opinions about energy consumption. In this study, 40 arable farms were selected randomly, as far as possible. From the initial analysis, it was found that 30 farms were irrigated and the rest were dryland farms. Irrigated farms were irrigated between one to ten times annually depending on the rainfall. Some irrigated farms have also been converted to dryland farms, or vice versa, in different years. The data for a large number of farming factors were gathered in the survey.

Average energy consumption for wheat production was estimated at around 22,600 MJ/ha. On average, fertilizer and electricity (mostly for irrigation) were used more than other energy sources, at around 10,654 MJ/ha (47%) and 4,870 MJ/ha (22%), respectively. The average energy consumption for wheat production in irrigated farming systems and dryland farming systems was estimated at 25,600 and 17,458 MJ/ha, respectively.

This study is the first to create an appropriate Artificial Neural Network (ANN) model to predict energy consumption in wheat production with optimum variables. This study would be the first to investigate the factors related to the efficient use of energy in agricultural production. A careful study of all factors was first made to find trends and correlations and their relationship to energy consumption. A two step approach to input reduction involving correlation and Principal Component Analysis (PCA) revealed five highly relevant inputs for predicting energy consumption. After testing different learning algorithms, neuron activation functions and network structures using genetic algorithm optimization, a modular network with two hidden layers was developed using Quick Prop learning method.

The final model can predict energy consumption based on farm conditions (size of crop area), farmers' social considerations (level of education), and energy inputs (amount of N and P used and irrigation frequency). It predicts energy use in Canterbury arable farms with an error margin of ± 2972 MJ/ha (12%) and this size of an error in agricultural studies with several uncontrolled factors and as an initial investigation is acceptable. Furthermore, comparisons between the ANN model and a Multiple Linear Regression (MLR) model showed that the ANN model can predict energy consumption better than the MLR model. As part of conclusions, this thesis

provides extensive suggestions for future research and recommendations for reducing energy consumption in wheat production with minimum income loss.

***Keywords**:* Energy, Fuel Consumption, Agricultural Operation, Wheat Production, Artificial Neural Networks, Canterbury, New Zealand

Acknowledgments

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Publications arising

Journal Articles

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M. Safa, S. Samarasinghe, S, Determination and Modelling of Energy Consumption in Wheat Production Using Neural Networks, Journal of Energy (Published)

Conference Proceeding

M. Safa, S. Samarasinghe, Modelling Energy Use in Wheat Production using Neural Networks, ICESE'10 (International Conference on Environmental Science and Engineering), Singapore, 25-27 August 2010

M. Safa, S. Samarasinghe, Energy use pattern in wheat production in Canterbury, 6th Annual Energy Post Graduate Conference, Massey University, Palmerston North, New Zealand, 26 - 27 Nov 2009

M. Safa, S. Samarasinghe, M. Mohssen, Modeling Fuel Consumption in Wheat Production Using Neural Networks, 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009

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Abbreviations

ANN	Artificial Neural Networks
ASABE	American Society of Agricultural and Biological Engineers
ASAE	American Society of Agricultural Engineers
bbls/d	Barrels per day
BP	Back propagation
cal	Calorie
EECA	Energy Efficiency and Conservation Authority
EIA	U.S. Energy Information Administration
FAO	Food and Agricultural Organization
FAR	Foundation for Arable Research
GHG	Greenhouse Gas
IFIAS	International Federation of Institutes for Advanced Study
IPCC	Intergovernmental Panel on Climate Change
h	Hour
ha	Hectare
hp	horsepower
J	Joule
K	Potassium
L	Litre
MED	Ministry of Economic Development
MJ	Mega Joule
MLP	Multi-Layer Perception
MSE	Mean square error
Mt	Million tonnes
MTOE	Million tonnes oil equivalent = 41.9 PJ
N	Nitrogen
NAS	National Academy of Sciences
NN	Neural Networks
NZEECS	New Zealand Energy Efficiency and Conservation Strategy
P	Phosphorus

PCA	Principle Component Analysis
PJ	Peta (10^{15}) Joule
PTO	Power Take Off
SSSA	Soil Science Society of America
UNESCO	United Nations Education Scientific and Cultural Organization
USDA	United States Department of Agriculture
W	Watt
WCED	World Commission on Environment and Development

Chapter 1

Introduction

The age-old necessities of life are food, clothing, and shelter. The 20th century has introduced a fourth: energy (Kitani, 1999; Pimentel & Pimentel, 2008). Humankind has come a long way from using its own energy, and the natural energy from sunlight, to using various modern energy sources, such as nuclear energy. “Nobel Laureate Richard Smalley characterizes the world’s quest for sustainability to ten prioritized problems: energy, water, food, environment, poverty, terrorism, disease, education, democracy, and population. Smalley argued that energy tops the list; because abundant, available, affordable, efficient, clean, and secure energy would enable the resolution of all the other problems” (Randolph & Masters, 2008). Even the economy, national security, and quality of life are strongly dependent on accessibility to energy from fossil fuel (Pimentel et al., 2007; Tester, 2005).

One of the most important goals of people throughout history has been to handle and control energy in all its forms. Humans have expended energy to control diseases; to store water; to produce goods; to transport goods; to produce food; and to perform all human activities. Energy starvation (the gap between demand and supply of energy) of the technologically complex system which maintains modern society may soon lead to a crucial problem in feeding the world’s hungry. Indeed, energy starvation could well precipitate more widespread food starvation, especially in developed countries (Singh & Mittal, 1992). Most global, political and economic problems today are related to energy resources. Some estimations show, fossil energy sources have decreased significantly and they will very likely be exhausted by the end of this century. It seems that the oil production has peaked and it has reserves for only sixty to seventy more years (Pimentel, 2009). Also, if the oil is replaced by coal, the world has only about 50-100 years of coal left to burn (Pimentel et al., 2007). However, it is very difficult to know exactly how large the oil reserves are as much previous estimation have failed. Moreover, new advanced exploration and extraction technologies have greatly improved our abilities to explore the subsoil and measure the amount of fossil fuel that we can collect from it (Maugeri, 2010).

Introduction

The current situation of increasing oil prices and decreasing energy availability gives rise to several challenges for all countries, especially, those that depend mainly on fossil energy sources. Therefore, developed nations have started to reduce their fossil fuel demands. For example, in the latter part of the twentieth century, energy consumption was reduced by 1.3-4.9% in developed industrial countries (Singh & Mittal, 1992). Also, European Union has decided to reduce its energy consumption by 20% by 2020 (Pimentel et al., 2007).

Energy and environment are two sides of the same coin; increasing energy consumption anywhere will be accompanied by increased negative effects on the environment. It is accepted that air pollution, acid rain, and, especially, global climate change have been mostly caused by greenhouse gas emissions from fossil fuel combustion. In addition, use of some renewable energy sources is expensive and, as well as having technological limitations, may cause environmental impacts (Boyle, 2004). Furthermore, with an increasing world population and rising living standards, the demand for energy throughout the world has steadily increased.

Finding a solution to the energy crisis is strongly dependent on the technology used for harnessing that energy. To make any physical change in nature, it is necessary to consider four resources: energy, matter, space and time. It is important to use a sufficient amount of energy in the right form at the right time. How well a task has been performed can be measured in terms of the amount of fuel consumed, the mass of material used, the space occupied, the hours of labour needed to accomplish the work, and the ingenuity with which these resources were utilized. Waste of limited energy sources, squandering of materials, or large expenditures of space and time cannot be tolerated if the necessities of life were to be provided for all; it should be noticed that some of the necessities of life are very desirable luxuries (Singh & Mittal, 1992). Technology addresses the efficient utilization of these four ingredients of physical changes. The era of conscious energy conservation, in the short-term, began due to the rising cost of energy. In the long term, the potential dire consequences of placing additional stresses on our biosphere, which is already showing serious signs of strain, require that energy conservation plans be economically viable.

Increases in oil and energy prices during the 1970s and 1980s, and in recent years, have increased worldwide interest in new technologies and strategies to create more efficient systems in different sectors, such as industry, transport, and agriculture. From the beginning, agricultural engineers were concerned with efficiency in the application of energy in agriculture. While energy efficiency was not always an explicit goal, it was often a major driving force as improved machinery, power units, water systems, and other technologies were developed (Stewart, 1979). Energy analysis, along with economic and environmental analysis, was an important mechanism to define the behaviour of agricultural systems.

Food systems have been divided into several categories; cropping, livestock and fisheries, food processing, packaging, trade, and households (Wallgren & Höjer, 2009). This extensive range of uses covers all activities from farm to kitchen. Crop yields and food supplies to markets are directly linked to energy (Stout, 1990; USDA, 2008). Agricultural operations include all farming operations that occur after the land is cleared and developed, such as tillage, planting, fertilizing, pest controlling, harvesting, post-harvesting, and transportation at the farm level and until the product leaves the farm gate.

During the last two centuries, the amount of energy consumed in the agriculture sector has increased more in developed countries than in developing countries. However, the percentage of energy use in the agriculture sector in developing and developed countries is similar. Energy needs for agricultural production are about 3% of the national energy consumption in developed countries and about 3.6% in developing countries (Karkacier et al., 2006; Sauerbeck, 2001; Stout, 1990). However, the energy input per hectare in developing countries for agricultural production is about 7,700 MJ and in developed countries, it is about 37,900 MJ. In developing countries, human labour is the major cost item of energy; while, in developed countries, mechanization and fertilizers are major energy inputs (Pimentel & Pimentel, 2008). The entire food system including production, processing, packaging, and transportation could require about 15% to 20% or more of a nation’s energy consumption (Pimentel & Pimentel, 2008; Stout, 1990; Ziesemer, 2007).

There are numerous ways to enhance the efficiency of energy consumption of agricultural systems. Fossil fuel energy can either be replaced by new sources of energy or its use can be optimized in an applied manner. One way to optimize energy consumption is to determine the efficiency of the methods and techniques currently used (Kitani et al., 1998). Organic farming may be characterized by better energy efficiency. The use of mineral fertilizers and pesticides lead to higher yields in a conventional cropping system, but also requires higher energy inputs compared with organic systems (Alfoldi et al., 1994; Dalgaard et al., 2001; Grastina et al., 1995). There needs to be a plan to reduce and optimize energy consumption; otherwise, with current population growth, the current life style and food consumption will be unsustainable.

Chemical fertilizers, pesticides, agricultural machinery, and other farm inputs are used extensively in modern agriculture. Efficient use of energy inputs in agriculture will reduce environmental impacts, prevent damage to natural resources, and improve the sustainability of agriculture as an economical production system (Kizilaslan, 2008). For example, reducing the energy derived from fossil fuels within agricultural systems has important implications for decreasing atmospheric emissions of greenhouse gases, thus assisting the mitigation of global warming. The identification of crop production methods, which maximize energy efficiency and minimize greenhouse gas emissions, is vital (Tzilivakis et al., 2005).

Energy consumption in agricultural production depends on several parameters that affect the final energy consumed. These factors range from machine and human factors to direct and indirect factors, which have varying degrees of effect on energy consumption. Given such complex relationships, conventional data-processing methods are not suitable for investigating the process and product parameters. They often lead to unsatisfactory results due to non-linear relationships among the factors. In other words, the difficulty in modelling energy consumption in agricultural production is attributed to its stochastic nature and its dependence on a large number of parameters, many of which are uncontrolled. In agriculture, several parameters, such as fuel, seed, pesticides, and fertilizers have direct effects on energy consumption. However, there are several other controlled and uncontrolled factors, such as annual rainfall, soil fertility, and farm conditions which may indirectly affect agricultural production and energy consumption.

The major hindrance in modelling the behaviour of energy consumption is that it is difficult to extract the constants of the mathematical models. Therefore, it is important for researchers to find a model-free estimator. This problem can be overcome by the use of nonlinear regression methods, which are powerful predictive tools. One method for modelling nonlinear (accommodating multivariate) and non-parametric data is Neural Networks (Fang et al., 2000), which is a model-free estimation. The neural network (NN) is a relatively new estimation model, which can be used for modelling and predicting energy consumption (Fang et al., 2000). The neural network approach does not require any external or *a priori* knowledge of the form of relationships between variables or factors. In this method, the relationship between the variables and the form of interaction is automatically incorporated into the network model in an implicit manner during a training process. Consequently, it eliminates the difficulty of extracting parameters for a mathematical model (Hagan et al., 2002) and artificial neural networks (ANN)s have become widely used for modelling complex input-output dependencies (Parten et al., 1990).

ANNs offer an alternative way to deal with complex and ill-defined problems (Baik et al., 2001). ANNs can be trained with examples; however, they may be susceptible to very noisy and incomplete data. With accurate data representing the desired process, ANNs can approximate any nonlinear multivariate relationship to any degree of accuracy and, once trained, they can perform predictions and generalizations at high speed. They have been used in diverse applications in control, robotics, pattern recognition, forecasting, medicine, power systems, manufacturing, optimization, signal processing, and social and psychological sciences. They are particularly useful in systems modelling, such as in implementing complex mapping and system identification (Kalogirou, 2000; Samarasinghe, 2007).

The accurate prediction of energy consumed in plant production and other processing units is necessary to minimize costs, to achieve more consistent product quality, and to manage different processes, which can be carried out using an artificial neural network system. The ANN model can predict energy consumption in wheat production under different conditions. Using several crucial input variables would improve the flexibility of the model and help farmers, scientists, and decision makers compare energy efficiencies in different farming systems under different farming conditions.

Chapter 2
Objectives

Energy is currently one of the most important issues in the world. Due to limited energy resources, technological barriers, and environmental impacts, scientists have focused on energy conservation by improving the methods and technologies. The researcher of this thesis strongly believes that to control and conserve energy use in agriculture, not only must the energy inputs be investigated, but also the direct and indirect social, technical, and geographical factors need to be studied. Investigation of the effect of direct and indirect factors on energy consumption forms the basis of this study.

Several published papers are available on the determination of energy consumption in agricultural production. However, these studies use dissimilar protocols depending on the different circumstances. As the literature review indicated, no paper was found on the artificial neural networks modelling of energy consumption in agricultural production. Thus, there was no chance to build on previous experience in this area in this study.

The first objective of this study was to determine the energy consumption in wheat production based on field operations and energy sources in Canterbury. For a better understanding, as well as estimating total energy consumption and operational (direct) energy use dryland farming and irrigated farming systems were estimated separately. Comparisons between the different farming systems, different operations and different energy sources would give a clear picture of energy use in wheat production. Additionally, this comparison would be useful in finding the most important operations and sources of energy consumption to focus on in future studies.

Two secondary objectives related to the first objective were also set: one was to explore the effects of indirect factors on energy use in agricultural production. To this end, several social, technical, and geographical parameters were investigated carefully; the other was to explore the effects of the direct and indirect factors on each other and on wheat production by using statistical methods.

The second objective of this research was to develop an ANN model to predict energy consumption per cultivation area for wheat production under different farming conditions, based on field operations, direct and indirect energy sources, and indirect factors, such as the size of field, wheat area, crop area, farmer's age, farmer's experience, farmer's education, soil conditions, tractor and machinery properties, and fertilizer and pesticide consumption. A comparison of the results of this ANN model and the linear regression model, as a common modelling method in agricultural studies, was a secondary aim of this objective.

In summary, the objectives of this study are as follows:

Main objectives

- Determine the energy consumption in wheat production

- Develop an ANN model to predict energy consumption in wheat production

Secondary objectives

- Explore the effects of indirect factors on energy use in agricultural production

- Explore the effects of the direct and indirect factors on each other and on wheat production

- Compare the results of the ANN model and the multiple linear regression models

Chapter 3

Literature Review

3.1 Wheat

In this study, the energy use in wheat production is investigated because of its importance in food production. There are also other products, such as dairy production, which may be of interest to some scientists and farmers. However, in this section, the global importance of wheat is discussed; and an attempt is made to give a clear picture of wheat production in the New Zealand agricultural system.

3.1.1 Global Importance of Wheat

Wheat is one of the eight food sources (wheat, rice, corn, sugar, cattle, sorghum, millet and cassava) which provide 70-90% of the calories and 66-90% of the protein consumed in developing countries (NAS, 1977). In other words, 80% of the world's food comes from cereal grains. Also, more than 40% of the world's grain is fed to livestock (Pimentel & Pimentel, 2008). Globally, wheat provides nearly 55% of the carbohydrate and 20% of the calories consumed (Breiman & Graur, 1995). Wheat is cultivated under a wide range of climatic conditions. Most people consume wheat more than any other cereal grain (Singh et al., 2007). Global production of bread wheat, in 2003, was 557 million tonnes (Mt), with an average yield of 2.68 t/ha (FAO, 2008). The world's major bread wheat producing areas are in northern China, northern India, northern USA and the adjoining areas in Canada, and in Europe, Russia, Latin America, and Africa (Kole, 2006). Wheat covers around 25% of the total global area devoted to cereal crops (Singh et al., 2007). It is the staple food of nearly 35% of the world's population. Recent statistics show that the demand for wheat grows faster than for any other major crops. In the last few decades, the development of new seed varieties has increased the yield. However, in many areas, because of the use of old growing systems, yields have stayed at less than desired levels (Ozkan et al., 2004; Rosegrant et al., 1995).

The forecasted global demand for wheat, in 2020, varied between 840 and 1050 Mt (Kronstad, 1998; Rosegrant et al., 1995). To achieve this target, global production will need to increase by 1.6% to 2.6% annually from the present production level of 560 Mt. Increases in realized grain yield have provided about 90% of the growth in cereal production since 1950 (Mitchell et al., 1997) and, by the end of the first decade of the 21st century, most of the increase needed in world food production must come from higher absolute yields (Ruttan, 1993). For wheat, the global average grain yield must increase from the current 2.7 t/ha to 3.8 t/ha (Figure 3.1) (Kole, 2006). This means that the average yield of wheat should increase by about 40% in the short term.

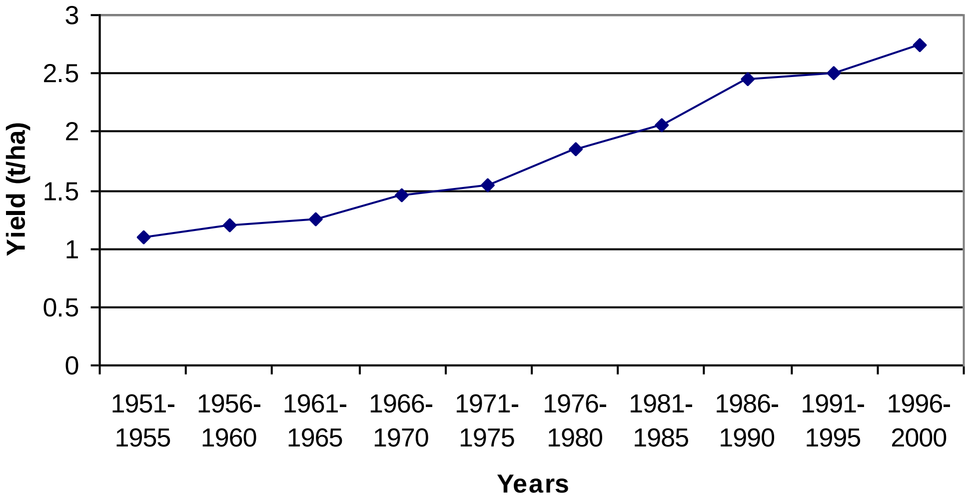


Figure 3-1 Global trend of wheat yields between 1951-2000 (Kole, 2006)

There are three ways to increase production: expansion of land area dedicated to wheat, land intensification, and yield increases. Land expansion is defined as the conversion of forest and grassland to agricultural land, and land intensification takes place through intensive farming and in increased use of fertilizer and other inputs (Vlek et al., 2004). Over the last decades, many pasture lands and forests have been converted to cropland; nevertheless, available cropland has been reduced through urbanization, erosion, and industrialization (Pimentel, 2009). According to the FAO (2000a), there is only a little more land that could be brought under cultivation in most areas of the world.

About 10% of the world's land area is used to raise crops (Da Rosa, 2005). As shown in Figure 3.2 (FAO, 2008), wheat area harvested over the past two to three decades has not changed significantly; however, the production has increased as a result of higher yield per hectare. Nevertheless, availability of food per capita over the last decades has fallen continuously (Pimentel et al., 2009). Comparison between Figures 3.1 and 3.2 indicate that the increases in wheat production depends more on increase in yield than on land use changes. Consequently, in the future, with increasing populations, the efficiency of farm production and farm operations should also increase.

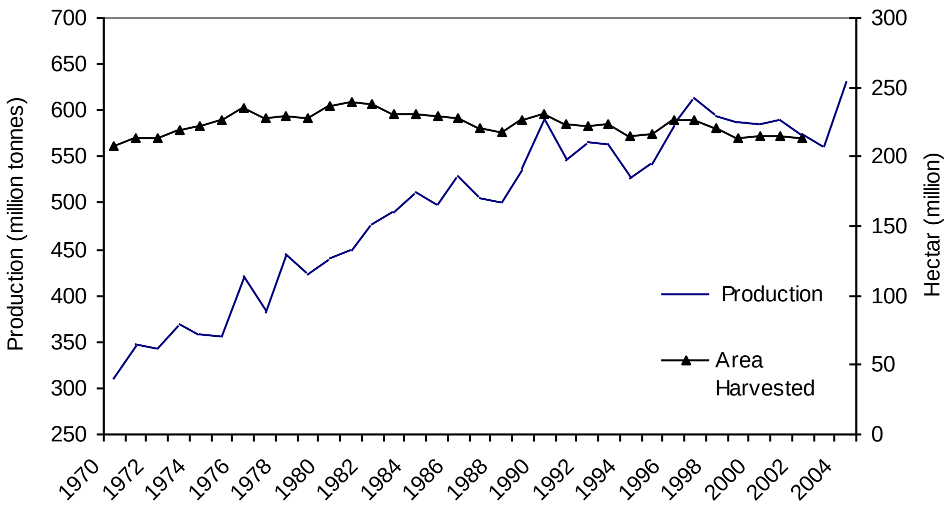


Figure 3-2 Global wheat production and area harvested between 1970-2004 (FAO, 2008)

Figure 3.3 (FAO, 2008) shows the trend of the worldwide rise in population and the accompanying (as is the case today) rise in wheat production. It shows a strong correlation between increases in population and wheat production. Intuitively, when 60% of the world’s population is malnourished (Pimentel et al., 2009), the food production graph can be expected to rise; however, there is no guarantee it will . The supply and demand of agricultural production is extremely complex and it depends on several political, economical and climatic factors. However, at present, reducing waste in agricultural production, using better storage methods, and better shipping and transportation systems can provide more food.

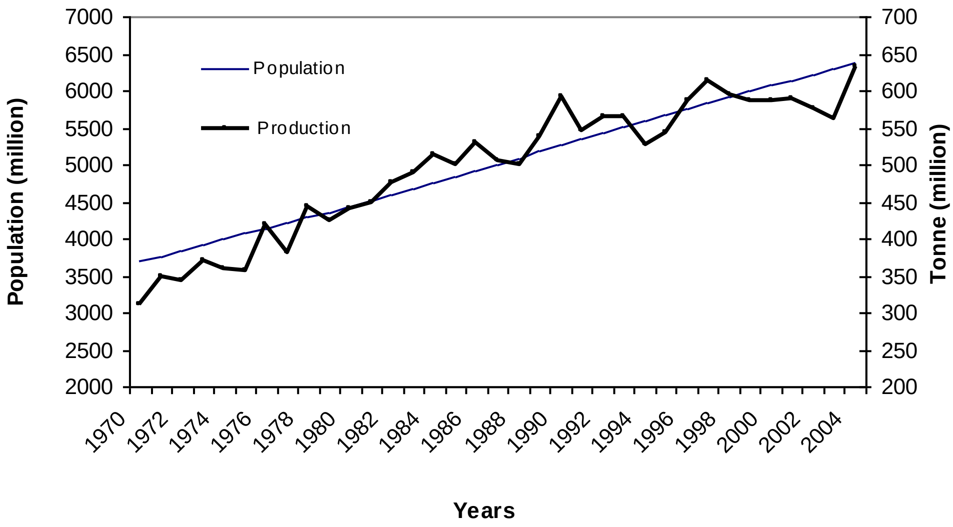


Figure 3-3 Comparison between global population and wheat production **(FAO, 2008)**

Future increases in food productivity will require substantial investment in research and development to improve the efficiency of wheat production systems through enhancing input-use efficiency along with other crops like rice, maize, barley, and tubers. A global targeting of wheat average yields of 3.8 t/ha by 2020 is a necessary step towards meeting the UN millennium goals (Kole, 2006). This increase is necessary to prepare food for the 3.7 billion malnourished people in the world (Pimentel & Pimentel, 2008).

Wheat may be sowed in spring or autumn. Wheat does not need deep tillage or heavy operations and it is cultivated in both rain-fed and irrigated farming systems (Pellizzi et al., 1988). It is sowed by air seeder or seed driller; nonetheless, in many poor areas, farmers still plant wheat by hand. The crops are usually harvested by combine (harvester); however, in some areas reaper-binders and harvesting by hand are still common.

Generally, wheat and other grains have a lower energy input than other agricultural production per unit (Dalgaard et al., 2001). However, the energy cost of total wheat production in 2004 in the USA was around 52% of total operating costs and it was higher than for other agricultural products (Shoemaker et al., 2006). Due to rising oil prices in the recent years, the price of agricultural production that depends more on fuel (mostly diesel) has increased faster than for other crops. Farmers, however, select agricultural products with minimum fuel shares. Moreover, in recent years, the production of ethanol from wheat has increased. Ethanol production from wheat (depending on oil price) could be highly competitive (Murphy & Power, 2008).

As well as the price of a particular production system, the price of other products and the price of farm inputs may affect farmers' interest in the type of crops cultivated each year. Additionally, several controlled and uncontrolled factors, such as precipitation can change the amount of agricultural production in each year.

3.1.2 Wheat Production in New Zealand

In New Zealand, wheat demand has increased continuously. Figure 3.4 (FAO, 2008) shows the amount of imported and produced wheat between 1992 and 2007, when wheat production in New Zealand grew 80%, from 191,039 to 344,434 tonnes per year. Simultaneously, the volume of imported wheat has increased by over 150%, from 135,480 to 343,042 tonnes per year. Prior to 2002, the volume of produced wheat exceeded that of imported wheat; however, after 2002 the relative values fluctuated. During this period, New Zealand did not export significant amounts of wheat, except in 2000 and 2006 when New Zealand exported about 1000 tonnes of wheat (FAO, 2008). The sharp reduction in wheat production between 2001 and 2002 may be due to the reduction of 12.5% and 13.6% of average precipitation in New Zealand and Canterbury, respectively (Statistics New Zealand, 2007a, 2007b). It is noticeable that due to population growth and feeding demand, the wheat demand will increase in the coming years and if New Zealand cannot produce enough wheat, more imported wheat will be needed.

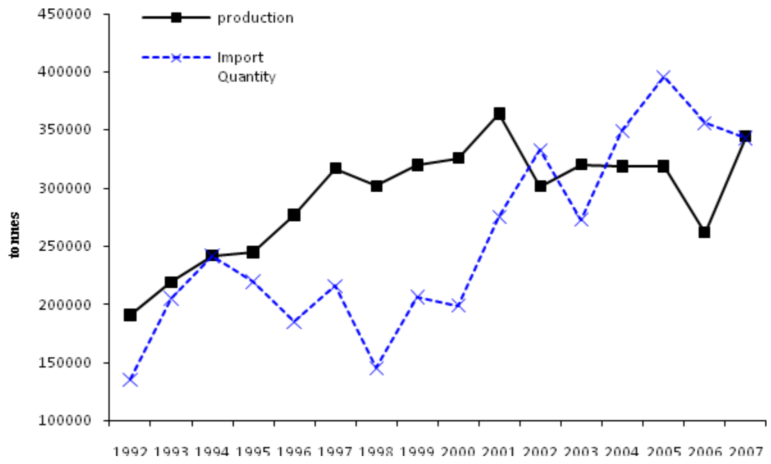


Figure 3-4 Volume of imported and produced wheat (tonnes /year) in New Zealand between 1992 and 2007 (FAO, 2008)

Figure 3.5 shows a comparison of global wheat price and wheat production from 1992 to 2007 (FAO, 2008). It indicates a similarity between wheat price and wheat production, except for the years between 1998 and 2003. Investigation of the price of a specific production is complex and many factors can influence it, such as the value of other products and value of US dollar in relation to foreign currencies. Comparing different currencies shows that the US dollar had a higher value between 1998 and 2003.

Changing the price of a particular product in comparison to other agricultural products may change the area dedicated to that product with respect to other products. Also, it seems that increases in price of agricultural products can encourage farmers to increase yield by investing in better technologies. For example, Figure 3.6 (FAO, 2008) compares the number of tractors in use in New Zealand and wheat prices between 1992 and 2007. Between 1992 and 1997 the wheat price increased; however, the numbers of tractors in use decreased. After 1997 however, when wheat prices dropped, the numbers of tractors in use decreased as well. This agreement continued after 2001, when both the price and numbers of tractors in use increased. Farmers prefer to produce crops with the highest profit and, in New Zealand, they have a choice of arable production, sheep production or dairy production. Also, in recent years many farms have converted to horse or deer farming.

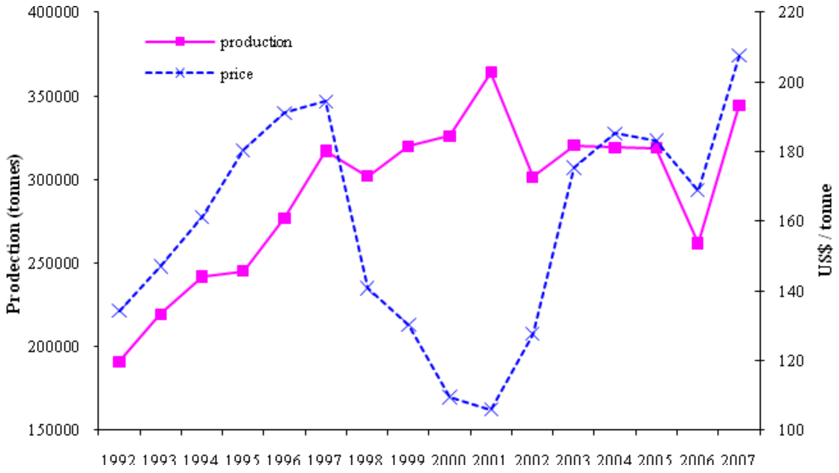


Figure 3-5 Wheat production (tonne) and wheat price (US$/ tonne) in New Zealand between 1992 and 2007 (FAO, 2008)

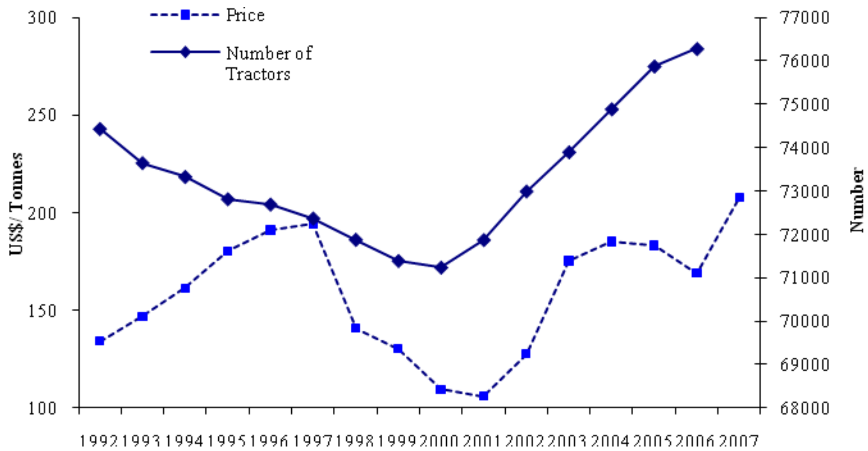


Figure 3-6 Number of tractors in use and wheat prices in New Zealand between 1992 and 2007 (FAO, 2008)

As previously stated, two ways to raise crop production are increasing the harvested area and increasing yield. As seen in Figure 3.7, wheat production in New Zealand increased from 191,039 to 344,434 tonnes per year between 1992 and 2007. Although wheat production has increased, the harvested wheat area has declined continuously, as shown in Figure 3.7, and this confirms global trends. Between 1992 and 2007, wheat farm sizes reduced by 140%, from 2075 to 866 thousand hectare. Increasing the yield allows farmers to produce more wheat in a smaller area in New Zealand.

Comparison between Figures 3.7 and 3.8 demonstrate the rise in wheat production in New Zealand is more closely related to yield than to harvested area.

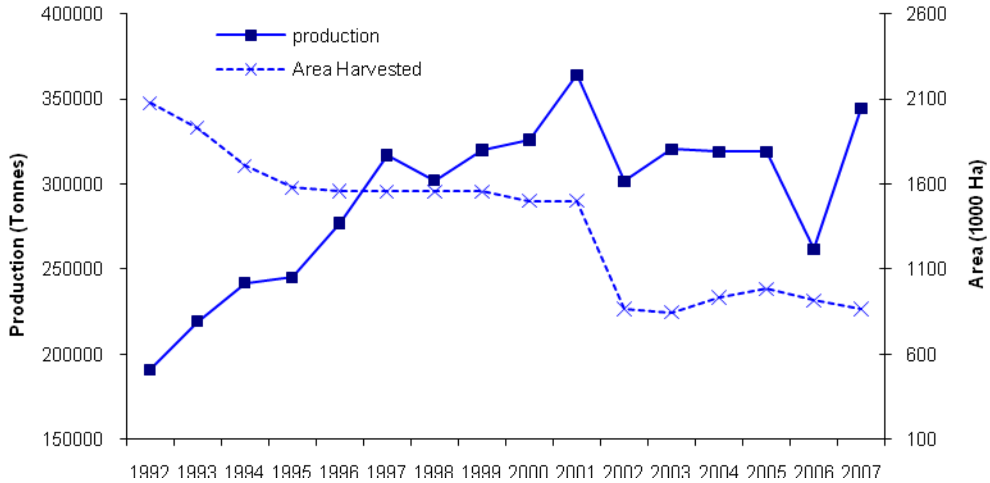


Figure 3-7 Wheat production and harvested area of wheat in New Zealand between 1992 and 2007 (FAO, 2008)

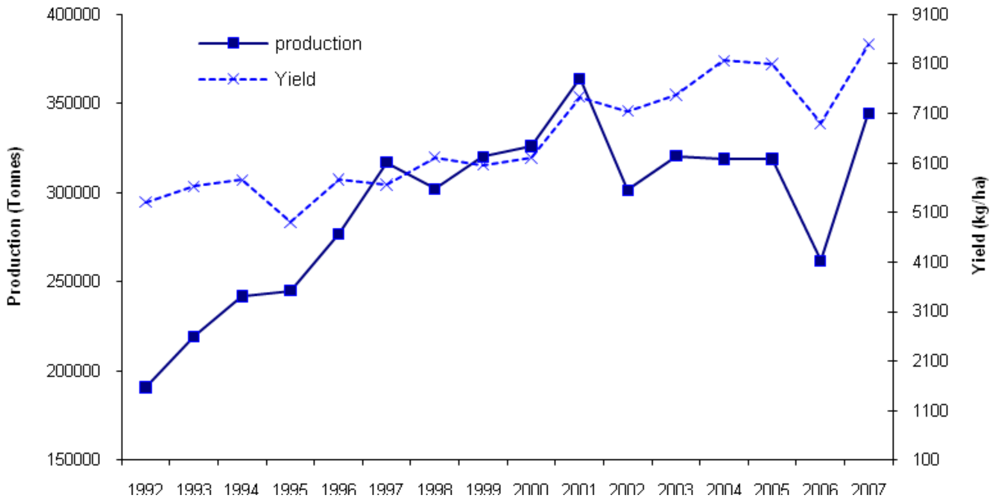


Figure 3-8 Wheat production and wheat yield in New Zealand between 1992 and 2007 (FAO, 2008)

Between 1992 and 2007 wheat yield in New Zealand increased by 60%, from 5300 to 8500 kg/ha. In the same period, global wheat yield increased from 2500 kg/ha, in 1992, to 2800 kg/ha, in 2007, an increase of only 11%, as shown in Figure 3.9. This growth is not enough to provide sufficient food for the world population.

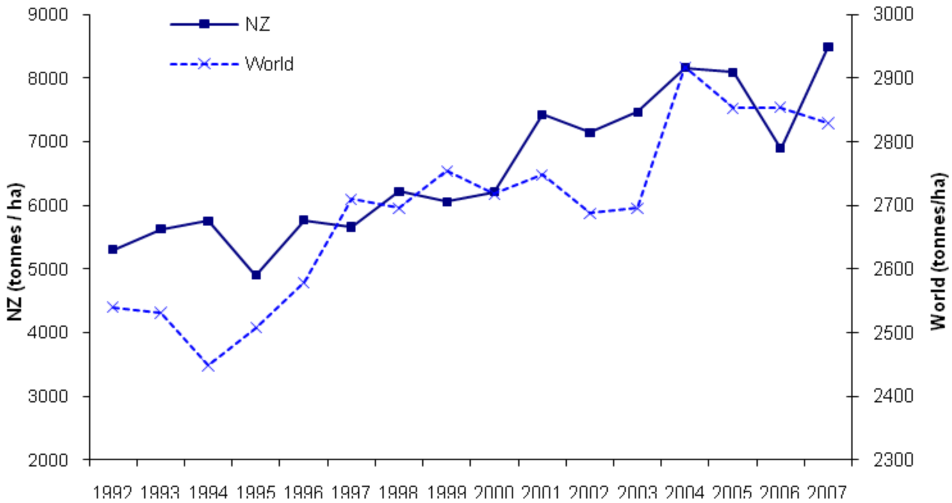


Figure 3-9 Global and New Zealand wheat yields between 1992 and 2007 (FAO, 2008)

3.2 Energy

3.2.1 Concept and History of Energy

Energy is an extensive concept, with its use ranging from bacteria in air-conditioning ducts refineries to nuclear power plants (Smil, 2008). Perhaps, 10,000 years ago, the first human-engineered energy conversion appeared; the discovery of fire. The invention of the wheel, stone tools, and the domestication of work animals extended mechanical energy use between 8000 BC and 4000 BC (Randolph & Masters, 2008). Aristotle (382-322 BC) attempted to know and analyse the first principles and causes in the universe. He believed that it was perhaps the most difficult thing for humankind to understand.

For the Greeks, the word *energein* meant to act, work, produce, and change. Study of these concepts continued during the Roman civilization, Islamic golden age, dynastic China, and medieval Europe for around two millennia (Smil, 1994). But the systematic understanding of energy was slow, because many founders of modern science had extremely faulty concepts about energy. For example, Galileo Galilei (1564-1642) believed that heat was a mental concept and it was an illusion of the senses, or for Francis Bacon, heat could not generate motion and vice versa (Smil, 2008). It is still difficult to find a standard definition of energy. Richard Feynman (1918-1988) believed “we have no idea of what energy is” (Coley, 2008).

The industrial revolution in the 19th century, shifted this organic energy system to a mineral energy system (Fouquet, 2008). James Watt (1736-1819) with his steam engine (the engine of the industrial revolution) opened the way to new studies on thermodynamics and heat theories. In the nineteenth century, a significant number of laws and theories defined fuels, engines, heat, motion, radiation, electricity, nutrition, metabolism, work, photosynthesis, and evolution (Smil, 2008). Carnot (1824) defined the efficiency of engines. He explained in his book, Reflections on the Motive Power of Fire, a simple law; it is impossible to have a perfect heat engine. This can be defined as the second law of thermodynamics (Boyle, 2004). In the twentieth century, studies on energy and the relationship between energy, economics, Darwinian evolution, and various other topics increased. Soddy, Einstein, and many scientists attempted to improve the understanding of the concept of energy in different fields, and these activities continue today.

Around 50 years ago, the energy challenge was simple; extracting, refining, and consuming oil from abundant oil supplies (Hood et al., 2007). Due to the abundance of fossil energy sources and the decreasing real costs of commercial energy, between 1945 and 1973, there was little interest in general energy research. However, the first oil price crisis (1973-1974) led to increased interest in energy studies. It created a wave of research and publications. The second energy crisis (1979-1981) was triggered by the conversion of the Pahlavi Dynasty to the Islamic regime in Iran. Since then, new concepts relating to energy have been defined, such as energy security and a sustainable energy environment (Boyle, 2004; Campbell, 2005; Coley, 2008; Fouquet, 2008; Mills, 2008; Odum, 1994; Outlaw et al., 2005; Randolph & Masters, 2008; Smil, 2008). Energy use has increased rapidly; between 1970 and 1995, it increased at a rate of 2.5% per year (doubling every 30 years); however, global population grows at the rate of 1.7% (doubling every 69 years) (Pimentel & Pimentel, 2008).

Today, the standard definition of energy in physics and mechanics is the capability to do work, as introduced by Thomas Young in his 1805 Bakerian Lecture to the Royal Society (Boyle, 2004; Pimentel & Pimentel, 2008; Tester, 2005). Work can be defined as the product of the force needed to move an object times the distance that it moves (Randolph & Masters, 2008). Our definition of energy is still not clear enough. Many scientists have tried to find a better definition of energy and several definitions can be found in books on thermodynamics, mechanics, and physics. Rose's (1986) definition is one of the best: energy "is an abstract concept invented by physical scientists in nineteenth century to describe quantitatively a wide variety of natural phenomena" (Smil, 2008).

Sometimes the word "power" is used as a synonym for energy; nonetheless, power is defined as the rate of doing work. The main unit of energy is the joule (J) and the main unit of power is the watt (W), which is defined as the rate of one joule per second (Boyle, 2004). The Joule is a new and SI unit (International System of Units) of energy; previously, the calorie was the common unit of energy. One J is the force of one Newton (mass of one kg accelerated by one m/s^2) acting over a distance of one metre (this definition covers only kinetic energy). The calorie is a non-SI unit of thermal energy. It is defined as the amount of heat needed to increase the temperature of one g of water from 14.5º C to 15.5º C (Smil, 2008; Tester, 2005). It is possible to convert these units to each other: 1 cal= 4.1855 J.

The use of energy is related to the two laws of thermodynamics. The first law of thermodynamics illustrates that energy may transfer from one type into another, but can never be created or destroyed. The second law of thermodynamics states that no transformation of energy will occur unless energy is degraded from a concentrated form to a more dispersed form (Pimentel & Pimentel, 2008). For example, electricity can be transformed into light energy. However, the efficiency is less than 100% and the rest of the electricity is transferred into heat.

It is very difficult to classify studies on energy. There is a standard classification of energy forms in mechanics, named kinetic energy and potential energy. It is also possible to categorize energy into energy types, such as chemical energy, muscular energy, mechanical energy, and electrical energy. However, as for importance, energy is classified as energy resources: fossil fuel and renewable energy. Fossil fuel energy resources include oil, natural gas, and coal, and renewable energy resources include solar energy, wind, bioenergy, tidal, hydro, and geothermal energy. It is important to note that some types of energy sources are more suitable for mechanical work.

Nuclear energy is different to the other energy sources and it faces an uncertain future. In the first years of the second half of the last century, nuclear power was thought to be a good solution to energy demands in the future; nevertheless, environmental and safety problems, such as nuclear waste and the Chernobyl accident, changed this perception. However, currently, nuclear power is used more than other new energy sources (Banks, 2007; Boyle, 2004; Boyle et al., 2003; Dell et al., 2004; Fluck & Baird, 1980; Fouquet, 2008; Hall et al., 1986; Jaccard, 2005; Kitani, 1999; Mallon, 2006; Ministry of Commerce & Eden Resources Ltd., 1993; Smil, 1994).

Environmentalists, economists, sociologists, politicians, militarists, geologists and engineers look at the energy concept in different ways and have different definitions of energy (Boyle et al., 2003; Campbell, 2005; Mills, 2008; David Pimentel & Pimentel, 2008; Smil, 1991, 2008). Undoubtedly, oil and other fossil fuel energy sources, which provide around 80% of total energy resources, are the most important energy sources and most of the actions and reactions around the energy concept depend on the oil market. Several conflicts around the Middle East and other major oil nations show the importance of oil in the political world (Banks, 2007; Boyle, 2004; Campbell, 2005; El Bassam, 2010; Mills, 2008; Nersesian, 2007; Smil, 2008; Tester, 2005).

3.2.2 Energy Consumption in New Zealand

It is difficult to obtain an accurate estimation of energy use from the various domestic and international statistics or information for a specific country. Also, some reports use national and journalistic terms for scientific subjects. In recent years, several reports and articles have been published on energy in ordinary journals and newspapers and these reports look at the subject of energy from different perspectives. Some journalists believe that there is no concern about energy security in New Zealand, because New Zealand is an energy rich country with large quantities of oil, natural gas, and coal. Also, massive amounts of wind, hydro, and geothermal energy are available. Furthermore, these reports confirm that New Zealand has the potential to produce sufficient amounts of biofuel; however, it is not easy to accept this idea. Energy production and consumption in New Zealand is described in this section and it shows how energy security in New Zealand is in danger. However, due to lack of suitable national and international information, it is impossible to give a strong prediction about the future of energy situation in New Zealand. Also, energy security is not the aim of this study.

Demand for energy in New Zealand has increased during the last century to 11.87 million tonnes of oil equivalent (MTOE), in 2000 (Hu & Kao, 2007). New Zealand is self-sufficient in most energy forms, except for oil and it is predicted that oil demand will increase around 2.1% per year between 1998 and 2020 (Elias, 2008; Kreith & Burmeister, 1993). New Zealand's oil self-sufficiency reduced from 1997 and it was less than 15%, in 2006. Imported oil costs New Zealand around 4.4 billion NZ$ annually (Lynch, 2008). As shown in Figure 3.10 from EIA (2009), the gap between oil production and consumption has increased annually; New Zealand has imported around 75% of oil consumed in recent years.

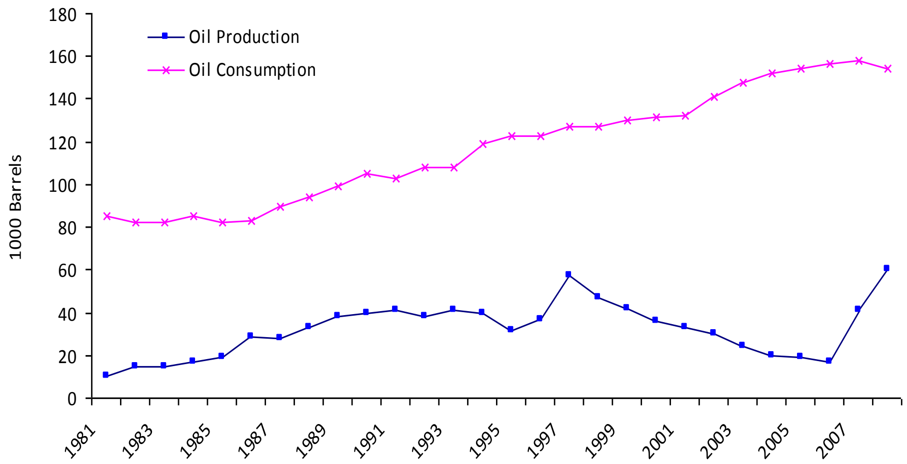


Figure 3-10 Daily oil production and oil consumption in New Zealand between 1981 and 2008 (EIA, 2009)

Between 1995 and 2004 energy consumption in New Zealand increased by 18.2%, to 516 Peta Joule (PJ). In this period, energy consumption in the transport sector increased more than in other sectors, by 23%, and energy use in the industrial sector increased less than in other sectors, by 11% (Ministry of Economic Development, 2006). Also, imported energy increased between 1997 and 2006 and it reached 41% of total energy consumption (Statistics New Zealand, 2008b). Figure 3.11 shows New

Zealand's consumption energy by sector in 1998 (EECA, 1998). This shows that the transport sector is the largest consumer of energy (40%) in New Zealand. However, it is important to note that farmers occasionally use general fuel stations' and fuel consumption by tractors and other agricultural machinery has been added to the transport sector; thus, the proportion of the agriculture sector must be more than the 5% shown in Figure 3.11. In 2007, Statistics NZ estimated the proportion of the transport sector fossil fuel energy use in New Zealand at about 80%.

In 2007, around 86% of New Zealand's oil consumption was in the transport sector (Ministry of Transport, 2007). Statistics NZ states that households are the largest user, with 31% of total energy consumption in 2006; however, in this report, petrol for private motor vehicles (56%) was estimated as the energy used by households (Statistics New Zealand, 2008b). Barber and Glenys (2005) believed that, in 2002, agriculture consumed 2.6% (13.4 PJ) of the national energy; however, Statistics NZ (2003) reported the proportion of the agricultural sector's energy use in New Zealand at around 3.7% (21.8 PJ) and it was 4.8% (24.7 PJ), in 2006. The Ministry of Economic Development (2007) estimated that the proportion of the agriculture sector in total energy consumption in New Zealand was around 4.3%. However, if the proportions of energy consumption in fishing, food, beverages, and tobacco manufacturing are added to the agriculture sector, the proportion of energy use in agriculture increases up to around 10% of national energy consumption. These types of differences between statistics from different sources increase the problem of data analysis. One important limitation to the available data is that some references use only primary energy sources or fossil fuel energy sources and electricity to estimate total energy consumption in New Zealand. If the secondary energy resources, such as fertilizer are added, the proportion of each sector will change.

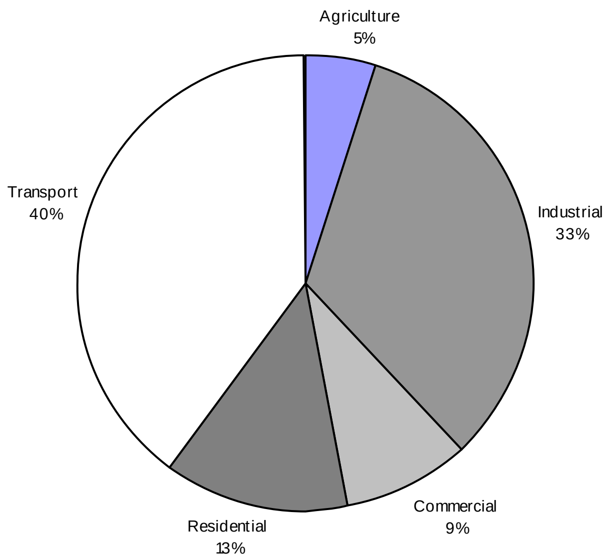


Figure 3-11 Energy consumed in New Zealand by sector in 1998 (EECA, 1998)

A significant proportion of fuel demand by the transport sector depends on two factors: New Zealand geography and its farm conditions. First, New Zealand is a narrow land and the population density, especially in rural areas, is low. Consequently, the facilities and service systems are centralized, resulting in increased travel distances to farms and other services. Second, New Zealand farms are large. This leads to relatively high fuel demands (Stout, 1990).

Natural gas is one of the most important primary energy resources in New Zealand; it is used as heat, power, and electricity and for petrochemical feedstocks. Another important primary energy is liquid fossil fuels, which make up about 43% of energy consumption. Approximately 80% of liquid fuels are used for transport. New Zealand produces around 60% of its own fossil fuel requirements from the Maui, Kupe, Waihapa, Taranaki, and Kapuni deposits (Centre for Advanced Engineering, 1996; Lynch, 2008). Renewable energy sources, mainly hydro and geothermal, generated around 62% of electricity, in 2004, in New Zealand (Barber & Benge, 2006).

The Maui field is the largest oil and natural gas field in New Zealand with about 61% of New Zealand's oil and natural gas stock. Kupe and Kapuni are the next largest oil and natural gas deposits with 14% and 13%, respectively. There are different statistics about New Zealand's oil reserves and it seems that, on average, there are approximately 3 trillion barrels to be recovered (Lynch, 2008). The statistics from the Ministry of Economic Development (2009) shows that natural gas production from 2002, and oil production from 1997, have reduced continuously in New Zealand. In other words, 1997 and 2002 had peak oil and peak gas production, respectively, in New Zealand, as shown in Figures 3.12 and 3.13. These two figures show the Maui deposit, New Zealand's largest oil and natural gas deposit is running out. There are two ways to enhance current oil self-sufficiency: improving energy efficiency and using new energy resources. Most oil and natural gas produced in the Maui field is consumed for electricity generation. Recent statistics show a significant shift from gas to coal for electricity generation, since 2002. For example, the 1,000-megawatt Huntly power station has been swapped from gas to coal. At the current New Zealand energy demand (around 600 PJ), coal can produce enough energy for 250-300 years (Hood et al., 2007).

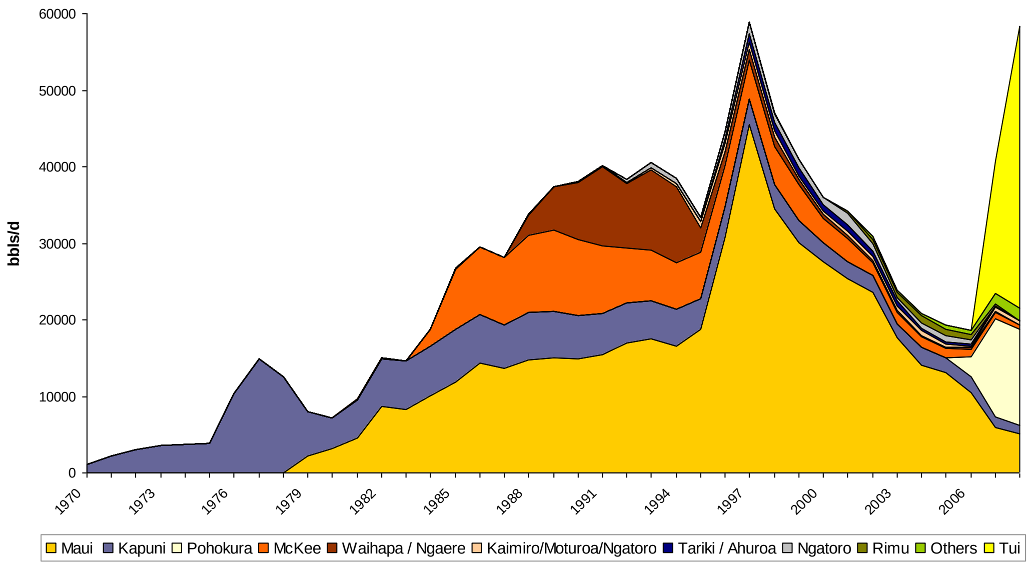


Figure 3-12 Average daily oil production (bbls/d) from oil fields in New Zealand from 1974-2008 (MED, 2009)

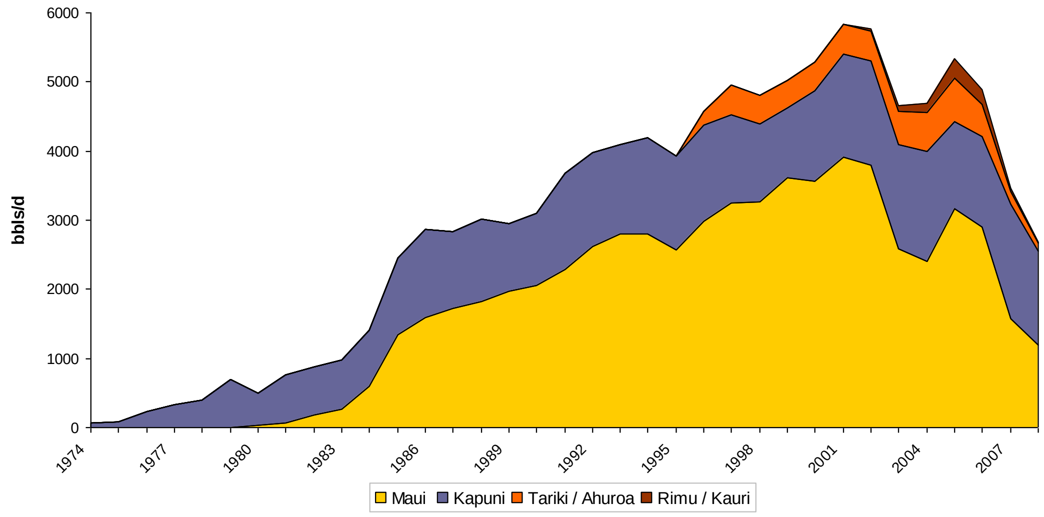


Figure 3-13 Average daily LPG production from gas fields in New Zealand from 1974-2008 (MED, 2009)

The existing link between the growth of fossil energy use and increase in biophysical productivity of modern economies implies that technical change has not provided any real 'emancipation' of production from the natural resources base (Karkacier et al., 2006; Mayumi, 1991). During the 1990s, most countries became energy efficient over time. Nevertheless, energy efficiency did not increase in New Zealand during this time (Hu & Kao, 2007). In 2001, the New Zealand government formulated the National Energy Efficiency and Conservation Strategy (NZEECS), which included energy efficiency, energy conservation, and the development of renewable energy systems (Elias, 2008; Kelly, 2007; Lynch, 2008). This set the agenda for government programmes to increase the energy efficiency and renewable energy. According to the New Zealand Minister of Energy (on 27 September 2001), the strategy set two national targets for 2012: a 20% improvement in energy efficiency and increasing renewable energy supplies to provide a further 30 PJ (EECA, 2006). It is too early to judge the success of the programme; however, early outcomes have demonstrated success in bringing forward emission reduction projects in New Zealand (Kelly, 2007), which has the 12^{th} highest per capita emission in the world (MED, 2007).

In New Zealand like many other countries, due to the significant role of the transport sector in energy consumption, CO_2 emission and other environmental impacts, most focus is on reducing energy use in the transport sector. Accordingly, MED (2007) predicted that only 2% of light vehicles will use fuel oil and diesel by 2050 and the rest, based on technological improvements, will work on electricity (60%), hydrogen (25%), and biodiesel (13%). It will be a hard target to achieve and if similar technological changes happen in other sectors, such as industry and agriculture, in the future, the effects of these changes on economic, cultural and social development must be taken into consideration.

Figure 3.14, from Statistics New Zealand (Statistics New Zealand, 2008b), demonstrates changes in population, energy demand per capita and GDP per capita. Between 1997 and 2006, New Zealand’s population grew by 11% and, in the same period, GDP per capita increased by 20%. Simultaneously, energy demand per capita rose by 9% between 1997 and 2004; while, after 2004, energy demand per capita did not grow. It appears that the growth of the above factors is linked and it presents the importance of managing energy conservation with minimum GDP reductions.

The data from Statistics New Zealand (Statistics New Zealand, 2008b) shows that between 1997 and 2006 the energy demand in New Zealand increased from 425 to 513 PJ (21%). Over the same period, GDP grew from $97 billion to $129 billion (33%), as shown in Figure 3.15 (Statistics New Zealand, 2008b). The growth of energy consumption for this period of time (Figure 3.16) was driven mainly by the increased use of fossil fuel resources, from 339 to 428 PJ (26%) (Statistics New Zealand, 2008b). It is possible to predict different scenarios for energy use in New Zealand in the future. All these scenarios depend on international and national parameters, such as the rate of population growth the rate of renewable energy growth, oil availability, global oil prices, and energy efficiency in New Zealand.

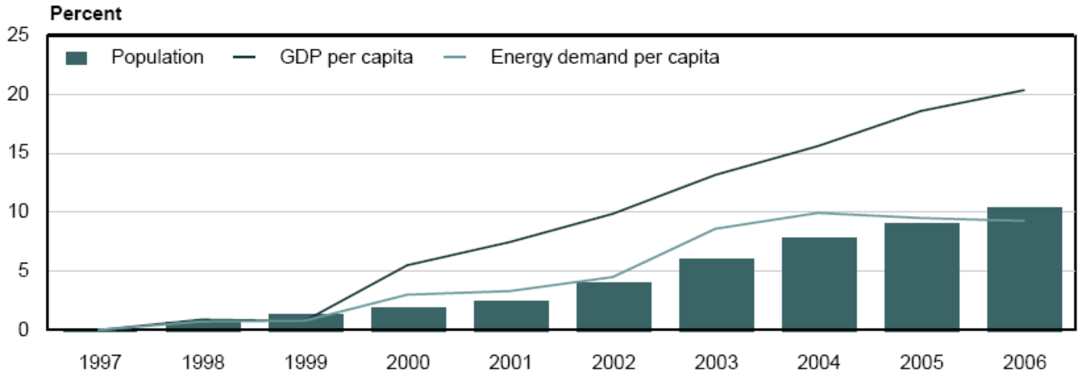


Figure 3-14 Change in population, energy demand per capita, and GDP per capita between 1997 and 2006

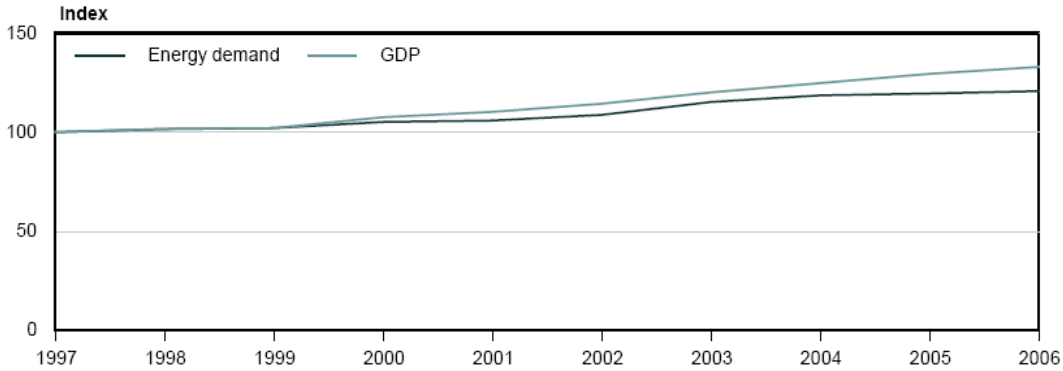


Figure 3-15 Change in total energy demand versus GDP between 1997 and 2007 (base:1997 =100)

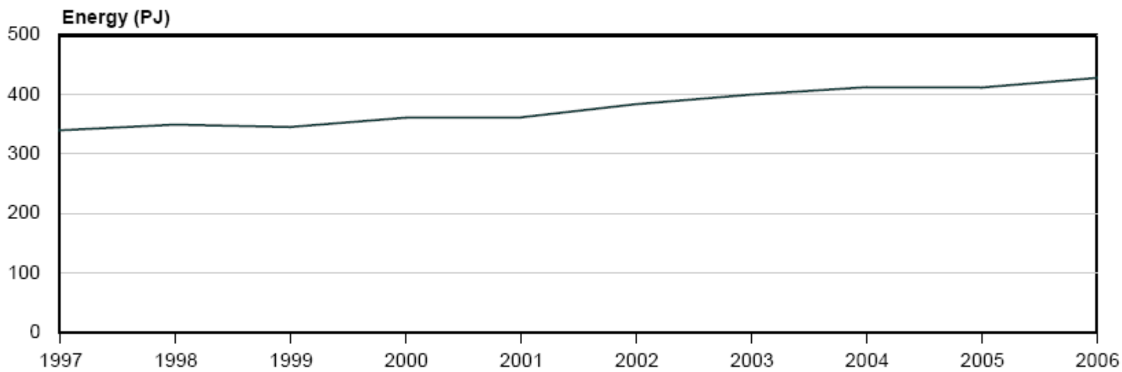


Figure 3-16 Fossil energy consumption between 1997 and 2006

The New Zealand Energy Efficiency and Conservation Strategy Report (October 2007) investigated New Zealand's targets in five important high-level targets, 1-

Energywise Homes, 2- Energywise Business, 3- Energywise Transport, 4- New Zealand's efficient and renewable electricity system and 5- Government. It is noticeable that in this report the agriculture sector was part of business (EECA, 2007); while, the previous 2001 strategy report did not mention agriculture or other primary sectors. It is predicted that energy consumption and energy prices will increase during the next decades; nevertheless, due to technical limitations, energy availability per person will reduce. The only way to reduce this gap is by a substantial improvement in energy efficiency (Elias, 2008). In other words, it is necessary to promote the security of both demand and supply of energy in New Zealand; especially, when the percentage of electricity generated from hydro and geothermal resources is still greater than 67% in New Zealand (MED, 2004). This means that for low winter inflows (dry year shortage, such as 1992, 2001, and 2003) and peak winter demands, optimal energy reserves are needed to achieve an efficient balance between supply and demand (Centre for Advanced Engineering, 1996; Lynch, 2008; Rutherford et al., 2007; Webb et al., 2002).

New Zealand has a high potential to use renewable energy resources, such as wind, solar, geothermal, biomass, and biogas. There are some financial, environmental, and technical barriers to the use of these resources. The most important barriers include lack of data, lack of research, lack of clear strategic statements by the Government, and limited capital (Hood et al., 2007). It seems that due to increasing oil prices and the recent progress in solving some of the technical limitations, the investment in renewable energy resources is more economical than before; however, concern about environmental impacts is still one of biggest barriers to the use of some renewable energy resources.

3.3 Energy and Agriculture

Agriculture is both a consumer and a producer of energy. Modern agriculture started through the domestication of fruits, nuts and grains (DeGregori, 2001). Agriculture is an energy conversion process. It converts two naturally abundant materials, water and carbon dioxide, to carbohydrate and other complex organic materials through the photosynthetic process and conserves and recycles mineral resources (Fluck & Baird, 1980; Odum & Odum, 1976; Pimentel & Pimentel, 2008; Stout, 1990; Tester, 2005).

Producing, processing, packaging, and distributing agricultural production from farms to houses needs around 1,900 of oil equivalents/person/year (Pimentel et al., 2007). As recently as the early 1900s, energy sources around the world were mostly agriculturally derived. Also, industrial products were mainly made from plant matter. Furthermore, early transportation fuels came from agriculture. The risk of volatile energy markets has renewed the interest in producing energy from agricultural products or by-products.

3.3.1 Agriculture as an Energy Producer

The world demand for petroleum and natural gas is increasing relative to world supplies. Fossil fuel energy can be either replaced with new sources of energy, or optimized in an applied manner (Kitani, 1999; Pimentel et al., 2007). It is predicted that even with the use of more efficient technologies and new energy sources, due to population and economic growth and improving quality of life in developing countries, the fossil fuel demand will increase in the coming years. Higher prices for petrol, diesel, and natural gas are making renewable sources of energy more attractive, economically, suggesting agriculture's role as an energy producer (Outlaw et al., 2005).

Energy consumption and carbon dioxide emissions are increasing at alarming rates (Ramanathan, 2005). Continued carbon dioxide (CO_2) emissions are likely to lead to catastrophic problems (Patterson, 1991; Smil, 2008). Energy activities are either contributing factors, or the main causes, of a significant number of environmental concerns. Major energy-related issues include global climate change, acid deposition, and deterioration of urban air quality (Patterson, 1991). Currently, renewable energy sources are more expensive than fossil fuel generation; however, if the environmental impacts and technical limitations are solved, it is possible to use more bioenergy resources in the future (Mallon, 2006; Tester, 2005; Warren, 2007). Since some thirty years ago, in some countries, such as Brazil, biofuels have been blended with fossil fuels. In these countries, cheap agricultural production, especially sugar, helps the use of biofuels in vehicles (*Biofuels in Brazil : realities and prospects*, 2007; Boyle, 2004; Gerin et al., 2008; Kitani, 1999; Mallon, 2006; Nersesian, 2007; Warren, 2007).

3.3.1.1 Fundamentals of Biomass

Green plants use sunlight to convert carbon dioxide and water into energy in the form of rich starches, cellulose, and sugars through the photosynthesic process; as yet, we do not understand fully how they do it. Biomass is defined as all material that was, or is, part of a living organism. Humans use biomass as the second energy source, after solar energy, for heating and cooking (Boyle, 2004; Mielenz, 2009; Tester, 2005). Biomass, still is the largest renewable energy source available (Randolph & Masters, 2008). Due to the need to find a substitute for fossil fuels and to reduce net CO_2 emissions, the use of biomass from natural materials, such as wood, waste, and alcohol fuels has increased in recent years (Sims, 2004).

Biomass can be used as solid fuels like wood, liquid fuels like ethanol and biodiesel, and gaseous fuels like methane and biogas (Boyle, 2004; Randolph & Masters, 2008). Biomass is commonly plant matter grown to generate electricity or produce heat. A wide range of biomass is available. For example, forest residues (such as dead trees, branches, and tree stumps), yard clippings, wood chips, by-products of industrial processes, and urban rubbish can be used as biomass (*Biofuels in Brazil : realities and prospects*, 2007; Mielenz, 2009; Pimentel et al., 2009).

It is possible to categorize biomass as extractives, carbohydrates, starch, cellulose, hemicelluloses, pectin, lignin, protein, and ash. Each one on the above list contains different materials and is used in different ways (Mielenz, 2009). Due to land limitations, increasing yields and using more plant residues are the best ways to increase biomass production (Boyle, 2004; FAO, 2000a; Pimentel & Pimentel, 2008; Randolph & Masters, 2008; Vlek et al., 2004). Carbon dioxide is one of the main by-products of biomass production; also, burning biomass releases CO_2 into the atmosphere. However, the system is sustainable and the carbon dioxide is absorbed by the next crop of biomass products. Therefore, biomass combustion is considered to be greenhouse gas natural (Nersesian, 2007; Randolph & Masters, 2008).

Biofuels like ethanol, biodiesel, and methanol contain somewhat less energy per litre than petrol; however, they can do the job as well as fossil fuels (Patterson, 1991; Warren, 2007). Most of the fossil fuel energy is used in the transportation sector and cars consume around half of all oil produced. Replacing petroleum with biofuels, such as ethanol and biodiesel, produces low amount of GHG emissions (*Biofuels in Brazil : realities and prospects*, 2007). If suitable solutions for some technical problems like the percentage of fibre and octane degree are found, biofuels can be used widely instead of fossil fuels.

The concept of using vegetable oil as an engine fuel dates back to 1895, when Dr Rudolf Diesel developed the first diesel engine to run on vegetable oil. Diesel introduced his engine at the World Exhibition in Paris in 1900 using peanut oil as fuel. Until the 1940s, vegetable oils were used in heavy-duty vehicles, but only in emergency situations. Biodiesel is still not very common and it is mixed with diesel in blends and this range from B-2 to B-100 (Boyle et al., 2003; Ghobadian et al., 2009; Kitani, 1999; Ministry of Commerce. & Eden Resources Ltd., 1993; Randolph & Masters, 2008; Reijnders & Huijbregts, 2009; Soetaert & Vandamme, 2009; Warren, 2007). Also, Henry Ford introduced the first Model T (Tin Lizzy) automobile based on 100% ethanol fuel in 1908; however, due to cheap oil resources in the middle decades of the twentieth century, the use of ethanol reduced until the first oil shock (Reijnders & Huijbregts, 2009; Soetaert & Vandamme, 2009). World ethanol production is increasing by about 20% annually. Interest in ethanol and other biofuels depends on global oil prices (Randolph & Masters, 2008; Warren, 2007) and increasing oil prices would make the ethanol production more economical.

3.3.1.2 Benefits and Limitations of using Biomass

A major attraction of biomass as an energy source is its domestic availability. There is a wide range of options to produce biomass in different areas. The raw materials, water, and carbon dioxide for biomass production are available and cheap in most areas. Furthermore, many forms of energy products can be made from biomass (Tester, 2005). However, some studies show that burning biomass is more harmful than burning natural gas. Furthermore, about 550 Mha of land are needed to produce enough transportation fuel from ethanol. This amount of land is one–third of the world’s cultivated land or approximately all agricultural land in the tropical areas (Ghobadian et al., 2009; Smil, 2008). It is important to note that land covers only 27% of the earth, but around 57% of the earth’s total biomass is produced in terrestrial systems. The average biomass production from crops is about 15 tonnes/ha.

The average biomass production in wheat production in North America is about 7 tonnes/ha (Pimentel & Pimentel, 2008). The rest of the biomass is produced in aquatic systems. However, using more biomass can increase some environmental impacts, such as soil erosion, water pollution, and air pollution (*Biofuels in Brazil : realities and prospects*, 2007; Pimentel & Pimentel, 2008). Additionally, it is important to note that every year, 15 million hectares of global forests are removed; around 60% of the forest is used for industrial roundwood and 40% is used for fuelwood. Furthermore, around 90% of fuelwood consumed in developing countries is used in an inefficient way, for cooking and heating (Pimentel et al., 2009).

The important economic benefit of biomass systems is the much lower investment cost per job created compared to industrial projects, petrochemical industries, and hydropower plants. Additionally, biomass production would enhance resource allocation related to rural infrastructure and services, such as rural settlement systems, communications, input distribution, extension, transportation, and marketing networks. Their link with regional agricultural growth is well established. "The decentralised and modular nature of bioenergy systems provides a unique opportunity for phased-in investment to allow a more regional distribution of wealth and equity in development between rural and urban areas. It also offers new frontiers to facilitate the process of reducing the present large rural-urban energy gap" states Oikawa (1995).

There are different ways to extract energy from agricultural production and wastes, such as biogas, combustion, gasification and pyrolysis (Dell et al., 2004). Moreover, petrol is still cheaper than biofuel. A litre of ethanol is around $0.83; while, the cost of petrol at the refinery is around $0.15. Also, due to its lower thermal value, for each litre of petrol, 1.5 litres of ethanol would be needed (Pimentel & Pimentel, 2008). It seems that energy use for cultivation and energy gain of ethanol from some crops, such as corn is very similar; therefore, ethanol fuel from corn in some conditions is an energy loser (Pimentel & Patzek, 2005; Tester, 2005). In addition, some studies show energy output from ethanol fuel is higher than energy input (Shapouri et al., 2004). This difference may be due to different methods of energy input estimation and different farming systems.

There is a consensus that the substantial expansion of bioenergy is a win-win proposition for developed and developing countries alike; it provides opportunities for poverty eradication and for satisfying energy needs in rural and remote regions; it helps generate employment and local economic development opportunities; it helps curb global warming and contributes to the improvement of human health by decreasing air pollution (El.Ashry, 2006; Sims, 2004). However, when 60% of the world's population is malnourished and the corn needed to make enough ethanol to fill the tank of a car is enough to feed one person for one year, consuming crops for biofuel instead of food can have negative consequences on human calorific intake. Moreover, deforestation to provide enough land for producing ethanol causes major environmental damage, not only by reducing the global capacity to absorb carbon dioxide, but also by increasing the release of carbon dioxide from the soil. At present, deforestation causes 18% of global green gas emissions. It is important to note that reduction in the growth of food production, in contrast to increases in population growth, creates a serious conflict between energy and food production and decreases the land available for biomass production. This means that the use of biomass, especially grains, as fuel must be limited because food supports essential and diverse needs of human activities. Even the use of crop residues as biofuel considerably reduces soil fertility and carbon stocks on farm soils considerably (Boyle, 2004; Gillingham et al., 2008; Hood et al., 2007; Kitani, 1999; Murphy & Power, 2008; Pimentel & Pimentel, 2008; Pimentel et al., 2009; Sauerbeck, 2001).

3.3.2 Agriculture as an Energy Consumer

3.3.2.1 The Role of Energy in Agricultural Development

Energy is one of the important elements in modern agriculture. Without energy, farming is impossible; especially, as modern agriculture depends totally on energy use and fossil resources. Energy consumption in agriculture has been increasing in response to the limited supply of arable land, increasing population, technological changes, and a desire for higher standards of living (Hatirli et al., 2006; Kizilaslan, 2008; Manaloor & Sen, 2009). Between 1900 and 2000, the global cultivated area increased 80-100% and energy harvested on farms grew six fold. However, in the same period, energy consumption increased 85-fold (Smil, 2008). There is a trend in agricultural production called "from farm to last consumer" where different sorts of energy sources are used for producing, transporting, processing, packaging, and shopping. The proportion of each part of the trend depends on many factors, such as properties of the crops, distance between the farm and market, kind of processing, and shopping system. It is estimated that around 19% of fossil energy consumed in the United States is used in food production (Pimentel & Pimentel, 2008).

Land, labour, energy, seed, and water were the most interdependent factors in the first agricultural societies, established around 3000 BC in Mesopotamia; since then, over the centuries, humans have slowly improved techniques and tools to increase yield and reduce labour intensity. Domesticated animals, such as oxen and horses helped farmers to cultivate more land; however, 10% of farms were devoted to prepare feed for those animals. Until the 19th century, farmers had lived in a subsistence economy. After the industrial revolution, populations increased and a large proportion of the population migrated from rural areas to industrial cities to find more employment opportunities. To reduce this gap, farming efficiency had been improved since the nineteenth century by introducing larger and more powerful breeds of horses, artificial fertilizers, and farm mechanization (Boyle et al., 2003; Pimentel & Pimentel, 2008). Energy consumption in agriculture has become more intensive as the Green Revolution led to the use of high yielding seeds, fertilizers, and chemicals as well as diesel engines and electricity (Hatirli et al., 2006). The energy requirements for the production of each crop are usually divided into four categories: crop protection, nutrition, cultivations, and culture (Tzilivakis et al., 2005). The sections are further sub-divided into:

i. Energy for the manufacture of crop protection chemicals and fertilizers (including packaging and transport to the farm).

ii. Energy required for carrying out field operations. Each operation is assigned a value based on the type and working width of the machine and, in the case of tillage operations, the operating depth and soil type.

iii. Indirect energy (the energy required for the manufacture of machinery and its maintenance), it includes the operating life times and depreciation periods of machines.

Agricultural economists identified energy consumption as an important determinant of agricultural productivity. In contrast to other sectors, the energy use in agriculture has generally received very little attention from scientists in different countries. The main reasons for this little scientific attention are data shortages and lower levels of multi-disciplinary work, which mean researchers, give little attention to marginal subjects in science. However, energy use in agricultural production has been increasing faster than that in many other sectors (Karkacier & Gokalp Goktolga, 2005). It is clear that energy use in modern agriculture has increased; however, the growth rate of production is higher. Thus, the current energy use per unit weight is less than before (Sauerbeck, 2001). It seems that there is a correlation between energy consumption in agriculture and the global rise of urbanization (Smil, 2008). Furthermore, energy has an important and unique role in economic and social development, especially in developing countries. However, there is a general lack of rural energy development policies that focus on agriculture. This is mainly due to lower levels of government attention given to the agricultural production, especially in developing countries. Another reason might be the "follower" character of developing countries as more industrialization is reached by the developed countries, less value they place on agricultural production. Besides that, less-educated and less-organized rural population in developing countries have not significantly influenced politicians as in the developed countries (Karkacier et al., 2006).

3.3.2.2 Energy Conservation in the Agriculture Sector

As discussed before, some studies show that there is a positive relationship between energy usage and productivity (Baruah & Bora, 2008; Hatirli et al., 2006; Karkacier & Gokalp Goktolga, 2005; Karkacier et al., 2006; Outlaw et al., 2005; Singh et al., 2004; Smil, 2008). Also, there is a significant relationship between output energy and weather, price, yield, and technology (Ozkan et al., 2004). The study of distribution of energy consumption in agricultural operations is important; the reason is that it shows which operation is more important for energy saving (Pellizzi et al., 1988). In addition, the agriculture sector is divided into different sub-sectors, such as dairy, livestock, poultry, arable, horticulture, forestry, and fisheries. Each of these sub-sectors has specific circumstances; also, it is important to note that between 12% and 15% of the total fuel consumption in developing countries and some developed countries is for agricultural transportation (Stout, 1990). There is a massive potential to conserve energy in the agriculture sector, by between 10-40%. Four potential changes that could reduce energy consumption in agriculture have been identified: using more efficient technologies, converting to organic farming, eating less meat and dairy products, and eating more seasonal products (Sauerbeck, 2001; Wallgren & Höjer, 2009).

Organic farming may be characterized by better energy efficiency. The use of mineral fertilizers and pesticides leads to higher yields in the conventional cropping systems; while, conventional farming requires higher energy inputs compared to organic systems (Alfoldi et al., 1994; Dalgaard et al., 2001; Grastina et al., 1995). For example, energy inputs for organic corn production are around 30% less than for conventional systems (Pimentel et al., 2005). In organic farming in Europe, average yields of cereal grains are from 30% to 50% lower than for conventional farming (Mader et al., 2002); this reduction in New Zealand has been estimated to be around 35% (Nguyen & Hignett, 1995).

In most countries, energy consumption in meat and dairy production depends mainly on the use of concentrated feed products (Wallgren & Höjer, 2009). In areas where cattle have more opportunity to graze on pastures, energy use is less than in areas where cattle rearing is based on a concentrated feed. In dairy production, livestock, and poultry farming, most of the energy is used in the form of electricity for producing heat, as hot water, and in ventilation systems; also, more electricity is consumed for chilling milk (Kitani, 1999). Therefore, efficient water heating and milk chilling technologies, insulated water cylinders, and milk vats can significantly reduce energy use in dairy production (Centre for Advanced Engineering, 1996). Furthermore, reducing the energy use in feed and pasture production can improve the energy efficiency in meat and dairy production. Eating less meat and dairy products; especially, from cattle rearing, can reduce energy use in developed countries. Nevertheless, in many developing countries, meat and dairy consumption per capita is still very low (Pimentel & Pimentel, 2008). One way to increase food supplies, with minimal energy consumption, is to consume more vegetables and plant foods (Pimentel & Pimentel, 2008; Wallgren & Höjer, 2009).

Appropriate agricultural mechanization would improve yields and reduce costs (Stout, 1990) and, in addition, it can reduce energy consumption per unit. Moreover, in irrigation, there is much potential to improve energy efficiency. More efficient fertilizers and agrichemicals, and better distribution methods, in addition to reducing input uses would reduce the environmental impacts (Centre for Advanced Engineering, 1996; Nemecek et al., 2008; Outlaw et al., 2005). Surface irrigation and fuel consumption are important input elements, which must be taken under close managerial supervision, for precise and accurate amounts and methods, in order to decrease the amount of energy consumed. Moreover, crop yield and energy consumption is highly influenced by the variability in soil and climatic conditions (Bertocco et al., 2008). It is noted that energy conservation in the agriculture sector is very complex and it contains a chain of activities that range from farms to houses.

The transport sector is one of the important components in all food systems. Shipping agricultural production from farms to homes is more complex than that in many other sectors. After harvesting, most of crops have to be processed and packaged in food industries and then shipped to wholesale and distributing centres. From there, foods are transported to groceries and supermarkets near population centres. At this stage, individual customers buy and transport packaged foods to their homes. Huge amounts of goods, supplies, and machinery are also transported to farms. In the United States, around 600 kg/ha of different materials are transported to each farm per year (Pimentel & Pimentel, 2008). There are different ways to reduce energy use in transport, such as improving energy efficiency of vehicles and logistics, supporting local and regional food production to reduce mileage of food products, and using e-commerce to decrease the dependence on private cars (Pimentel et al., 2007; Wallgren & Höjer, 2009).

3.3.2.3 Energy Saving in Agricultural Operations

Most energy demand from arable and horticultural farming is for fuel. Fuel is consumed for agricultural operations, such as tillage, planting, fertilizer distribution, spraying, and harvesting. Recently, many new types of agricultural machinery have been developed to save time and energy consumption in the field; for example, a combination of disk harrows and cultivator sweeps and a combination of chisel plough and zone. Moreover, new farming operational methods, such as strip tills, minimum tillage, and conservation tillage, have been introduced to replace conventional tillage to save time, costs and fuel and to reduce environmental impacts by reducing the number of passes made by tractors on farms (McLaughlin et al., 2008; Smil, 2008).

The tractor is the most important machine in modern agriculture. Most of the fundamental innovations in tractors happened during the early decades of the twentieth century (Smil, 2008). The worldwide number of tractors in use increased from 11 million, in 1961, to 28 million, in 2006 (FAO, 2008). In contrast, in some regions, the older tractors were replaced with fewer, but more powerful, new ones (Smil, 2008; Stout, 1990). There are a considerable variety of tractors available (brand, model, power, and design). Selecting the right tractor and equipment can make a significant difference to farm efficiency. Some studies show fuel consumption can be reduced by as much as 30% when the tractor is driven with maximum efficiency (Centre for Advanced Engineering, 1996; Pellizzi et al., 1988). Several factors should be considered before selecting tractors, such as engine type, transmission system, and tyre type (Stout, 1990).

To achieve optimum fuel consumption, the tractor and equipment should be adjusted for each specific task and good driving practices must be followed. Moreover, several other factors, such as regular maintenance, optimum wheel slip and tyre size, the use of four wheel drive tractors, operating in higher gears at lower engine speeds and correct tyre pressure, can improve tractor efficiency and reduce fuel consumption on farms. In addition, reducing transport distance, creating larger and longer paddocks, selecting appropriate speeds and depths of operations, and choosing the right time for agricultural operations are some key components of efficient tractor operation (Ashrafi Zadeh & Kushwaha, 2006; Barber, 2004; Centre for Advanced Engineering, 1996; Conforti & Giampietro, 1997; Kitani, 1999; Pellizzi et al., 1988; Smil, 2008; Stout, 1990).

Mismatches of tractors and equipment are common on farms. In heavy load operations, such as primary and secondary tillage, tractor size can influence fuel consumption per hectare. Usually, farmers have a limited number of tractors on which to load different equipment. Finding the correct load for all of the heavy and light load applications is difficult. To reduce the problem, farmers always use more powerful tractors for heavy load applications, such as tillage, and use lighter tractors for light load applications, such as mowing and drilling. Using larger field equipment can also help with the correct loading. Using contractors for some specific operations, such as spraying and fertilizing is another common way to reduce load problems. Many indirect factors, such as cultural practices, the availability of capital, personal opinions, and the availability of machinery dealers, also influence the size of tractors and agricultural equipment (Barber, 2004; McLaughlin et al., 2008).

3.3.3 Energy Analysis in Agriculture

There are four analytical methods that provide the rational information needed on which to base energy decisions; life-cycle assessment, energy analysis, economic cost-effectiveness, and environmental assessments (Randolph & Masters, 2008). In this study, the energy analysis method has been used to estimate energy consumption in wheat production. The energy analysis method uses engineering methods to estimate, measure, and predict energy consumption and energy efficiency in different fields (Randolph & Masters, 2008).

Crop systems and energy consumed in agricultural production are very complex. They are affected by weather, soil physicochemical factors, management conditions, pests, diseases, weeds, field size, degree of mechanization, oil prices, livestock production, and the interaction of many other factors. Crop models usually include material (carbon, nitrogen, and water) and energy balance. (CIGR, 1999; Kuesters & Lammel, 1999; Liu, 2009; USDA, 2008; Vlek et al., 2004). On the other hand, agricultural energy analysis includes the identification, estimation, measurement and analysis of energy use in agricultural systems (Fluck & Baird, 1980). Energy analysis research began as a new subject in agricultural production after the first oil shock, in the 1970’s. Consequently, improving agricultural methods and finding new energy resources were noted as important to reducing dependency on fossil fuel energy resources (Fluck & Baird, 1980; Kitani, 1999; Smil, 1991; Stout, 1990). Energy analysis serves different economic, management, and technical purposes (Stout, 1990).

In the first step of energy analysis, the energy inputs and energy outputs should be identified and evaluated (Kitani, 1999). In 1974, Odum established the first energy analysis method (SSSA, 1997) and, at the same time, the energy evaluation method was suggested by the IFIAS (International Federation of Institutes for Advanced

Study) (Fluck, 1992). Since then, several methods have been used to determine and analyse energy consumption in agricultural production. These studies consist of three methods: statistical analysis, input-output analysis, and process analysis (Fluck & Baird, 1980). Concern about the rising reliance of agricultural production systems on fossil energy sources prompted the use of energy analysis techniques to study the level of energy dependence and comparative energy efficiency of agricultural systems (Stout, 1990). Odum (1994) attempted to understand the principle of general systems theory in relation to environmental systems. He discussed the relationship between energy inputs and outputs in ecological systems using mathematics. He also stated that energy analyses in agriculture have much wider error margins than energy analyses in industry.

It is important to note that the results of energy studies depend on the set of assumptions used, such as defining outputs and inputs, and the energy equivalent of inputs (Conforti & Giampietro, 1997) but it needs to be pointed out that local results may not be representative of other areas (Liu, 2009). There are different methods to estimate energy consumption; consequently, comparison and evaluation of results from past studies are difficult. For example, human labour has been considered as an energy input in some studies, but not in many others (Conforti & Giampietro, 1997; Fluck, 1992; Hu¨lsbergen & Kalk, 2001; Sartori et al., 2005; Saunders et al., 2006). Furthermore, a general international agreement on how to estimate energy input has been difficult to achieve. In addition, a lack of reliable data for each country and region often forces researchers to take values from other countries without making adjustments for the different circumstances in those countries (Conforti & Giampietro, 1997; Kitani, 1999).

One of the most important problems in energy analysis is the nonhomogeneity of different sources (Fluck & Baird, 1980) and the different norms and coefficients that have been used in different studies. For example, the same amount of fertilizer can have a different energetic cost depending on the technical level of the manufacturing industry. Energy contents depends on the distance of transportation, which is variable, but can be taken as an average value for a region (Kitani, 1999), similarly, two different fuels might have the same energy content; while, they have different attributes (Fluck & Baird, 1980).

There are also problems with energy assignment in the case of multiple outputs, when there is more than one output from a system. In this instance, it is difficult to divide the energy inputs from the outputs. For example, it is impossible to separate the energy needed for grain production from that needed for straw (Conforti & Giampietro, 1997; Fluck & Baird, 1980). Because of these problems, it is difficult to compare one set of data with other published assessments of energy consumption in agriculture in different countries. An appropriate comparison would require a preliminary check on: (i) the primary data; (ii) definitions of inputs and outputs; and (iii) conversion factors used in the calculation (Conforti & Giampietro, 1997; Kitani, 1999); these are explained in the next section.

3.3.4 Energy Sources in Agriculture

From the mid twentieth century until recent years, the quantity of fertilizers, pesticides, fossil fuels, and electricity consumption in agriculture has increased about 20-50 fold. For example, between 1950 and 1980, fertilizer used in corn production in the US increased from 5 kg/ha to about 150 kg/ha (30 times) (Pimentel & Pimentel, 2008). These increases were necessary to produce more agricultural production. However, the rate of input increase was significantly more than yield increases.

The inputs in energy analysis in wheat production include direct factors or operational energy consumption (field machinery, human labour, and irrigation pumps (electrical or fuel)) and indirect energy sources (fertilizer, pesticides, and seeds) (Bailey, Gordon, Burton, & Yiridoe, 2008; Kitani, 1999; Kizilaslan, 2008; Mohtasebi, 2008; Ozkan, Kurklu, & Akcaoz, 2004; Safa & Tabatabaeefar, 2002; University of Canterbury. Centre for Advanced Engineering., 1996). Thus, agricultural energy use can be classified as either direct or indirect (Mohtasebi, 2008). The primary means of direct energy (operational energy) use on-farm involves the consumption of fuels, such as diesel, furnace oil, petrol, other petroleum products, electricity and wood. Some studies indicate that the use of diesel in tractors and diesel engines for various operations contribute 27.2% to the total energy input under irrigated conditions; while electricity use in irrigation only supplies 12.7% of total energy use (Singh & Mittal, 1992). Indirect energy is the energy used to create and transport farm inputs, such as pesticides, machinery, seeds and fertilizers. Indirect energy accounts for 70% of total energy use on dairy and hog (pig) farms and about 50% on arable farms (Bailey et al., 2008; Meul et al., 2007; Wells, 2001).

Energy includes not only the ‘useable’ energy, but also the energy expended or lost during processes, such as extraction, conversion, refining and transportation (Barber, 2004; Centre for Advanced Engineering, 1996; Kitani, 1999; Mohtasebi, 2008). Some scientists categorise energy use on farms in other ways. For example, Walls (2001) breaks the energy inputs of the production processes down to three major components: 1- direct (Fuel and electricity), 2- indirect (fertilizers, agrichemicals, seeds and animal feed) and 3- capital (energy used to manufacture items of capital equipment, such as farm vehicles, machinery, buildings, fences, and methods of irrigation). However, in most studies only direct and indirect terms have been used.

For each farm operation, different methods and machinery are used. For example, tillage systems vary from no-tillage[1] to conventional tillage. In each operation, different factors may affect energy use, such as speed and depth of operation, soil moisture, and width of machinery (McLaughlin et al., 2008). Additionally, the total energy requirement for each operation has different components. For example, total energy in tillage consists of energy requirements associated with four factors: (1) soil-tool interactions; (2) interactions between tilled and fixed soil masses; (3) energy requirements associated with soil deformation; and (4) the acceleration of the tilled soil (Ashrafi Zadeh & Kushwaha, 2006). Consequently, the choice of the most suitable tillage system for each farm could be different depending on the farm condition, farmer’s knowledge, and financial constraints or the energy factors considered (Bertocco et al., 2008). For example, fuel consumption in disc and plant tillage (conservation tillage) is 66% less than for conventional tillage (Smil, 1991). This example confirms the importance of the appropriate method and machine selection for reducing energy use in agricultural production and it shows the importance and complexity of analysing operational energy consumption.

[1] No tillage, sometimes called zero tillage, leaves residues from the previous crop on the field as a way of growing crops from year to year without soil preparation through tillage. No-tillage is an emergent agricultural technique which can increase C content and the amount of water in the soil and decrease erosion and energy consumption. It may also increase the amount and variety of life in, and on, the soil but may require increased herbicide usage; also, the risk of yield reduction is higher than for conventional tillage (Baker et al., 2007; Gajri et al., 2002).

Energy management is one of the crucial issues in agricultural mechanization. Due to farm conditions and the effects of several direct and indirect factors on farming system, an appropriate management tool for energy use on farms is essential. A mathematical model of energy requirements may be a good energy management tool. Mathematical modelling has been successfully applied to a variety of farm machines including tillage, spraying machines, and crop handling machines (Alvarez, 2009; Bertocco et al., 2008; Fang et al., 2000). Before designing a usable mathematical model, sufficient data and information is necessary.

In most countries, for a number of reasons, national statisticians pay very little attention to the energy consumption of the agriculture sector. First, only fuel purchased by farmers at subsidized prices is considered when analyzing fuel consumption in agricultural production. Second, diesel oil and petrol purchased by farmers from normal petrol stations are included in the transport sector. Third, farmers use only a percentage of the total electricity consumed in the agriculture sector. Finally, most indirect inputs are included in the industrial sector (Pellizzi, 1992).

For each energy source and field operation, there is a corresponding norm, which is called a conversion coefficient or energy equivalent. Conversion coefficients help to standardize the unit of all inputs to MJ/ha. However, different coefficients have been used in different studies for the same energy input; therefore, selecting a suitable energy coefficient for each energy input is one of the most critical parts of energy studies. The next section describes the energy resources used, specifically, in wheat production.

3.3.4.1 Human (Labour)

Before the invention of the tractor, hand and draught domestic animals were the only choices for power generation needed for agricultural operations. Introducing new machines reduced human labour requirements in this industry; however, in field activities, human labour still plays a large role (Smil, 2008). Even now, human power is the main source (73%) of energy in agricultural operations in many of the developing countries (Stout, 1990). Globally, around 48% of the total labour force worked in the agriculture sector over the period 1990-1992 (CIGR, 1999). Human labour is used for almost every task on farms, from driving, repairing machinery, irrigation, spraying, and fertilizer distribution to management. Many labour activities can be replaced with tractors and other machinery in agricultural production. However, sometimes this change has little or no effect on crop yields. If all agricultural operations are undertaken by human power, at least 1200 hours/hectare are required. This means that each person can mange just one hectare during a growing season (Pimentel & Pimentel, 2008).

New machines and tractors allow farmers to raise their crops by spending only 11 hours per hectare (Pimentel, 2009). In future, human labour 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 (Pimentel et al., 2005; Wallgren & Höjer, 2009; WCED, 1987) and, in some crops, it could be up to 35% (Pimentel et al., 2005; Wallgren & Höjer, 2009; WCED, 1987).

There are several different thermodynamic and sequestered methods for analysing human energy (Fluck & Baird, 1980). Human energy is analysed through measuring heart rates and recording oxygen consumption (Stout, 1990). The energy output of humans depends on gender, weight, body size, age, activity, and climate (Smil, 1994). Therefore, there are different estimations of energy output in human labour. In wheat production, depending on technology, there is a wide range of labour inputs, from 684 h/ha, in Kenya, to only 7.8 h/ha, in the US (Pimentel & Pimentel, 2008). The average human energy input per unit has been reduced by improving technology. The average energy input per tonne for wheat production has reduced from 30 hours, in 1800, to just two hours, in 1970 (Coley, 2008).

In modern agriculture, human energy used is less than other energy inputs (sometimes less than 1%). Therefore, it is not calculated in many recent energy studies. The energy output for a male worker is 1.96 MJ/hr and 0.98 MJ/hr for a female worker. (Mani et al., 2007; Singh & Mittal, 1992). One must recognize that human energy, especially in developed countries, is the most expensive form of energy in field operations. It encourages farmers to use better machinery and cultivate crops with minimum need for labour.

3.3.4.2 Fuel

Fossil fuels have continued to increase in importance as an energy input in society since the introduction of steam engines. In recent decades, oil has become by far the most important source of energy in all economic and production sectors (Hall et al., 1986; Singh & Mittal, 1992; Tester, 2005). Until the 1890s, the availability of nutrients and the amount of land for growing food for animate prime movers were the major limits to agriculture, and fossil fuel has solved both these problems (Coley, 2008). The fuel energy input in agriculture is not only of interest to researchers and environmental scientists, but also of importance to farmers who want to minimize production costs (Nguyen & Hignett, 1995). Official statistics pay very little attention to fuel consumption in agriculture. First, in many countries, only fuel purchased by farmers at subsidized prices is considered when analysing fuel consumption in agricultural and animal production. Second, farmers buy petrol and diesel directly from normal service stations, which are classified in the transport sector (Pellizzi, 1992). According to Siemens & Bowers (1999), "depending on the type of fuel and the amount of time a tractor or machine is used, fuel and lubricant costs will usually represent at least 16% to over 45% of the total machine costs". However, due to subsidies, the percentage of fuel and lubrication costs is lower in some countries than others.

Minimizing fuel consumption, maximizing the tractive advantage of the traction device, and selecting optimum ground speed are the most important factors for the efficient operation of tractors (Grisso et al., 2004). The proportion of fuel consumed in each operation depends on several factors. For example, in warm and dry climatic areas, more fuel is used for irrigation than in other operations; while, in dryland farming, most energy is consumed for tillage and seeding (Centre for Advanced Engineering, 1996; Safa & Tabatabaeefar, 2002). Fuel consumption in specific operations depends on soil conditions, crop type, ground-speed, and rolling resistance (Smil, 1991).

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 amount (Stout, 1990). Fuel consumption, expressed as litres per hectare (l/ha), is a better measurement of fuel consumption than litres per hour (l/h) as it uses the same basis to compare different inputs and operations (McLaughlin et al., 2008). Specific volumetric fuel consumption (SVFC) is the most common method used to estimate energy efficiency of a tractor using the units of l/kW h. However, sometimes instead of SVFC, specific volumetric fuel efficiency (SVFE), with unit of kW h/l, is used (Grisso et al., 2004).

Diesel fuel is the main source of fuel in agricultural machinery because diesel engines are stronger, have a higher efficiency and longer life than petrol engines (Kitani, 1999). Petrol is used only for light trucks and portable sprayers. There are several methods to estimate the fuel consumption of tractors based on the power of tractors; nevertheless, due to the influence of several factors, such as height above sea level, soil conditions (soil type, moisture, density, and residue cover), air pressure, humidity and temperature on tractor power and fuel consumption, most of these methods work only in specific areas (Bertocco et al., 2008; McLaughlin et al., 2002; Serrano et al., 2007). Furthermore, these methods are useful to predict fuel consumption of diesel engines under full load, but under partial loads and conditions when engine speeds are reduced from full throttle, they usually do not work (Siemens & Bowers, 1999). For example, according to the ASAE EP496.2 (2003), most tractors tested and used for agricultural purposes over the last 25 years have had diesel engines and the conversion equation for diesel engines is as shown below:

$$Q_{avg} = 0.223 \times P_{pto} \tag{3-1}$$

where, Q_{avg} is the average diesel consumption, l/h; and P_{pto} is maximum PTO power, kW.

This equation was developed by Siemens and Bowers (1999) and adopted by the ASAE (2003). The ASAE suggested that the results from equation 3-1 be increased approximately by 15% to account for farming conditions dissimilar to the original study. Grisso et al. (2004) stated that this equation has changed, due to technology improvements leading to more efficient fuel consumption, and the estimated fuel use has decreased by about 4.8% annually over the last 20 years. Also, Bowers (1985), Riethmuller (1989) suggested linear relationships between the draught per unit of equipment width and fuel consumption per hour, and Serrano et al. (2007) introduced a nonlinear relationship between the PTO power utilisation and fuel consumption per hour, as shown in Eqs 3-2, 3-3 and 3-4, respectively.

$$Q_{avg} = 1.2774 \times P_{drf} \quad (3\text{-}2)$$

$$Q_{avg} = 1.1306 \times P_{drf} \quad (3\text{-}3)$$

$$Q_{avg} = 266.4 + 884.5\, e^{(-Ppto/124)} \quad (3\text{-}4)$$

where, Q_{avg} is the average diesel consumption, l/h; P_{drf} is the specific draught in kN/m; and P_{pto} is the PTO power utilisation in kN/m. For an exact and accurate estimation, fuel consumption is determined before and after any operation by filling the tractor's fuel tank and recording the difference in volume. Different sizes of tractors are used for different operations on different farms. After sampling several different farms and conditions, the formula is estimated by using mathematical methods (Safa & Tabatabaeefar, 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 3-5.

Energy (input)/hectare = Operation fuel consumption (l/ha) × Fuel energy (MJ/l) (3-5)

The formulae for fuel consumption depend significantly on field efficiency. The efficiency of tractors and self propelled machines is analyzed with respect to engine, power transmission and wheel soil system (Pellizzi et al., 1988; Serrano et al., 2007). When the efficiency of engines and tractors improved, the formulae changed. Matching of tractor and implement, using hydraulic 3-point linkage equipment, using Power-Take-Off (PTO) equipment, selecting the right travel pattern on farm, 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 lead to fuel savings and improved field efficiency (Barber, 2004; Grisso et al., 2004). Using appropriate tractors and machines under the conditions can save 10% of fuel consumption in crop production (Pimentel, 2009). Still, in many developing countries, diesel is used in water pumps; while, due to higher efficiency, electric pumps are used more in developed countries. Table 3.1 shows average fuel consumption rate for agricultural operations in different studies.

Table 3.1 Average fuel consumption rate for agricultural operations in different studies

	Fuel Consumption (l/ha)				
	Wells NZ (2001)	Dalgaard Denmark (2001)	Lincoln University NZ (2008)	Witney US (1988)	Kitani (1999)
Mouldboard Plough	18	22	21	21	25
Chisel Plough	#	#	#	#	13
Heavy-duty Disc	12	#	13	13	9
Field Cultivator	6	6.2	8	8	8
Spring tine Harrow	4	4	3	#	#
Rotary Cultivator	#	#	#	13	4
Combined Tillage	#	#	#	#	24
Air Seeder	5	#	#	#	5
Grain Drill	10	3.2	4	4	5
Fertilizer Spreader	3	1.9	3	3	2
Boom-type Sprayer	3	1.2	1	1	1.5
Harvester	#	14	#	11	18

The reference did not indicate the value for the item

3.3.4.3 Fertilizer

Next to water, soil nutrients are the most important barrier for crop productivity (Pimentel & Pimentel, 2008). For better growth, farmers use extra nutrients that are named fertilizers. Around 60% of world fertilizer demand comes from developing countries where it is used, mainly in cereal production (55-58%) (FAO, 2000b). Three different kinds of fertilizer are used in agriculture: chemical (mineral), organic, and biological. Chemical fertilizers have increased the yield more than other innovations in agriculture (Smil, 1991, 2008). Traditionally, soil fertility was maintained and improved by adding livestock manure, planting legumes, and leaving plant residues on the soil (CIGR, 1999).

The use of mineral fertilizers is the fastest growing form of energy consumption in agricultural production (CIGR, 1999; Da Rosa, 2005; Fluck & Baird, 1980; Kitani, 1999; Smil, 2008; Stout, 1990). The global use of agricultural fertilizer increased from 30.5 million tonnes, in 1961, to 102 million tonnes, in 2002 (FAO, 2008). Without using chemical fertilizers, more land needed to be converted from forest and grassland to arable farms. Land use changes may produce more greenhouse gas (GHG) emissions than fertilizer use (Vlek et al., 2004).

There are 16 important elements necessary for the normal growth of plants (Stout, 1990). Plants absorb directly most of these elements from the soil and air. The level of these elements available in soil are based on: 1) the type, amount, and frequency of fertilizer applications; 2) crop and animal production; 3) nutrient contents in products (Nguyen et al., 1995).

Since the nineteenth century, artificial fertilizers (phosphorus and potassium) have been used on farms. At the same time, European countries imported considerable amounts of sodium nitrate (saltpetre) from Chile. During the First World War, ammonia (NH_3) was first produced, using the Haber-Bosch process, by German scientists (Boyle et al., 2003; CIGR, 1999; Smil, 1991). Nowadays, it estimated that one-third of the protein in global food supplies is derived from the Haber-Bosch process (Pimentel & Pimentel, 2008; Smil, 1994). By 2000, average global consumptions of N, P, and K were 53kg/ha, 9 kg/ha, and 12 kg/ha, respectively (Smil, 2008).

After the green revolution, fertilizer use in wheat production increased dramatically (Manaloor & Sen, 2009). In conventional wheat production, nitrogen and Phosphorus fertilizers were used more than other fertilizers; thus, environmental impacts of N and P were more than for other fertilizers (Meisterling et al., 2009). New chemical components, accurate methods of application, and better agricultural management, such as appropriate rotations, timely sowing, and improved water management can significantly enhance the efficiency of fertilizer use on farms and minimize potential environmental degradation, particularly the degradation of water quality (Ashrafi Zadeh & Kushwaha, 2006; Centre for Advanced Engineering, 1996; Kitani, 1999; McLaughlin et al., 2002; Murphy & Power, 2008; Nemecek et al., 2008; Pellizzi et al., 1988; Stout, 1990).

Nitrogen fertilizer (ammonia is the basic source of nitrogen fertilizer) is by far the most important mineral fertilizer in world agriculture, both in the level of plant nutrients used and in energy requirements. One kilogram of nitrogen is needed to produce one kilogram of protein (Da Rosa, 2005). The contribution of fertilizer to total energy consumption in developed countries is more than in developing countries. About 30-70% of energy input in crop production is based on nitrogen fertilizer (Kuesters & Lammel, 1999; Pimentel et al., 2007; Vlek et al., 2004). World demand for N fertilizer is expected to increase at the rate of 1.8% annually (FAO, 2000b). It is, however, possible to recapture some valuable nutrient resources from crop residues and livestock manure. Global crop residues are estimated to be 430 million tonnes/year. This amount of crop residue contains about 4.3 million tonnes of nitrogen, 0.4 million tonnes of phosphorus, 4.0 million tonnes of potassium, and millions of tonnes of other useful elements. Most of the nitrogen volatilizes through ammonia when the manure is left on the surface of croplands and pastureland. Therefore, only a small amount of the total nitrogen in the manure is useful and recoverable with present technology (Pimentel & Pimentel, 2008).

Currently, most chemical fertilizers are produced from fossil fuel resources (Fluck & Baird, 1980; Kitani, 1999) and around 5% of annual total oil consumption is used for the Haber-Bosch synthesis (Smil, 2008). Comparing different databases, Figure 3.18 shows that there is a similar trend in global fertilizer price and wheat price between 1991 and 2007. Thus, as the main source of nitrogen fertilizer is fossil sources, any fluctuations in the oil market leads to increases in the price of agricultural production.

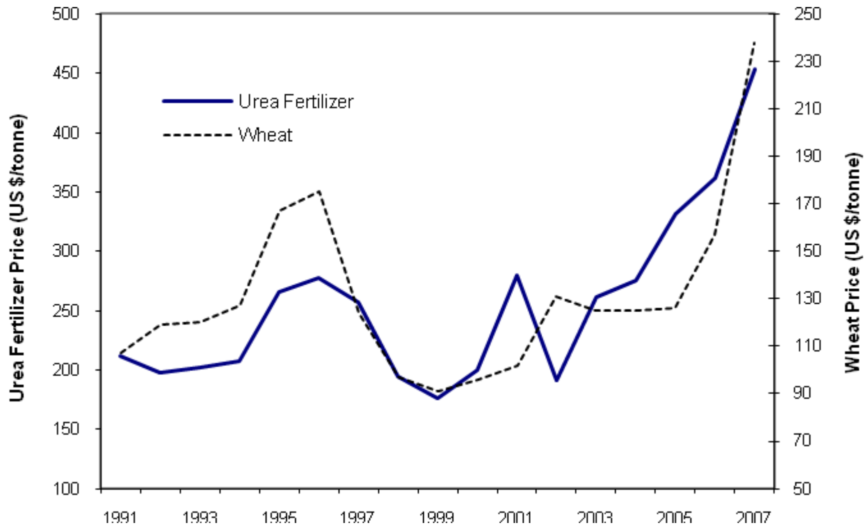


Figure 3-17 Comparison between global wheat prices (FAO, 2008) and urea fertilizer (USDA, 2008) between 1991 and 2007

The massive use of chemical fertilizers has caused some environmental impacts, such as eutrophication, poisoning of water courses, biodiversity depletion, and greenhouse gas emissions (Bertocco et al., 2008; Boyle et al., 2003; Nemecek et al., 2008). Fertilizers can increase yields; however, with further increases in the amount of fertilizer, the rate of yield increase becomes smaller until a peak is reached. Further application of fertilizer after this peak will reduce the yield (Fluck & Baird, 1980). Better farming management and selection of appropriate rotations can reduce fertilizer consumption on farms. Also, using more efficient application techniques can save around 20% of energy used in ammonia production (Pimentel & Pimentel, 2008). Costs of fertilizer production and transportation will rise due to increasing global oil prices; for example, during the last decade, the price of nitrogen fertilizer has increased 300%. Leguminous clover crops, manure, and organic amendments from off farm can be an alternative nutrient source that may be used instead of mineral fertilizer in agricultural production (Pimentel, 2009). However, these methods cannot provide enough nutrients for the whole world as much as oil and natural gas. Another way to reduce nitrogen fertilizer is using controlled release nitrogen fertilizers (Pimentel et al., 2005).

Leguminous clover crops can provide 100-200 kg/ha nitrogen on farms. Additionally, these plants can collect around 80% more solar energy than conventional crop production. Using leguminous clover crops in appropriate rotation systems can reduce fertilizer requirements by about 40% with minimum yield reductions (Pimentel, 2009; Pimentel et al., 2007). Also, crop rotations can help control pests on farms. Some studies show that better timing and application management can reduce nitrogen fertilizer inputs without yield reductions (Pimentel et al., 2007).

The energy component in fertilizer comes mainly from its manufacture and transport. However, perhaps only 10-20% of the nitrogen applied to farm crops is absorbed by the plants themselves, and this amount is influenced by soil type, temperature, and rainfall (Pimentel et al., 2005; Witney, 1988). Four paths of fertilizer loss include run-off, erosion to rivers, leaching to ground water, and gas emissions (Nemecek et al., 2008). The effect of soil quality on crop yield and energy consumption is well illustrated by soil erosion. On average, the depth of top quality soil is around 18 to 20 cm. Some studies show that the loss of each 2.5 cm of topsoil leads to a yield reduction of 250 kg/ha of corn, 161 kg/ha of wheat and 175 kg/ha of soybeans. Also, erosion is a cause of loss of nutrients, organic matter, and soil biota. These losses may reduce crop production by around 15-30% (Pimentel, 2009; Pimentel & Pimentel, 2008).

The most popular fertilizers in New Zealand farms are urea, ammonia, phosphate ammonium, ammonium sulphate, and super phosphate. Nitrogen (N) fertilizer is very energy intensive; while, phosphate (P_2O_5) and potash (K_2O) do not require high feedstock energy. In contrast, demand for chemical fertilizer in New Zealand agriculture has increased more than the average world demand (Stout, 1990). For example, from 1990 to 2005, the amount of nitrogenous fertilizer used in New Zealand increased by 824%, and the amount of phosphorous (P) fertilizer used increased by 121%. From 1992, New Zealand became a net importer of N fertilizer and, in 2005, 72.5% of N fertilizer used was imported (Jiang et al., 2009).

In New Zealand, nitrogen fertilizer is one of the most important factors of energy consumption in cereal crops, with 23-63% of total energy inputs (Nguyen & Hignett, 1995). Due to environmental impacts and the need for expenditure reduction, farmers prefer to use controlled release nitrogen fertilizers. In recent years, a close competition has started between fertilizer companies to introduce more efficient nitrogen fertilizers. Therefore, a significant reduction is expected in fertilizer consumption in the coming years. The most common source of nitrogen used in

Canterbury arable farms is urea. In New Zealand, urea is produced using natural gas in the petrochem industry at Kapuni. Some urea is also imported from the Middle East (Wells, 2001).

3.3.4.4 Pesticides

The average worldwide growth in the use of agrichemicals is around 4.4% per year (Vlek et al., 2004). Pests destroy 37% (insect 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 & Pimentel, 2008). Three different methods of pest control - chemical, mechanical, and biological- are usually applied to control or eliminate fungus, insects, and weeds on farms. On small farms, organic farms, and in areas with cheap labour sources, farmers use more mechanical methods. However, most farmers choose chemical methods because they are faster and cheaper; they are also more effective than mechanical methods. Global pesticides use is about 3 billion kg, costing nearly 40 billion US $ per year (Pimentel & Pimentel, 2008). Nevertheless, 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 by using cultivators is half the energy used for herbicide weed control (Pimentel, 2009).

In agriculture, there are a wide range of pesticides used for a variety of purposes. Pesticides should control weeds, insects, and fungus without seriously injuring to crops (Smil, 2008). Their responsibilities are prevention, avoidance, monitoring, and suppression of weeds, insects, diseases, and other pests. Pesticide use reduces crop losses; however, several hazards from pesticide use including human and animal poisoning, cancer, other chronic effects, reduced biological diversity, and water pollution, 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 & Pimentel, 2008).

The use of pesticides is increasing rapidly worldwide. It is becoming a major environmental hazard and the main source of pollution in agriculture (Lal, 2004). Due to public concern about the environmental effects of agrichemical use, research has begun to quantify it. New components have been introduced to reduce pesticide losses from runoff and leaching and reduce pesticide residues in crops. Also, some research has been carried out to introduce new natural methods. For example, improving the genetic resistance of crops to pests, encouraging pests' biological enemies, employing crop rotation, combinations with conservation tillage and utilizing natural forages and trees are the most important natural biological pest control mechanisms (CIGR, 1999; Lal, 2004; Pimentel & Pimentel, 2008). Some governmental programmes in Canada, Sweden, and Indonesia have reduced pesticide use by 50% to 65% with minimum impact on yields and quality (Pimentel et al., 2005).

The most common chemicals used in Canterbury are Roundup, Glean, Cougar, Mcp A, Karate, Xeon, and Opus tune. These are used to fight against diseases, insects, and weeds on wheat farms. In New Zealand, aeroplane spraying (air spraying) and tractor-mounted spraying are used to apply chemicals. The most important diseases on Canterbury wheat farms are Septoria Leaf Blotch, Stripe Rust, Leaf Rust, and Powdery Mildew (FAR, 2009). Pesticides vary more than other agricultural inputs. Therefore, the volume consumed is not a good index to compare the energy consumption and environmental impacts of different kinds of pesticides. For example, new pesticides are more biologically effective; therefore, the consumption per hectare is less. However, it is very difficult to find the energy component of all different pesticides.

The energy component in agrichemicals comes mainly from its manufacture, packaging, and transporting (CIGR, 1999; Kitani, 1999; Stout, 1990). Agrichemicals must be formulated in powder, emulsive oil or granules (Kitani, 1999). Most raw materials used in agrichemical production come from petrochemical industries and agrichemicals are the most energy intensive of all farm inputs (Stout, 1990). As stated earlier, additional energy is required for packaging and transportation.

3.3.4.5 Equipment, Tractors and Vehicles

Even today, in many developing countries, human power is the main source of power in agricultural operations. The number of tractors and other machinery in agriculture have increased during the last century and the number of tractors worldwide has risen from 11 million in 1961, to 28 million, in 2006 (FAO, 2008). Most commercial energy in agriculture is used in agricultural machinery manufacture and operation

(Stout, 1990). This energy can be categorized into energy required for manufacturing, maintenance, and repair (Fluck & Baird, 1980). In some studies, such as Barber (2004) and Wells (2001), it has been calculated as capital energy. Estimating the energy cost of field machinery is much more complicated than determining energy consumption of other agricultural inputs (Smil, 2008). In the agricultural processes, farmers use different agricultural machinery. The determination of the energy consumption in the production of agricultural machinery is very complex, because different companies use different processes for machinery production; also, farmers use machines in different ways. Furthermore, when the farmers cultivate different agricultural products on their farms, it is very difficult to separate the proportion of energy consumption of machinery for a specific agricultural production.

To compare energy use for producing and repairing tractors and equipment, usually energy use per kg has usually been used. Due to different technologies and different components, weight would not be a good estimation index to compare energy consumption in producing machinery. There are large differences between different estimations: Roller et al. (1975): 75 MJ/kg , McChesney et al. (1978): 90 MJ/kg, Hornacek (1979): 80.23 MJ/kg, Fluck and Baird (1980): 27 MJ/kg, Stout (1990): 85 MJ/kg, and Wells (2001): 80 MJ/kg for implements and 160 MJ/kg for tractors. Comparing the above rates, it appears that improving technology does not change the energy consumption in producing agricultural machinery. Energy required for producing and repairing different agricultural machinery, as estimated by Kitani (1999), is shown in Table 3.2. Kitani (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, and the energy consumption for transporting the machine to the consumer and so forth, and the energy used in repairs and maintenance (Kitani, 1999).

Table 3.2 Energy coefficients for producing and repairing different types of agricultural machinery (Kitani, 1999)

Equipment	*Energy(MJ/kg)*
Tractor	138
Mouldboard Plough	180
Chisel Plough	149
Heavy-duty Disc and Field Cultivator	149
Spring tine Harrow	149
Rotary Cultivator	148
Combined Tillage	180
Air Seeder and Grain Drill	133
Fertilizer Spreader	129
Boom-type Sprayer	129
Harvester	116

To calculate the annual energy input from tractors and other equipment, it is necessary to know the weight, working life span, and average surface on which the machine is used annually. Also, there are some studies that find correlations between different machinery properties. For estimating the weight of machinery, it is possible to use these studies as well as catalogues. For example, as shown in Eq 3-6, Serrano et al. (2007) presented the relationship between disc harrow mass and width.

$$m = -965.71 + 1041.9\,w \qquad (3\text{-}6)$$

where m is disc harrow mass in kg and w is the implement width in m.

3.3.4.6 Electricity (Irrigation)

In New Zealand, electricity is mainly used in arable farms for water pumping and irrigation. Different irrigation systems have been used on farms, such as guns, centre pivots, and rotary rainers. Due to the importance of electricity use in irrigation, in this section most focus is on irrigation.

From the past to the present, water resources are one of the most important barriers in agriculture because it is crucial for agricultural production and there are limited water resources in most farming areas (Pimentel & Pimentel, 2008). Soil and water are the most important controlling factors in agricultural production. Agriculture consumes about 70% of freshwater withdrawn per year (FAO, 2000a; UNESCO, 2001). The water required by foods and crops is quite variable; ranging from 600 to 3000 litre of water per kilogram (dry) of crop yield. For example, producing 9 t/ha of corn requires around 7 million litres of water, the production of 1 kg of corn needs around 780 litres of water and, on average, wheat requires about 2.4 million l/ha of water for a yield of 2.7 t/ha (Pimentel et al., 2009).

The increasing demand for food and other societal needs forces people to use more and more high quality water resources. In agriculture, the quantity of water requirements on irrigated farms depends on the influence of several factors, such as precipitation, soil type, climate, land topography, and irrigation method. There is a non-linear relationship between virtual water content and crop yield (Liu, 2009). Yield increases have encouraged farmers to increase the size of irrigated farms. The annual growth of irrigated farms has been around 1.8% since 1960 and it is higher in developing countries than in developed countries (FAO, 2000a).

The area of irrigated farms changes from year to year, depending on environmental conditions (USDA, 2008). Conserving world water resources must be a priority for all countries in the near future. The agriculture sector consumes around 70% of global freshwater; thus, it should be a prime target to focus on when conserving water. Some practical strategies that help water conservation in agricultural production include monitoring soil water content; adjusting water application needs to specific crops; using organic mulches and crop residues to prevent water loss; using appropriate crop rotations to reduce erosion and runoff; and using new irrigation technologies, such as precision irrigation and drip irrigation (FAO, 2000a; Pimentel & Pimentel, 2008; SSSA, 1997).

In many cases, it is necessary to transport large quantities of water to agricultural farms or drill the ground soil to make use of well water (Kitani, 1999); therefore, irrigation is one of the most expensive operations in agriculture. In the U.S, the cost of irrigation is two to three times the cost of all other inputs (Pimentel & Pimentel, 2008). Globally, crop yields on irrigated farms are greater than on dryland farms, around 17% of the world’s farm lands are irrigated, but produce around 40% of global agricultural production (FAO, 2002). Therefore, increasing the amount of irrigated land would increase agricultural production. However, it is expected that increasing the cost of energy can reduce irrigated farms and could pose a significant challenge for the 60% malnourished people in the world (Pimentel et al., 2009).

Due to increasing demand for water in the industry and household sectors, the proportion of water available for agriculture has declined. During the past decade, global irrigation land per capita has reduced by approximately 10% (Pimentel & Pimentel, 2008). It seems that improving the efficiency of irrigation systems is the best way to increase the number of irrigated farms. Until the second half of the 20th century, all irrigation systems depended on gravity fed systems. Since then, efficient engines, pumps, and impact sprinklers allowed farmers to use rainfall systems on their farms. The efficiency of furrow Irrigation may be around 20-40%; however, the efficiency of some new irrigation systems can be more than 65%. It may reach up to 95% in drip irrigation and some sprinkler systems (CIGR, 1999; Kitani, 1999; Pimentel & Pimentel, 2008; Smil, 2008).

It is not possible to irrigate farms without some water loss due to leakage, evaporation, percolation, and seepage (Kitani, 1999). The need to reduce expenditure and increase farmland encourages farmers to use more efficient systems. It is possible to improve the irrigation efficiency in some areas by the following methods: 1) improving water distribution systems and preparing better drainage systems; 2) using appropriate implements and more efficient methods; 3) better tillage and soil preparation before irrigation; 4) selecting appropriate field layouts; 5) improving service and maintenance of equipment and pumps; 6) selecting and matching the equipment, pumps and farm; 7) increasing average annual use of irrigation systems (Centre for Advanced Engineering, 1996; Kitani, 1999; Stout, 1990). In new irrigation systems, both electrical and diesel pumps are used; however, diesel pumps are used in smaller systems, especially, in developing countries (Centre for Advanced Engineering, 1996).

New irrigation systems, especially sprinkler systems, can avoid extended soil saturation and runoff. Due to increased application precision and reductions of unnecessary applications, water can be conserved and energy can be saved. Also, these systems require very little labour for fixing and managing and they can reduce energy in land levelling; however, more energy is required for running the system. The energy consumption of the pressure irrigation distribution systems is influenced by both the performance of the pumping stations and the spatial distribution and layout of the networks (Abadia et al., 2008; CIGR, 1999). Over the last few years (from 1998), both diesel prices and electricity tariffs have gone up significantly and this has forced farmers to use more efficient irrigation systems (Mukherji, 2007). Water management on irrigated farms, particularly, using more efficient irrigation systems, such as centre pivots, and using new technology, such as soil moisture sensors can reduce the direct use of electricity and can reduce energy consumption in wheat production. Additionally, sowing new wheat varieties with less water demand can reduce energy use in irrigation.

Energy use in irrigation consists of two parts; energy for pumping the water and energy for distribution of the water. In areas close to surface waters or with high water tables, the energy use for pumping is much less than in other areas. Unfortunately, it is difficult to estimate a standard figure for the power requirements for any system as there are many variables (Abadia et al., 2008; Mukherji, 2007). Specially, the required energy for irrigation varies with the depth of the water table, type of irrigation system, the water requirements of crops, frequency, water resources (rain, dam, groundwater and river), pump efficiency, delivery system and distance and energy sources (diesel, electricity, and renewable energies) (Smil, 2008; Stout, 1990; Vlek et al., 2004).

In irrigation systems, the main energy component includes the energy used for constructing the water supply source, providing the conveyance works and maintaining, and operating the system (Stout, 1990). Many studies show the maximum energy consumption on farms is in irrigation (Devi et al., 2009; Safa & Tabatabaeefar, 2002). Overall, the proportion of energy consumption in irrigation is higher in dry areas. Some crops require large quantities of water in dry areas; therefore, they need large amounts of energy for the pumping and applying that water. In some areas, irrigated wheat needs three times more energy than rain fed wheat for producing the same amount of wheat. It is predicted that oil supply reduction could decrease irrigation frequency by 50% in the future (Pimentel et al., 2009).

3.3.4.7 Seed

Agricultural crops can be propagated by seeds, tubers or bulbs. Unfortunately, there is little information about energy requirements for seed production (Kitani, 1999). Clean and proper seeds are provided in packages from seed producer companies and private Institutes. However, some farmers still use their own seeds. Therefore, the wheat seed, under these different circumstances, requires different energy rates. Different varieties of wheat seeds are used for autumn sowing and spring sowing in Canterbury, such as Option, Torlesse, Savannah, and Regency. Moreover, different varieties are used for feeding wheat and milling wheat and for irrigated farming and dryland farming (FAR, 2009).

On farms, there is a wide range of machines and methods used for planting seed. Different methods use different amounts of seed. There have been several studies to estimate energy consumption in seed (wheat) production and there are significant differences between these estimates of energy consumption in seed production (Table 4.2, Chapter 4).

3.3.5 Energy Consumption in New Zealand Agriculture

New Zealand economy is heavily dependent on exports of agricultural production, which account for nearly 51% of New Zealand export by value (Statistics New Zealand, 2008c). In general, New Zealand farmers practice a form of ‘industrialised’ agriculture that relies on relatively high inputs of fossil fuels, not only to power machinery directly but also for manufacturing of artificial fertilizers and agrichemicals (Wells, 2001). In New Zealand, the agriculture sector is around 4.6% of total GDP; while its proportion of greenhouse gas (GHG) emissions is, surprisingly, over 54% (Environment., 2009; Kelly, 2007).

In New Zealand, there are some studies on energy use in agricultural production between 1974 and 1984 following the first oil shock in 1973 (Barber, 2004; Wells, 2001). From that time until the mid-1990s, very little research on energy use in agriculture sector had been conducted. From the mid-1990s onwards, research resumed with the work by Wells (2001) and Barber (2004) being the most well-known in New Zealand (Saunders et al., 2006). The energy studies on agriculture in New Zealand were mostly started by McChesney (1981; 1979, 1983a, 1983b; 1982;

1978) and Pearson (1976, 1977). For the first time, Bell and Sorrenson (1977) reported the energy inputs and production of three dairying systems in Waikato (McChesney et al., 1978) and Pearson (1977) prepared a wide range of papers and studies on energy use in agriculture. In 1978, McChesney et al. (1978) compared energy use on Canterbury mixed cropping farms. He found the average energy input per hectare into crop production ranged from approximately 3000 MJ/ha to almost 7000 MJ/ha. Dawson (1978) estimated the energy requirements of different direct and indirect inputs to agriculture in New Zealand. McChesney et al. (1979) estimated energy use on hill country sheep and beef farms near Cheviot, North Canterbury and he found that fertilizer and fuel were the most important energy inputs in sheep and beef production making up 33% and 26%, respectively. Also, in his study, energy use for some crops was estimated, for example, energy use in wheat production was estimated at around 5800-6600 MJ/ha.

Odum et al. (1981) attempted to explain New Zealand's energy and environmental systems. They used flow charts as models to explain the relationship between different direct and indirect factors in energy consumption in agriculture and the environment. Their flow charts were extremely useful to create a real picture of energy inputs and outputs; nonetheless, some flow charts were very complex. McChesney (1983b) estimated fuel demand in the most important agricultural products in New Zealand. McChesney (1983a) investigated electricity use for irrigation in New Zealand. Stanhill (1984) compared the intensity of energy output, fossil fuels, and labour inputs in different countries in the 1970s. He shows that in contrast to the United States, New Zealand had low food output-low fossil fuel energy input system.

Since that time, and up until the mid 1990s, no further research on energy in agriculture has been done where energy efficiency in agriculture was negotiated as part of a wider study on opportunities for the adoption of energy efficiency across the economy (Sims et al., 1996). However, still there is no national energy consumption information for the arable sector unlike other agricultural sectors (Barber & Glenys, 2005); there are only some simple and primary data and figures of crop area and yield in the Ministry of Agriculture and Forestry (MAF) and Department of Statistics. In recent years, rising energy costs and environmental impacts have renewed scientists' interest in studying energy use in agriculture (Barber, 2004). Currently, the Energy Efficiency and Conservation Authority (EECA) has provided an energy end use database. It can estimate energy use for different sectors in different regions. However, the agricultural information is divided into dairy agriculture and non-dairy agriculture. Therefore, it is difficult to use this database for studies which relate to specific crops.

Primary energy consumption in agriculture includes diesel (50%), petrol (30%), and electricity (15%) (EECA, 1996). Figure 3.17 shows the proportion of energy consumption of each agricultural sector, with a total of 14.2 PJ (Barber & Glenys, 2005).

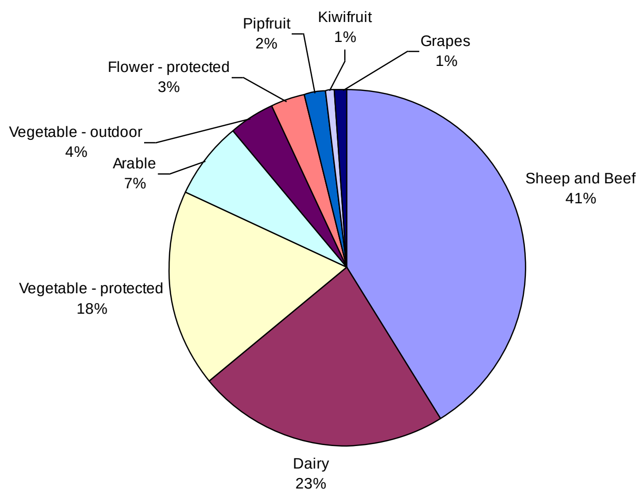


Figure 3-18 National agricultural energy use up to the farm gate (Barber & Glenys, 2005)

As shown in Figure 3.17, most of energy consumption in the agriculture sector is in the livestock and animal industry. Until late 1960s, proportion of livestock export in New Zealand was around 80%; since then, it has reduced and export earnings from manufactured goods have more than doubled. Nonetheless, agriculture still has a central position in New Zealand economy (Stout, 1990).

New Zealand's climate is not extremely cold or hot; therefore, some high energy modifications are not used in New Zealand, such as animal housing or heating. Moreover, 99% of cows and sheep graze directly on pasture. This helps to reduce energy consumption in harvesting operations. However, compared to many countries, productivity in New Zealand farms is still low and there is potential to increase yields and improve energy efficiency (Stout, 1990). Due to New Zealand's geographical location relative to the most important markets, products imported from New Zealand need to travel very long distances. Thus, it is necessary to estimate the energy consumption and carbon footprint of production and transportation of New Zealand agricultural products and compare them with other countries. For example, McChesney et al. (1982) compared the energy inputs of some agricultural products in the UK and New Zealand. They found that due to a favourable climate and lower use of fertilizer nitrogen, the energy use for cereals in New Zealand was half that of the UK; however, energy consumption in potato production was 60% higher than the UK.

Nguyen and Hignett (1995) compared energy and labour efficiency of three pairs of conventional and alternative mixed cropping (pasture-arable) farms in Canterbury and they showed that energy consumption in conventional farming system was higher than other systems. Wells (2001) studied total energy indicators of agricultural sustainability (dairy farming case study). This study is one of the best studies in New Zealand on energy use in agriculture and most subsequent studies follow its methods. He estimated the most direct and indirect energy inputs in dairy production. Barber (2004) estimated the total energy use in seven case study farms. Barber and Glenys (2005) investigated the energy use and efficiency measures in the New Zealand arable and outdoor vegetable Industry. In 2006, Barber and Benge conducted the first study on energy use in the kiwifruit industry that compared total energy indicators in benchmarking Green, Green Organic and Gold kiwifruit orchards.

Saunders et al. (2006) compared food miles, life cycle assessment (LCA), energy use, and CO_2 emission of barley, onion, apple and lamb production in New Zealand and the UK from samples from a limited number of farms. Most of these studies are interesting and provide useful information about energy consumption in the agriculture sector in New Zealand. However, agriculture is a complex system and it is not easy to estimate the average energy use of the whole country from a limited number of farms. Many energy studies in New Zealand have used a small number of farms or did not mention the sample size. Also, some of them did not indicate the location of the farms on which they estimated energy use. Some simple information is necessary to make use of energy studies, such as the location of the farms, year of study, and numbers of samples. Moreover, most studies only estimated energy consumption in agricultural production while some compared energy use of different methods and in different countries. In order to reach sustainability in agriculture, it is necessary to do more than just estimating and comparing. Analysing energy production and investigating the effect of direct and indirect factors in energy use in agriculture may be a good starting point for a new generation of energy studies in New Zealand.

3.4 Interaction Effects between Energy, Environment and Agriculture

Throughout history, humankind has tried to control energy in all its different forms. The link between the growth of fossil energy use and increases in biophysical productivity by modem economies in the last century implies that technical change has not provided any real 'emancipation' of production from the natural resources (Mayumi, 1991). From the 1980s, a new factor began to influence energy policy, namely, the environment. Some scientists even believe that energy sources control environmental systems (Odum, 1994). Extraction, transportation, and use of energy have a wide range of environmental impacts (Randolph & Masters, 2008).

In recent years, there has been increasing public concern over the environment (Coley, 2008). First, acid rain and its effects and then global warming gradually raised the agenda for the environment. Governments began to adopt uni-lateral and multi-lateral targets to control greenhouse gases and other environmental impacts (Hatirli et al., 2006; Helm, 2002; Kitani, 1999; Tester, 2005). Germany and Japan were the leaders of the first significant activities to control NO_x emissions in the 1980s (Smil, 2008). Since the Kyoto Protocol became effective, in February 2005, reducing the consumption of fossil fuels has been a main point of environmental policy in many developed and developing countries. Following the Kyoto Protocol, 160 countries agreed to reduce their emissions of CO_2 and five other greenhouse gases.

The energy system plays a central role in the interrelated economic, social, and environmental aims of sustainable human development (Randolph & Masters, 2008; WCED, 1987). In many societies, reducing economic growth due to environmental harm is unacceptable. There are at least two ways to achieve sustainable growth; technological change and conservation and recycling (Coley, 2008). In other words, there are two basic approaches to reduce environmental impacts in the future; 1) mitigating environmental impacts through technology, planning, and policies, and 2) adapting to climate change by lessening its impacts using technology, planning and anticipating effects, and modifying practices and patterns of development in agriculture (Randolph & Masters, 2008).

It is important to remember that the energy issues have become closely linked to environmental and ecological concerns (Patterson, 2006) as the use of fossil fuels and other chemical components are the main contributors to global warming, ozone formation, human toxicity, acid rain, and air and water pollution (Kitani, 1999; Kreith & Burmeister, 1993; Nemecek et al., 2008). Moreover, pollution linked to them have caused many problems for human health, such as eye irritation, asthma attacks, and chronic respiratory diseases (Smil, 2008). Energy industries also make significant contributions to other forms of pollution, ranging from chronic acid mine drainage to recurrent catastrophic spills of crude oil from tankers (Smil, 2008).

Energy consumption and greenhouse gas (GHG) emissions are increasing at alarming rates (Ramanathan, 2005). If GHG emissions continue to increase at the current rate, it is likely to lead to catastrophic problems (Patterson, 1991; Smil, 2008). For example, the atmospheric concentration of CO_2 has increased 31% from 280 ppm, in 1750 to 367 ppm in 1999 (IPCC, 2001). Increased concentrations of CO_2 and other GHGs in the atmosphere trap more energy from the sun and are recognised as one of the important causes of global warming. Global warming would have several unpredictable effects on the planet. For this reason, the Kyoto Protocol confirmed that GHGs should be reduced to below 1990 levels by the year 2012.

To maintain population growth, food production should continue to rise; therefore, humans must protect the environment, including land, water, energy, forests, and other biological resources (Pimentel & Pimentel, 2008). Energy consumption in crop production increased in developed countries more than in developing countries as a result of 1) increasing population, 2) migration from rural areas to urban areas, and 3) development of new production techniques (Kitani, 1999). Today, developed countries use 70% of global fossil energy annually and developing countries, with 75% of the world population, consume only 30% of the world’s fossil energy (Pimentel & Pimentel, 2008). Between 1945 and 1985, global total energy consumption increased 500% and the petroleum and natural gas consumption increased by about 900%, while the world's population increased by 200% (Haldenbilen & Ceylan, 2005). Studies show that some environmental impacts, such as sulphur dioxide, surface ozone, smog levels, and especially, O_3 concentration, may significantly reduce the yield of several agricultural crops, such as wheat, soybean, and corn (Aunan et al., 2000).

Humans have changed and managed ecosystems by using energy to provide more food (Pimentel & Pimentel, 2008). The main problem of increasing the dependency of food production on fossil energy is related to the fact that the rate of fossil energy consumption is certainly faster than that of its production (Martinez.Alier, 1990). This implies that current agricultural techniques are unsustainable in the long term because the present consumption of fossil energy will rapidly reduce the availability of fossil fuels for future generations (Conforti & Giampietro, 1997). It is predicted that atmospheric levels of carbon dioxide in the 21st century will be twice the 19th century levels. As a consequence, the global temperature would increase by 1.5˚ C to 4.5˚ C over the next 100 years (Odum, 1994; Stout & Best, 2001). Additionally, high levels of carbon dioxide can reduce the nutritional quality of major agricultural crops, such as wheat, barley, rice, soybean, and potato. It may reduce protein levels by about 15% (Pimentel & Pimentel, 2008).

Global warming resulting from greenhouse gas emissions from agricultural activities is one of the most important environmental issues. Many people believe that agriculture does not play a key role in environmental impacts. But fertilizers, agricultural residue burning, deforestation for land clearing, and domestic animals account for 80% of dinitrogen oxide flows into the atmosphere, 67% of nitrogen fixation, 65% of methane flow into the atmosphere, and 40% of non-methane hydrocarbon emission into the atmosphere (Boyle et al., 2003). Also, the use of fertilizers and pesticides in agricultural production has created a number of health problems (Pimentel et al., 2005).

The contribution of global agriculture to air pollutions through the consumption of energy is small, accounting for about 5-7% of annual GHG emissions (Dalgaard *et al.*, 2001; Outlaw *et al.*, 2005). The global climate is quite a complex system; therefore, it is extremely difficult to predict what will happen to climatic factors, such as rainfall and wind patterns as a result of global warming and changes in the levels of key greenhouse gases, such as CO_2, CH_4, and N_2O (Stout & Best, 2001). Land use changes from forest and grassland to arable farms are the most important source of carbon release from the soil and dead plants into the atmosphere (Lal, 2004; Sauerbeck, 2001; Vlek et al., 2004). Land use changes cause emissions of around 20% of the global annual CO_2 emissions (IPCC, 2001). Also, CO_2 emission from burning fossil fuels is another important environmental impact of crop production (IPCC, 2001; Koga et al., 2003).

Due to land limitations and environmental impacts, crop yield increase is the main source of growth in agricultural production. Thus, more agricultural inputs, mainly fertilizer, will be needed. There is a significant correlation between agricultural production, energy use, and CO_2 emissions (Snyder et al., 2009; Stout, 1990; USDA, 2008). It is predicted that increasing global temperatures could lead to melting glaciers and the resulting thermal expansion of sea water may raise sea levels. This could threaten some coastal areas and small islands. However, it may also create new opportunities for agriculture. For example, reducing glaciers made way for new lands to appear in Canada, Siberia, and Greenland.

Some suggestions to mitigate GHG emissions in the agriculture sector are by using better farming techniques, reducing fuel consumption in farming operations, manure management practices, and improved grain production practices to raise the stock of organic carbon in soils and biomass (Vlek et al., 2004). Due to the circumstances in agriculture, investigation into the effects of economic changes on farm production in the short term is difficult. Farmers' reactions to price changes are always slower than in other sectors. They cannot easily change their plants and trees after sowing and they cannot convert their farms from dairy to arable use in a short time. Also, while changes in input prices, especially the price of oil, influence farmers' decisions, the final net benefits also play a key role. Therefore, it should not be expected that price manipulations would lead to a significant reduction in CO_2 and other GHGs (Manaloor & Sen, 2009; Manos et al., 2007).

Due to the variety of operating conditions and farming methods, estimating the emissions from agricultural operations is not easy. For example, burning fuel in agricultural operations gives off CO_2 and NO^+; nevertheless, their emission rates very depending on the size, type, and age of the machines and farm conditions. Electricity use in agriculture does not emit any pollution directly. However, its use may cause significant emissions in the transmission and at the power plant. Transportation of farm inputs and agricultural production also cause concern as emitters of air pollutants. The critical part is finding the best balance between domestic production with high energy consumption and overseas production with low energy consumption for production, but high energy use for transportation.

Fuel consumption in agricultural operations has been identified as an important contributor to global warming in most agricultural activities (Meisterling et al., 2009). Some studies show that burning fossil energy is responsible for approximately 30% of greenhouse gas emissions (Dalgaard et al., 2001). Also, new research will be required for finding best management practices to minimize N_2O and soil C levels in agricultural production. Furthermore, the direct and indirect impacts of agriculture are substantial, including global warming, eutrophication, and biodiversity depletion.

Due to increasing food, feed, and other industrial production, more energy will be required in the future for food production. In every sector of production and service activities, energy conservation and effective uses of energy are necessary. Using renewable energy resources is one of the important solutions to reduce environmental impacts (Kitani, 1999). It seems that research should be focused on carbon, nitrogen, and sulphur more than other elements because these elements are water soluble, airborne, and play an important role in the biosphere (Smil, 2008).

3.5 Modelling

Nature is a complex system that includes many interacting and interdependent systems. Different mathematical tools such as models have been developed to solve biological, ecological, and environmental problems. Models can be used to predict an output, classify data, and understand processes. Modelling plant behaviour, due to genetic, environmental and soil conditions, and several direct and indirect factors, is a complex process.

3.5.1 Background of Energy Modelling

The excessive use of energy in the developed and developing countries has created several environmental, commercial, technical, and, even, social problems, which need to be studied. Analysing numerous amount of different sorts of information is necessary to reduce the energy consumption and its environmental impacts. For analysing the data, predicting estimates for different conditions, and making better decisions, it is necessary to use powerful tools, such as mathematical representations, known as modelling.

Energy modelling is an interesting subject for engineers and scientists who are concerned with energy production and consumption and its environmental impacts (Al-Ghandoor et al., 2009; Tester, 2005). In the energy area, a wide range of models have been used, from geological models in research on natural resources, to modelling future energy demand (Tester, 2005). The first simple model was designed by Landsberg (1977) to find the best condition of economical solar energy conversion. Since then, several modelling studies on energy have been completed. Most studies have focused on marketing and trade of crude oil and natural gas and these include Marchetti (1977), Stern (1977), and Borg (1981). Since the early 1980s, scientists, such as Fawkes (1987), Hsu et al. (1987), and Hammarsten (1987), started research on modelling technical aspects of energy. These studies can be classified into energy supply–demand models, forecasting models, optimization models, energy models based on neural networks, and emission reduction models.

The forecasting models can be divided into commercial models, solar models, wind models, biomass models, and other renewable energy resources models (Jebaraj & Iniyan, 2006). For example, Sfetsos (2000) used time series analysis, traditional linear autoregressive moving average (ARMA) models, feed forward and recurrent neural networks, adaptive neurofuzzy inference systems (ANFIS), and neural logic networks to compare various forecasting techniques applied to mean hourly wind speeds. Also, the IPCC (2001) had developed a number of models to predict the major environmental impacts of energy use in the future. Most research in the energy area has focused on renewable energy sources and the energy use in the transport sector, building sector, and industry. Therefore, it is a challenge to find expert studies on modelling energy consumption in agricultural production, such as Raja et al.’s (1997), who established a linear model for sustainable agricultural development in India. However, complexity in agricultural production requires modelling methods that can incorporate complex and nonlinear system instructions. Neural Networks is one such recent development that holds much potential for impacting energy research.

3.5.2 Neural Networks for Energy Modeling

3.5.2.1 Introduction

In the past, regression analysis was the most common modelling technique used in energy studies. However, recently, neural networks (NN)s have been increasingly used in energy studies (Sözen, 2009). Due to the ability of neural networks to model complex nonlinear systems in a flexible and adaptive manner, NNs are being used more and more at present (Jebaraj & Iniyan, 2006). Several studies have used NNs for classification, prediction, and problem solving in the energy field. NNs have been applied in a wide range of applied areas, such as mathematics, engineering, medicine, economics, environment, and agriculture (Sözen, 2009). Numerous researchers have applied neural networks for modelling various scenarios to solve different problems, in which no explicit formulations were available (Fang et al., 2000). The main advantage of neural networks is that they are able to use prior information (i.e historical underlying process data) to model complex nonlinear systems. Capturing the underlying process is called the learning of a neural network (Linko & Zhu, 1991).

In the last twenty years, the use of neural networks in energy studies has increased and a wide range of studies using neural networks (NNs) in energy systems has been carried out (Kalogirou, 2001). Nizami and Al-Garni (1995) applied seven years of data to develop a two layered artificial neural network forecasting model to relate the electric energy consumption in the Saudi Arabia to weather data, global radiation, and population. A NN was developed by Mohandes et al. (1998) to predict wind speed. Kalogirou and Bojic (2000) developed and applied a multilayer back propagation learning algorithm to predict the energy consumption of a passive solar building. Kalogirou and Bojic (2000) have reviewed various applications of NNs in energy studies. Fang et al. (2000) developed a NN model to estimate energy requirements for the reduction of cultivated wheat area. Aydinalp et al. (2002) used a simple NN based energy consumption model for the Canadian residential sector. An artificial neural network model to predict the regional peak load of electricity in Taiwan has been used by Hsu and Chen (2003).

Economists use neural networks for forecasting, predicting, and managing the energy markets and analysing the trends of supply and demand for different energy sources (Ashhab, 2008; Azadeh et al., 2007, 2008; Geem & Roper, 2009; Javeed Nizami & Al-Garni, 1995; Kavaklioglu et al., 2009; Sözen, 2009; Sözen & Arcaklioglu, 2007; Yu et al., 2008). In the transport sector, neural networks have been used for transport simulation to reduce the energy demand. Unsupervised neural networks (a NN method that works with only input data to find clusters) have a great ability to compare different transport systems and predict the best solution under different conditions (Ashhab, 2008; Azadeh et al., 2007, 2008; Geem & Roper, 2009; Himanen et al., 1998; Javeed Nizami & Al-Garni, 1995; Kavaklioglu et al., 2009; Sözen, 2009; Sözen & Arcaklioglu, 2007; Yu et al., 2008). NNs have been used in environmental studies to analyse the effects of the use of energy sources on environmental systems. NNs can predict the environmental impacts of different energy resources on the atmosphere, oceans, and the whole of the planet through analysing relevant historical data (Juang et al., 2009; Linker et al., 1998; Sözen & Ali Akçayol, 2004; Yusaf et al.). Also, there are numerous studies using neural networks to analyse energy use in engineering systems, the household sector, and other sectors. However, it is very difficult to find a neural network model to manage or predict energy use in agriculture.

The benefits of using NN models are the simplicity of application and the robustness of the results. The NN has developed into a powerful approach that can approximate any nonlinear input-output mapping function to any degree of accuracy in an iterative manner. NNs have many attractive properties for the modelling of complex production systems: universal function approximation capability, resistance to noisy or missing data, accommodation of multiple non-linear variables with unknown interactions, and good generalization ability (Hagan et al., 2002).

At the base of the NN modelling methods are biological neuron activities. Neurons learn to respond to a situation from a collection of examples represented by inputs and outputs (Himanen et al., 1998; Linko & Zhu, 1991) and neurons control and manage their reaction to the same situations. Scientists have tried to mimic the operation of the human brain to solve various practical problems by using mathematical methods. They have found, and used, various neural networks to solve practical problems. Neural networks include a wide range of mathematical methods and artificial neural networks (ANN), a commonly used term to differentiate them from biological neural networks, have become one of the most important modelling methods that have been used more than other modelling methods for mapping complex input-output dependencies (Linko & Zhu, 1991; Pachepsky et al., 1996). Samarasinghe (2007) states that ANN can solve many biological, ecological, and environmental problems, and can predict an outcome, understand or explain a process, or classify the outcome of a process. ANNs are good for tasks involving incomplete data sets. These capabilities help scientists create a variety of neural networks for a number of tasks including predicting outputs for known inputs. With a brief introduction to biological inspirations for neural networks, the next section provides an introduction to neural networks relevant to the thesis.

3.5.2.2 Biological Neural Networks

The brain processes information through neural networks. The brain has remarkable ability to process the primary (noisy, complex, irrelevant, and missing) data and it learns concepts over time. The incredible capability of the brain comes from its massive, complex, and parallel neural networks. It can process, classify, and even, simulate the information, which it receives via senses to form an internal model (Samarasinghe, 2007).

A biological neuron is shown in Figure 3.19. In the brain, the axon of each neuron transmits its information to other neurons through synapses via an electrochemical medium called neurotransmitters. The synapses of a neuron receive information from approximately 10,000 other neurons. It is estimated that the human brain has around 100 billion interconnected neurons (Hagan et al., 2002; Kalogirou, 2001; Kalogirou & Bojic, 2000). The repeated activation of neurons in a network results in a response of the brain. The brain reacts differently to various excitations. The biological neurons adapt themselves throughout their life to various external stimuli. Sometimes, the brain does not think about the required reactions because it uses previous experience. For example, eyes are closed quickly after any unexpected action in front of the face. However, it is important to note that more than just logic and experience, the human brain is involved in perception, awareness, emotional preferences, values, and the ability to generalise and weigh options to solve problems, which machines are not able to do (Hagan et al., 2002; Kalogirou, 2001).

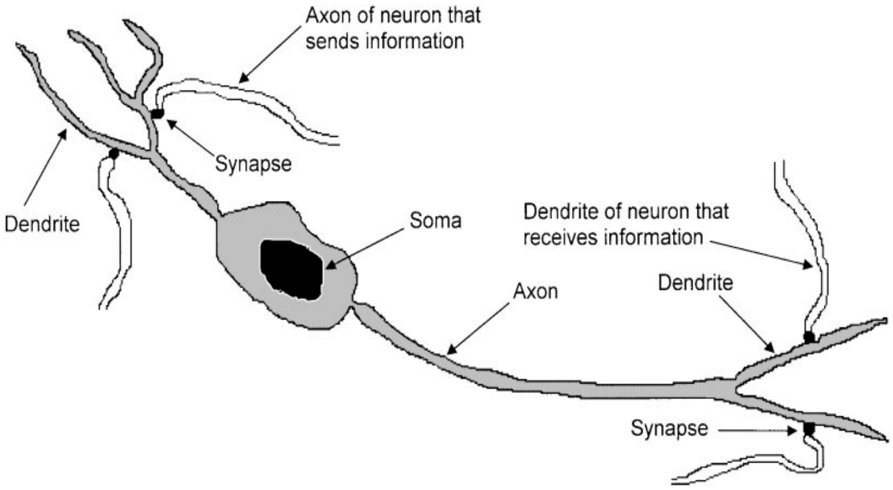


Figure 3-19 A simplified model of biological neuron

A biological neuron consists of three main components: 1) dendrites, which channel input signals; 2) a cell body, which processes the input signals; 3) an axon that transmit the output signal to other connected neurons. The other neurons, which receive this output signal (and the output signals from other neurons), process the signal and pass the output signal to other neurons until the process is completed (Samarasinghe, 2007).

3.5.2.3 Fundamentals of Artificial Neural Networks

Knowledge-based systems generally have two important components: knowledge base and an inference mechanism (Ferraro, 2009). Neural networks use the concept of self-adjustment of internal control parameters (Melesse & Hanley, 2005). Artificial neural network is a non-parametric method that mimics some operations in the human brain. ANNs have flexible mathematical structures; consequently, they can adjust to, and identify, complex non-linear relationships between input and output data using historical data.

In an ANN, neurons are grouped in layers. In complex problems, more than one layer is necessary as shown in Figure 3.20; these neural networks are called feed forward multilayer neural networks or multilayer perceptron (MLP). The layers between the input layer and output layers are called hidden layers; signals are sent from input layers through hidden layers to output layer. In some networks, the output of neurons is fed back to the same layer or previous layers (Xing & Pham, 1995).

Each neuron is connected to other neurons in a previous layer and the next layer through adaptable weights that are adjusted during training of a network. The weights are the parameters of the network. The signals from a preceding layer are multiplied by the weights of their corresponding connections. Each neuron in the hidden layers and output layer sums the corresponding weighted inputs and then computes its output according to a transfer function. In the case of a hidden layer, this output is passed on to the next layer; whereas, in the case of the output layer, neuron(s) output is the network output. In most studies, a feed-forward MLP network trained by a learning method called back propagation (BP) is used to develop apparatus, processes, and product prediction models more than other feed-forward networks (Heinzow & Tol 2003; Hornik et al., 1989; Jebaraj & Iniyan, 2006).

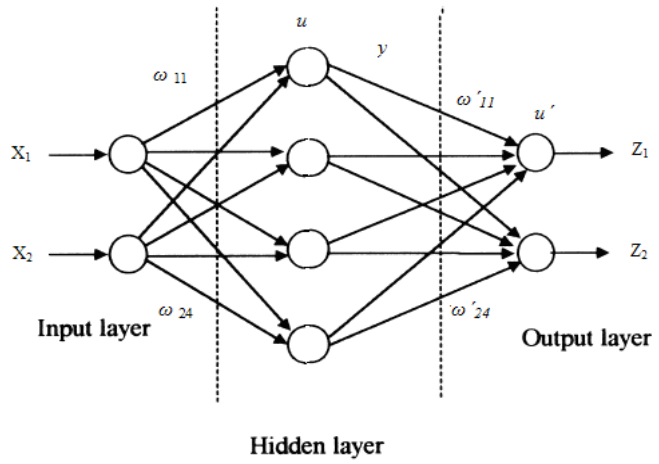


Figure 3-20 A schematic diagram of a feed forward neural network with one hidden layer

In a neural network, it is essential to define how to present the related data to the network. For this purpose, sometimes two different data formats can be used; actual and incremental (change) data. The reason for using such data is to provide the most relevant information to the network and then let the network do pattern matching among the inputs and outputs. Sometimes, not only the straight (actual) data are provided, but also the differences between the present and previous status of the data is important, which are called incremental rate data (Kermanshahi & Iwamiya, 2002).

For simple nonlinear problems, one or a few hidden neurons may be sufficient. However, for highly nonlinear problems involving many input variables, a large number of neurons may be necessary to simulate correctly the desired input-output relationships. Selecting the number of neurons and layers is an iterative process at the moment. When the number of hidden neurons is fewer than the required, errors increase and correlation between inputs and outputs becomes weak, and when the number of hidden neurons is more than the required, problem of over learning causes increasing variance in the predictions (Kermanshahi & Iwamiya, 2002).

In the processing of inputs by the network, each neuron in the first layer (hidden layer) processes the weighted inputs (initial weights are selected randomly) through a transfer function to produce its output. The transfer function may be a threshold, linear or a nonlinear function. Some commonly used transfer functions include Logistic, Hyperbolic-tangent, Gaussian, and Sine (Table 3.3). The output depends on the particular transfer function used. This output is then sent to the neuron in the next layer through weighted connections and these neurons complete their outputs by processing the sum of weighted inputs through their transfer functions. When this layer is the output layer, the neuron output is the predicted output. For example, for neuron j receiving n inputs, x_1, x_2... $x_{n,}$ transmitted through corresponding weights ω_{1j}, ω_{2j} ... ω_{nj} ,the weighted sum (u) is equal to

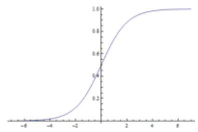
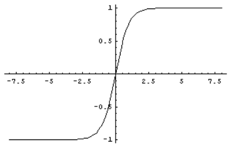
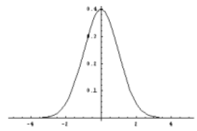
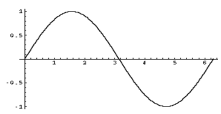
$$u_j = \sum_{i=1}^{n} \omega_{ij} x_i \qquad (3\text{-}7)$$

When u is processed through the neuron function f, the output $y_j=f(u_j)$ is generated as shown in Table 3.3. For a network with n inputs, one hidden layer with m neurons, and one output neuron, the final network output z is

$$z = f'(u') = f'(\sum_{j=1}^{m} \omega'_j y_j) == f'(\sum_{j=1}^{m} \omega'_j f(u_j)) \qquad (3\text{-}8)$$

where ω'_j is the weight in the output layer and f' transfer function in the output layer.

Table 3.3 Some nonlinear neuron functions

Function	*Neuron activation (f)*	*Neuron Output (y=f(u))*
Logistic		$1/(1+e^{-u})$
Hyperbolic- Tangent		$(1+e^{-u})/(1-e^{-u})$
Gaussian		$e^{-u\wedge 2}$
Sine		Sin (u)

Training is a learning process that adjusts connection weights between neurons in the layer. These are set at random values initially. Usually a group of matched input and output vectors (training vectors) is used for training the network because the hypothesis of training is that outputs are dependent on the inputs. For each input vector ($x_1 ... x_n$), the network produces the predicted output and it is compared to the desired or the actual output to determine the error. During learning, training vectors are randomly drawn and presented to the ANN and weights are adjusted in a way that the error is minimised over training iterations. Learning can also take place in batch mode where weights are adjusted after a group of training vectors have been processed by the network.

The base of learning in a network is the error between the actual and predicted output. Several methods of error estimation have been proposed. The Mean square error (MSE) is the most commonly used error indicator over all the training vectors. MSE is very useful to compare different models; it shows the network's ability to predict the correct output. The MSE can be written as:

$$MSE = \frac{1}{2N}\sum_{i}^{N}(t_i - z_i)^2 \qquad (3\text{-}9)$$

where t_i and z_i are the actual and the predicted output for the i^{th} training vector, and N is the total number of training vectors (Samarasinghe, 2007).

In an ideal model, MSE should be zero; however, in real world problems, the chance of reaching this target is slim. Root mean square error (RMSE) is another error estimation, which shows the error in the units of the actual and predicted data. Additionally, there are other error estimations suggested in different studies, such as mean squared deviation (MSD) and root mean square deviation (RMSD) (Kobayashi & Salam, 2000).

The most common learning method is back propagation (BP) based on gradient descent. This involves adjusting the weights according to the gradient of the error surface with respect to the weights so that the error reaches minimum as quickly as possible. After each iteration, weights are adjusted by an increment decided by the learning algorithm. For example, after a particular iteration *m*, a weight ω_m is incremented by $\Delta\omega_m$ calculated as:

$$\Delta\omega_m = -\mu\frac{\partial E}{\partial \omega_m} = -\mu d_m \qquad (3\text{-}10)$$

where E is the MSE, $\frac{\partial E}{\partial \omega_m}$ or d_m is the error gradient with respect to weight ω_m and μ is a constant learning rate, between 0 and 1, that controls the rate of weight adjustment. The new weight ω_{m+1} is:

$$\omega_{m+1} = \omega_m + \Delta\omega_m \qquad (3\text{-}11)$$

The learning rate is used to control the distance of descent. A larger learning rate may lead to faster training; however, the weights may oscillate around the minimum and never reach it (Kalogirou, 2001; Samarasinghe, 2007). The learning process can be further stabilised by using a momentum term that tags the exponential average of previous weight changes to the current weight increment as shown in Table 3.4 (Gradient descent with momentum).

If there is a significant difference between the actual and predicted outputs, more training with training vectors is necessary to correct the weights and reduce error. Learning generally involves presenting the dataset to the network a number of times (epochs) incrementally. When the system reaches an acceptable level of error, the network training ends; and with the final weights thus obtained, another independent validation dataset is used to test the model predictions (Hagan et al., 2002; Haykin, 2009; Kalogirou, 2001; Samarasinghe, 2007).

There are other variants of gradient descent (learning method) to reduce the final error, such as delta-bar-delta, steepest descent, QuickProp, Gauss-Newton, and Levenberg-Marquardt (LM) learning methods (Table 3.4). These gradient descent methods can improve the efficiency of learning owing to their special attributes. For example, in delta-bar-delta, learning rate for each weight is unique and adjusted in each iteration and can be coupled with momentum; QuickProp implicitly incorporate second derivative of error; and Gauss-Newton and LM are explicitly second order error minimisation methods (Samarasinghe, 2007). The problem with Gauss-Newton is that it can, in some cases, lead to increase in error by moving towards a maximum of error surface and this problem is efficiently addressed by LM.

Table 3.4 Various learning methods used in NNs [1]

Learning Method	$\Delta\omega_m$
Gradient descent with momentum	$\theta\ \Delta\omega_{m-1} - (1-\theta)\ \mu_m\ d_m$
Delta-bar-delta with momentum	$\theta\ \Delta\omega_{m-1} + (1-\theta)\ \mu_m\ d_m$ $\mu_m \begin{cases} \mu_{m-1} + k & for\ \ d_m f_m > 0 \\ \mu_{m-1} \times \varphi & for\ \ d_m f_m \leq 0 \end{cases}$
QuickProp	$d_m \Delta\omega_{m-1} / (d_{m-1} - d_m)$
Gauss-Newton	$-\mu\ d_m / d^{s}_{m}$
LM	$-d_m / (H_m + e^{\lambda} I)$

θ = momentum, or weighting, on the previous weight update

d^s = Second derivative of error

H_m = Hessian matrix for iteration m = second derivative of the network error with respect to weights

I = Identity matrix

λ = a learning parameter that is adjusted during training so that when error increases, such as when the weight change make the error moves towards the maximum of the error surface and then λ allows the training to switch to steepest descent (gradient descent) to facilitate the move towards the minimum error surface

f_m = exponential average of past error gradients

Samarasinghe (2007) states that "neural networks are very powerful when fitting models to data". For example, Kalogirou (2001) in his research has shown the prediction of the energy consumption of a passive solar building in summer and winter, as shown in Figures 3.21 and 3.22. Sufficient numbers of variables help the model to predict the output with minimum error. The size of the data sample is extremely critical because without enough examples, neural networks cannot form the correct relationships. The size of the data sample can vary from a few to sometimes thousands; however, in most research, approximately one hundred examples tend to be acceptable. The size of the dataset depends on the complexity of the problem and quality of data.

[1] Details on each of these learning methods can be found in books on Neural Networks. Neural Networks for applied Sciences and Engineering by Sandhya Samarasinghe (2007) provides an extensive treatment of the subject.

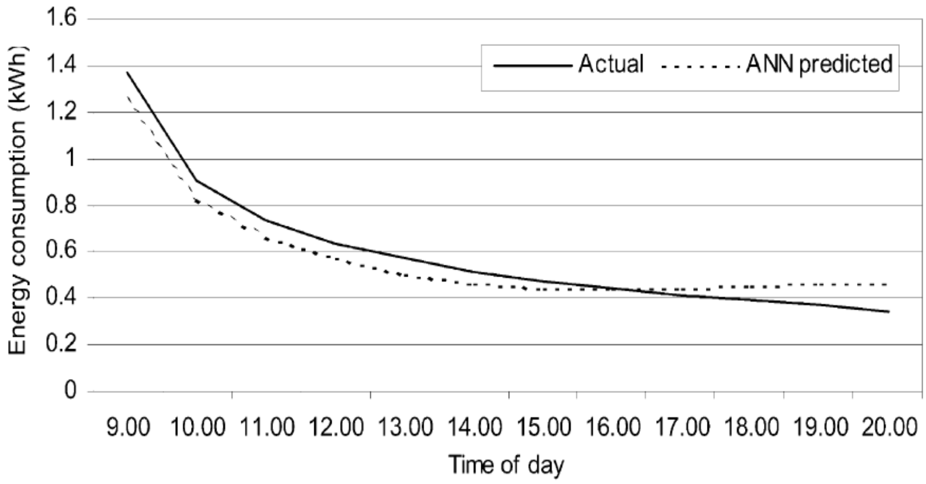


Figure 3-21 Comparison of predicted and actual (simulated) energy consumption—summer (Kalogirou, 2001)

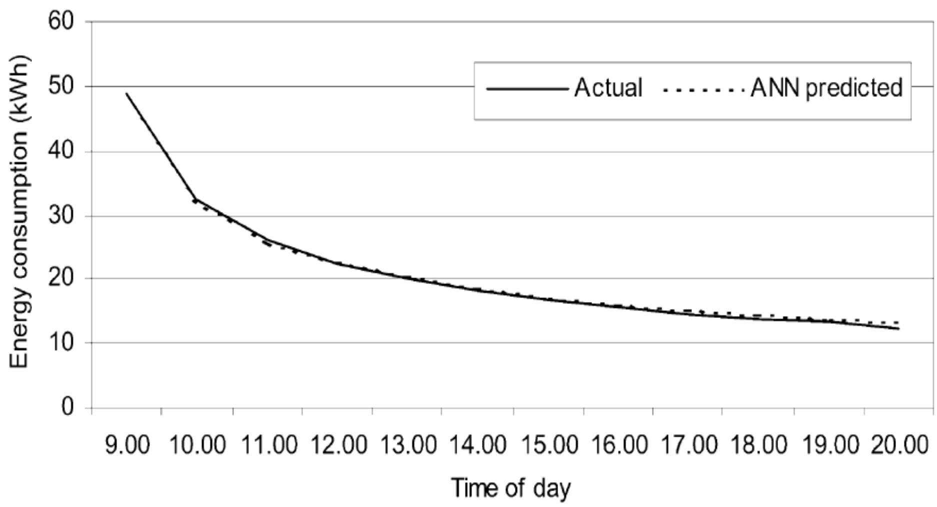


Figure 3-22 Comparison of predicted and actual (simulated) energy consumption—winter (Kalogirou, 2001)

Accuracy of the data set is very important because mistaken inputs or outputs change the model or increase the error (Kalogirou, 2001; Samarasinghe, 2007). Sometimes, finding an accurate database is challenging. Increasing the tolerance in inputs and outputs will increase the tolerance in the predicted outputs. One of the important problems of modelling is that some input-output relationship are complex and nonlinear; thus, understanding their principles can be very difficult (Samarasinghe, 2007). Neural networks excel in capturing such underlying complex nonlinear relationships. Also, in neural networks, it is necessary to use numeric data. In non-numeric data, such as ID numbers, the numbers do not have any order or relevance;

therefore, weights cannot create the correct and proper interaction between inputs and outputs. To solve this limitation, transferring qualitative data to quantitative data through meaningful classification is commonly used. Moreover, in neural network training, a range of inputs data determines the range of applicability of the model; consequently, if the data focuses only on a limited range or some input factors are not incorporated, the model will not be as powerful (Kalogirou, 2001).

When inputs factors have dissimilar ranges, normalization is the best way to reduce differences in the magnitudes of the variables. Normalization puts all the variables in a similar range; therefore, they can be compared better. Standardization, simple range scaling, and whitening are the most common normalization methods (Samarasinghe, 2007). When the number of variables is very high, especially when there are limited numbers of samples, data reduction is useful. The most commonly used method for data reduction is principle component analysis (PCA). PCA is a useful method to select the most important uncorrelated variables. PCA uses the mean and variance of each input variable and the covariance between variables to create a covariance matrix (COV). The PCA transforms the COV matrix through a singular value decomposition method to create new variables, called principle components (PC). The PCA method allows the selection of the required number of input variables from the significant PCs and only these uncorrelated variables are used instead of all the original input variables. Threshold cumulative variance of PCs is a common method to select the number of PCs. A threshold cumulative variance range between 75-90% is sufficient in most studies (Samarasinghe, 2007).

Uncorrelated variables from PCs also help improve the stability of NN outputs. When some input variables correlate with one another, it gives rise to the problem known as multicollinearity. Correlation between inputs reduces the chance of having a unique output due to correlation compensation that can take place in training a network with new random initial values with the same data (Samarasinghe, 2007). Furthermore, it is better to solve any problem using the minimum number of variables. Genetic algorithm is another approach that has been used to select inputs. Genetic Algorithms is a branch of evolutionary approaches and it efficiently searches large solution spaces using the concepts of biological evolution (Hagan et al., 2002).

What give neural networks remarkable capacity to map nonlinear functions is the hidden neurons. Currently, determining the accurate number of neurons is a challenge and there is no standard method to do so. Smaller than the required number of neurons gives rise to the problem of bias, or under-prediction; and too large a number of neurons results in over-fitting leading to increased variance in the predictions. The most common problem in neural network training is overfitting due to the use of a larger than the required number of neurons. In order to avoid overfittng, usually, an approach called early stopping is used where a calibration dataset, extracted from the training dataset, is used at certain intervals during training to test the model performance in order to stop training at the point where overfitting sets in at which point prediction error of the model on the calibration dataset starts to increase. Among various approaches proposed to automate the selection of the optimum number of hidden neurons is Genetic Algorithms (Samarasinghe, 2007).

As a result of the continuous growth in the cost of farm inputs, the price of agricultural production will increase at different rates, which has prompted farmers to change their production patterns. This raises concerns for the global food production in the future. The strong correlation between agricultural production and CO_2 emissions and other environmental impacts creates a selection challenge between global warming and adequate food production. Therefore, expert studies about energy, agriculture, environment, and their interactions are essential. The energy consumption in the production of agricultural plants is a complex interaction involving several parameters that affects the final energy consumed. Therefore, neural network models are appropriate to investigate complex subjects, such as energy consumption and crop production. Accurate data collection, appropriate number of samples, and the appropriate conversion coefficients play a large role in energy use estimation and model creation. In the next chapter data collection, model structure, and selected conversion coefficients are explained in detail.

Chapter 4

Research Methods and ANN Development

For estimating and modelling energy consumption in wheat production, it is necessary to give a clear picture of the study region and the most important direct and indirect farm inputs as well as the methods used to collect relevant data. This study is the first study that investigates, selects and uses a wide range of dissimilar technical and social factors to predict a technical parameter (energy consumption) in agriculture using artificial neural networks. Consequently, the methods used in this study were developed step by step. The first crucial part was choosing appropriate conversion coefficients and formulae to transfer the different qualitative and quantitative data into energy units. The second step, data collection, involved designing a useable and simple survey and finding the best way to contact farmers. The actual data collection process took substantially more time than the initial estimation as will be discussed later in this chapter.

The next step is data analysis for estimating energy consumption and identifying important factors and the last step is developing the neural network model for predicting energy consumption. For data analysis, a series of spreadsheets were essential. As data constituted the core of the study, the database should be flexible, accessible and simple, for both data entry and data analysis. MS Excel was used to evaluate the inputs and estimate the total energy consumption. After a process of data reduction, a sufficient number of variables are used to design the final model to predict energy use in wheat production under different conditions. The model development process was far more complicated than it appeared initially due to the complexity of the domain. In this chapter, the process of data collection, design of spreadsheets, data analysis, and the artificial neural networks (ANN) model are explained.

4.1 General Information about the Site Analysed

Canterbury is the largest region in New Zealand, with an area of 45,346 square kilometres (Statistics New Zealand, 1999). Due to its narrow shape, Canterbury is separated into North, Mid, and South Canterbury. It is the region with the second-largest population in New Zealand, with 559,200 people (Statistics New Zealand, 2009). There are around 35,300 hectares of wheat fields in Canterbury representing 87% of the national wheat area harvested (Statistics New Zealand, 2008a, 2008c).

There are a wide range of landscapes in Canterbury from sweeping coastlines and dry plains to rugged bush-covered mountain ranges. Canterbury soil comprises yellow-grey earths, and their associated stony soils, over a very thick layer of gravel covered by fine materials of variable thickness. These soils were appropriate for intensive cropping of cereals and fodder crops and high-density sheep grazing. The maximum daily average temperature in summer is between 20˚C and 23˚C. Furthermore, the average annual rainfall in most areas is between 650-700 millimetres; however, the high mountains receive over 4000 millimetres of rain annually (Statistics New Zealand, 1999, 2004). In 2007, Canterbury contained a total of 77,600 hectares of arable land; approximately 66% of New Zealand arable land. From 2006 to 2007, the wheat area harvested increased by 7% to 40,500 hectares and the tonnage harvested increased by 32%, to 344,400 tonnes, in New Zealand (Statistics New Zealand, 2008a, 2008c).

4.2 Agricultural Inputs and Energy Coefficients

In this study, energy consumption in wheat production was analysed based on the direct and indirect energy sources. Energy consumption was defined as the energy used for the production of wheat until it left the farm. Data were collected from three different sources: a questionnaire, the literature review, and field measurements. The initial questionnaire was improved step by step through interviews with farmers and scientists of Lincoln University, Landcare Research Ltd, Plant and Food Research Ltd, and some other institutes and companies. This study used a cradle-to-gate analysis, meaning that the transport and waste disposal components of the product’s life cycle were not considered after they left the farm gate. In other words, the energy inputs estimated in this study are those that go into on-farm production systems before the post-harvest processes. The study has considered only the energy used in wheat production, without taking into account the environmental sources of energy (radiation, wind, rain, etc).

To design the survey, it was necessary to recognize the main farming inputs and outputs. The methods adopted by earlier researchers were investigated carefully and the most appropriate ones were chosen to determine the important farming parameters as the following discussion presents in detail. As discussed previously, operational energy involves direct energy sources and in this study direct energy consumption was analysed on the basis of farm operations including tillage, planting, spraying, fertilizer distributing, irrigation, and harvesting. The indirect energy is that used in the manufacture of fertiliser, seed and machinery and their maintenance. Table 4.1 presents these operations, energy sources, and some crucial parameters that the questionnaire collected from farmers. Next sections discuss these selected attributes in detail.

Table 4.1 Variables used in the study

Energy Sources	***Field Operation***	***Indirect Factors***
Human	Tillage	Farm information
Fuel	Planting	Farmer’s attributes
Electricity	Spraying	Soil condition
Pesticide	Fertilizer distributing	Irrigation conditions
Fertilizer	Harvesting	Tractor conditions
Electricity	Irrigation	Machinery conditions
Seed		

4.2.1 Farming Operations

Choosing the appropriate machines and the right method for each operation is important for reducing energy use on farms. Operational (direct) energy consumption in wheat production, such as in tillage, planting, fertilizer distributing, spraying, irrigating, and harvesting, was determined in irrigated and dryland farming systems. The number and duration of operations and the amount of human labour were collected by questionnaires and personal interviews with randomly (as far as possible) selected farm owners who had completed the questionnaires.

The total energy consumption in irrigation was related to the frequency and duration of irrigation, the quantity and source of the water applied, the distance from the source and type of irrigation system. Energy consumption in irrigation was determined for water pumped to the land surface (depths of water well varied from 40 to 150 metres throughout Canterbury) and for surface irrigation.

4.2.2 Energy Sources

Some of the energy sources in the agriculture sector were classified in other sectors. For example, fuel consumption in farm operations may be classified in the transport sector, or, indirect energy sources (fertilizers, seeds, and agrichemicals) may be estimated in the industrial sector. Consequently, official national statistics do not usually show accurate energy use in agriculture and pay very little attention to the energy consumption in the agriculture sector (Pellizzi, 1992). Another important term to include in the survey was the period of energy use, as some energy inputs and outputs were continuous and others were used only once. For example, farmers use tractors routinely for several years; however, they apply seed once for each cultivation. The total energy input (E) was determined as the sum of the input factors (A_i) multiplied by the appropriate energy conversion coefficient for each factor (C_i) as follows:

$$E = \Sigma(A_i C_i) \tag{4-1}$$

For converting farm inputs and outputs to energy, different energy conversion coefficients are needed. Table 4.2 shows values for energy equivalents of different inputs and outputs from some important references. The differences between them come from the technology and estimation methods used and some differences like energy use in seed production were considerable. Selection of the correct energy conversion is very important as without comparing energy equivalents in different studies (see Table 4.2) it is difficult to compare their results.

Table 4.2 Energy equivalents of different inputs and outputs in wheat production

	Energy Coefficients (MJ)					
Input	Mani 2007 (India)	Saunders 2006 (NZ)	Pellizi 1992 (Italy)	McChesney 1982 (NZ)	Ozkan 2007 (Turkey)	Kitani 1999 (US)
Human(h)	1.96	#	#	#	2.3	#
Diesel(l)	56.31	43.6	#	46.7	56.31	47.8
Petrol(l)	#	39.9	#	42.3	#	#
N (kg)	60	65	73.75	65	64.4	78.1
Phosphorus (kg)	11.1	15	13.14	15	11.96	17.4
Potassium(kg)	6.7	10	9.10	10	6.7	13.7
Sulphur (kg)	#	5	#	5	#	#
Herbicide (kg)	#	310	85.95	270	#	*
Insecticide (kg)	#	315	50.55	#	#	*
Fungicide (kg)	#	210	#	#	#	*
Seed(kg)	14.7	#	9.12	2.5	25	13
Outputs						
Seed (kg)	14.7	#	9.12	#	14.7	13
Straw(kg)	12.5	#	10.5		12.5	

* For different varieties, different equivalents were used

The reference did not indicate the value for the item

In the next sections, the method of estimating different energy inputs used in this study is explained.

4.2.2.1 Human (Labour)

The proportion of human energy in the total energy use was not significant; especially, as nowadays new technologies help farmers minimise their physical inputs. Most physical activities on farms involved driving, adjusting, and servicing tractors and machinery, which consumed significantly less energy than the physical activities farmers performed in traditional systems. In this study, the amount labour input (hours) was obtained by the survey and then the work done for each operation was estimated. However, it was difficult to estimate human energy use in operations such as tractor servicing which also contributed to other farm products. It was clear that farmers expended different amounts of energy per hour for each operation and several factors, such as gender, weight, and age can influence their energy use. In this research, most farmers and labourers were male; nonetheless, some female labourers were occasionally seen. Currently, the energy output for a male worker is about 1.96 MJ/hr and for a female worker 0.8 MJ/hr (Mani et al., 2007).

The technique used in this study to estimate the labour energy use was to estimate the hours of activities requiring labour. Energy consumption was determined by multiplying the energy coefficient of the workers by the total hours of human activities in different farm operations.

4.2.2.2 Fuel

The main fuel input into crop farms was diesel. The best way to measure fuel consumption was by field measurements; filling the tractor tank twice, before and after each operation; however, for some operations, such as harvesting this method is too difficult. Due to different soil and machinery conditions and the large number of farms in this study, it was originally decided to use the average fuel consumption for each operation on farms. However, it became apparent that most farmers did not know the fuel consumption for their activities. Many farmers had no estimation of fuel consumption on their farms and it appeared that many of their estimations were incorrect; therefore, fuel estimations were derived from the Financial Budget Manual (2008) of Lincoln University.

There was no doubt that the fuel consumption on farms was related to many factors so it is not correct to use the same rate of fuel consumption for different operations; however, it was difficult to estimate fuel consumption separately for all operations on all farms. In selecting the best coefficients, different reports and studies were investigated and, finally, the ASAE report from Kitani (1999) was selected. Thus, energy consumption for diesel was taken to be 47.8 MJ/l.

Fuel consumption by contractors was estimated by the amount of work carried out on the farms surveyed. In Canterbury, some farmers use contractors mainly for spraying and fertilizing and rarely for planting and harvesting.

4.2.2.3 Fertilizer

Chemical fertilizers were one of the most significant energy inputs on arable farms. The technique used in different studies to estimate the energy use for fertilizer manufacture has been to estimate the requirements for producing one unit of different varieties of fertilizers. In this study, the energy consumption for fertilizer production was determined through multiplying the basic energy for N and P by the percentage of these elements in the final fertilizer.

Farmers in Canterbury predominantly used ammonia-urea (45% N by mass) and super phosphate (20% P by mass). In this study, the energy coefficients for N and P were obtained from the ASAE report (Kitani, 1999) and these were 78.1 and 17.4 MJ/ha, respectively.

4.2.2.4 Pesticides

The most common agrichemicals used in Canterbury to fight against diseases, insects, and weeds on wheat farms were Mcp A, Karate Xeon, and Opus tune. In New Zealand, spraying by aeroplane (air spraying) and tractor-mounted spraying were used to apply agrichemicals to fight wheat farm pests. The most prevalent diseases on Canterbury wheat farms were Septoria Leaf Blotch, Stripe Rust, Leaf Rust and Powdery Mildew.

The technique used in this study to estimate the agrichemical energy use was to estimate how much herbicides, insecticides, and fungicides needed to be sprayed. Energy consumption was determined by multiplying the energy coefficient of pesticides by the total amount of herbicides, insecticides and fungicides. In this study, the energy coefficients for herbicides, insecticides, and fungicides were taken from Saunders et al. (2006) report and these were 310, 315, and 210 MJ/kg respectively.

4.2.2.5 Equipment, Tractors, and Vehicles

The energy needed for producing and repairing different agricultural machinery are given in Table 3.2. To calculate the energy input of tractors and other equipment, it was necessary to know the weight, working life span, and the average surface area on which they were used annually. In this study, the estimated life was taken from the ASAE Standard D497.5 (2009), the annual use of the different machinery was estimated from the questionnaire, and the average weight of different machines and equipment was taken from Wells (2001).

Wells (2001) showed that there was a correlation between tractor mass and related power (hp); tractor power in New Zealand ranged from approximately 25 hp to almost 400 hp. Additionally, an attempt was made to check the power and weight of tractors, combines, and other machinery using catalogues and websites. In recent years, there has been a general trend towards higher horsepower tractors to save farmers' time and expenditure (Centre for Advanced Engineering, 1996; Outlaw et al., 2005; Serrano et al., 2007; Witney, 1988). To calculate the energy used in producing and repairing agricultural machinery, the following formula was used:

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

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) (Table 3.2); 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:

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

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 D497.5 (2009).

Table 4.3 Average mass and estimated life of implement

	Estimated Life (h) (ASAE, 2009)	*Field Efficiency (%) (ASAE, 2009)*	*Estimated Mass(kg) (Wells, 2001)*
Tractor, 2WD	12000	#	*
Tractor, 4WD	14000	#	*
Mouldboard Plough	2000	85	1500
Chisel Plough	2000	85	1500
Heavy-duty Disc	2000	85	1000
Field Cultivator	2000	85	1000
Spring tine Harrow	2000	85	200
Rotary Cultivator	2000	80	200
Air Seeder	1500	70	2000
Grain Drill	1500	70	2000
Fertilizer Spreader	1200	70	200
Boom-type Sprayer	1500	65	100
Combine Harvester	3000	70	*

* Mass estimated by Eq 4-4 and using catalogues

The estimated economic life (T) from ASAE standards and weight (G) of machines are as in Table 4.3. For estimating the weight of tractors and combines, the following equation taken from Wells (2001) was used:

Mass (kg) =40.8×Power (hp) +190 (4-4)

4.2.2.6 Electricity (Irrigation)

As discussed previously, electricity is used mostly for irrigation in Canterbury. Irrigation is one of the most important aspects in agriculture, not only in dry areas, but also some areas with sufficient rain, as irrigation is used to increase the final yield. Irrigation requirements in general are related to annual rainfall, soil type, and plant variety. In New Zealand, electricity is mainly used in arable farms for pumping water from wells and rivers to irrigate farms. The conversion factor in ideal condition for electricity is 3.6 MJ/kWh. However, this conversion factor does not take into account the efficiency of electricity generation and conversion. Saunders et al. (2006) estimated that the primary energy content of electricity in New Zealand was 8.14 MJ/kWh.

Different irrigation systems have been used on farms in Canterbury, such as guns, centre pivots, and rotary rainers. Unfortunately, the large number of variable involved precludes the estimation of a standard power requirement of each system. The main cost in terms of power is pumping/moving of water. Some pumps may take water out of an irrigation ditch–resulting in a lift of only a couple of metres, whereas others may have to lift water from 30 metres below ground level or more, thus resulting in a far greater energy requirement. Additionally, there is the need to move the water from the source to the point where it is required, as well as, in some cases, move the water uphill. Furthermore, there is the friction of the water moving inside the pipes to be overcome. One way to reduce this friction is to use larger diameter pipes; however, this obviously increases the capital cost, so a compromise is usually found.

Over the last 50 years, irrigation systems have been improved; as a result of raising efficiency, water consumption and labour costs have significantly been reduced. However, some of the new irrigation systems, such as sprinkler systems (centre pivot and linear) require large investments and vast infrastructure. One considerable obstacle to using irrigation systems in Canterbury was the shape of the paddocks; some irrigation systems, such as centre pivot covered a circle and others irrigated rectangular areas with a fixed width; however, farm paddocks were usually rectangular or trapezoidal shape; thus, making it difficult to irrigate the paddocks evenly. Irrigating corners and marginal areas reduced efficiency and increased expenditure; moreover, remaking these paddocks, due to natural and artificial barriers, such as roads, trees, neighbours, rivers, and buildings is difficult.

The frequency of irrigation, its duration, and pump power for wheat production were collected from the farms surveyed. The correlation between these factors and energy use in wheat production was investigated separately; also, they were used to estimate electricity use and energy consumption.

4.2.2.7 Seed

In Canterbury, clean and certified seeds are provided in packages from the seed producer companies and private institutions; however, some farmers still used their own seeds. On farms, a wide range of machines and methods are used for planting. Different methods and machinery use different amounts of seed. Germination rates and drilling systems are the main factors used to estimate the amount of seed per hectare. Therefore, under different conditions, the wheat seed require different energy rates. Different varieties of wheat seeds are used for autumn and spring sowing in Canterbury, such as Option, Torlesse, Savannah and Regency. Moreover, different varieties are used for feeding wheat and milling wheat and for irrigated farming and dryland farming. For feeding wheat, Option, Savanah, Claire, and Weston are sown more than other varieties in Canterbury (FAR, 2009).

Several studies have estimated the energy consumption in seed (wheat) production and there are significant differences between the different estimates. Comparison between these studies shows that new seed preparation methods use more energy than previous. Table 4.2 shows the result of some from these studies. Nguyen & Hignett (1995) estimated the energy requirement for wheat seed preparation in Canterbury at approximately 16.6 MJ/kg and this rate is used in this study. The amount and type of seed were collected from the survey and the energy requirement for seed was estimated by multiplying the above energy rate by the amount of seed used.

4.3 Indirect Factors

In addition to direct and indirect energy inputs, there were other technical, social, geographical, and financial factors which may influence energy consumption indirectly. It was not very difficult to find energy inputs; however, for finding the most important indirect factors, several scientists and farmers were interviewed. A wide range of factors were studied, including farmers' social status, age of tractors and equipment, power of tractors, number and sizes of paddocks, and yield.

The above indirect factors and the previously discussed energy inputs were examined to design an ANN model to predict energy consumption in wheat production. Involving indirect factors in energy prediction may help reduce energy consumption with minimum cost and reduction in farmers' income. Therefore, it was necessary to design a practical survey to recognise and collect the most important data linked to indirect factors as well as the necessary energy inputs.

4.4 Survey

Each farm was a unique unit, characterised by different soil types, machinery, farmers' background, and production pattern. Thus, it was necessary to design a flexible and practical survey in order to determine total energy inputs on each farm. The survey included several sections with specific objectives and each section was designed to collect accurate data quickly but comprehensively. The survey design was based on a questionnaire. The questionnaire, incorporating the direct and indirect energy inputs mentioned before, should be capable of collecting all useful factors related to wheat production on farms.

4.4.1 Questionnaire

Data collection was a critical part of this study. As explained in Section 4.4.2, farmers' responses were obtained mainly through face to face interviews (face to face interview and mailing methods were tested and it was found face to face interview were the best way to carry out the survey) conducted in 2008/2009. Before data collection, the survey form was pre-tested by a group of ten randomly selected farmers and these pre-tested surveys (pilot study) were not included in the final data set. The questionnaire included questions about outputs and inputs related to wheat production. The questionnaire included a cover letter (Appendix C) explaining the purpose of the survey and gave some simple information about energy and benefits of this study for New Zealand agriculture. The cover letter also included some information about the researcher and his contact address.

Diversity in the farming communities was high; therefore, it was important to design and use appropriate questions relevant to the whole community. More closed-ended questions were prepared than open-ended questions as such questions are easier and faster to answer and analyse. Also, multiple choice questions were used to help farmers find the right answers in a short time. It was easier for farmers to choose the right answers for categorised questions. For the purpose of the model, some of the parameters were converted from qualitative data to quantitative data. For example, farmer's education was divided into five categories: primary school, high school, Diploma, undergraduate, and postgraduate.

The pre-test group included 10 farmers with different ages, education, production, and background. They were asked to read and answer the questionnaire and give their opinions. Their opinions were investigated carefully, which helped to improve the survey. The experience gained in the pilot study in becoming familiar with New Zealand farming culture, behaviour and beliefs of farmers were invaluable in this survey. The survey questionnaire was further improved by consulting with several scientists and some research students in the university. In this long and iterative process, several options were added, removed, or changed in order to develop a questionnaire that is easy to understand and answer.

In the pilot study, it was found that some farmers preferred a larger font and when two sided printing was used, some forgot to answer the back of some pages. For better outcome, questionnaires were printed single sided and in the largest possible font. Some technical terms were also changed to the names that were commonly used in Canterbury.

Farmers were conservative about answering the financial questions or any questions related to their expenditure and income; therefore, asking financial questions was avoided.

The first section of the questionnaire was designed to establish baseline information about farmers and farms. The second section was designed to estimate different energy sources used in wheat production. Questions were asked on issues relating to the amount and variety of inputs. The third section was designed to establish baseline information on agricultural operations and machinery. Also, the questions can be separated into those related to calculating energy consumption and those related to indirect factors that might be used in the model as inputs.

Data collected included: 1) simple personal information, 2) simple information about farm and production, 3) type and amounts of seed, fertilizers, and chemicals, 4) type and number of field operations, power and age of tractors and combines, and size and age of equipment. Some questions were also designed to identify farmers' attitudes and opinions about energy and fuel saving. For example, in attempt to understand farmers' opinion about improving energy consumption on their farms, the questionnaire asked about their activity and innovations towards saving energy.

As discussed previously, the indirect factors have a crucial role in this study; this is because, adding the relationship between them and energy use on the farm into the NN model could open new doors to energy and agricultural studies. The data include these factors and they were selected cautiously, without making any prior judgments. To this end, several farmers and scientists were interviewed to help choose the right factors. In the next sections, different parts of the questionnaire are explained.

4.4.1.1 Personal Questions

In recent years, due to the use of more powerful tractors and equipment, the human work on farms has reduced. Nonetheless, still farmers managed, drove, and serviced tractors and other machinery. Social and personal attributes, such as emotions, knowledge, education, and experience would influence farmers' behaviours, decisions, and activities.

However, it was difficult to measure some of the social factors without local knowledge and background. Age, education, and relevant experience were the most important personal questions in this study. In general, farmers become experienced with age; however, some farmers started farming at a later stage in life. Experience help farmers make better decisions in critical circumstances; also, it improves farmer's control over farming processes by helping them to select better farm inputs and machinery. It was hypothesised that older farmers usually had a lower level of education and many were not familiar with new technologies and methods, and they were hesitant to use new tools and methods. Because many farmers grow up on their parents' farms and they start to work when they are quite young; it is difficult to exactly estimate the farmers' experience. Consequently, there could be some errors in estimating experience.

Farmers' education was investigated to compare their knowledge and its effect on energy use in wheat production. However, education can only show a part of farmers' knowledge, and other factors, such as personal studies, intelligence, and attendance at technical workshops may improve farmers' knowledge. For better analysis in the model, farmers' education was divided into five categories: primary school, high school, diploma, undergraduate, and postgraduate. The multiple choice questions were designed to select the options by clicking on the right age, experience and education level.

4.4.1.2 Questions on Farm Properties

As discussed before, farms were individual units with diverse characteristics. When the first settlers started to create a new society in New Zealand, they selected the best areas to live. For farmers, soil fertility, water availability, and security were the most important factors; thus, the first rural communities were established around areas with better soil fertility and close to water resources (Velde et al., 2010). Therefore, the distance of the farm to the nearest town was examined in this study.

Another important factor was the size of farm. In addition to the total farm area, the size of the crop area and the size of the wheat area were asked to understand how much farmers concentrated on crop and wheat production on their farms. Due to rotations and prices, the proportion of wheat and other crops on farms might change each year.

Especially, after the increases in the prices of dairy production in 2007 and 2008, many farms were converted from arable farms to dairy farms and some farmers started to keep more cows on their farms. The number of cows and the number of sheep were asked to compare different farming methods and the effect of the concentration of other products on energy use in wheat production.

Although the proportion of each crop may change each year, due to the importance of wheat, it constitutes a high percentage in most rotation systems in Canterbury. The total number of paddocks and the number of wheat paddocks were asked to calculate the average size of the total paddocks and wheat paddocks, respectively. Paddocks have different sizes and shapes; and for various reasons, the average size of paddocks on some farms may be larger than others.

Soil is one of the most important factors in agriculture; it influences pesticide use, fertilizer consumption, farm operations, and the final yields. Plants absorb most of their nutritional elements and water from soil. There are different ways to classify soil in engineering and soil science. In soil science, it is common to classify soil based on soil morphology. Soil texture, soil structure, pH, porosity, and several other factors affect soil classification. In New Zealand, regional soil names, such as Lincoln and Templeton are commonly used by farmers, and scientists and farmers identify soils trough this classification. After several consultations with soil scientists at Lincoln University and other research institutes to find the most understandable terms for farmers, soils were classified based on soil texture into sandy, sandy-loamy, loam, loamy-clay, and clay. This classification helped to convert the soil condition into numeric data based on the soil texture.

Yield is the most important target of farming, and farmers attempt to increase yield, even by spending more energy. As mentioned before, some studies showed that there was a correlation between energy consumption and agricultural production. The pilot study, personal investigation, and official statistics were used to find the most realistic yields and an average yield of between 5 and 14 tonnes/ha was expected in Canterbury. The multiple choice question covered the range between 3 and 15 tonnes/ha. Yield was one of the farm outputs; therefore, it was not included in the NN model.

Farmers were asked about annual rainfall. Precipitation varied from one area to another and from year to year. In the areas with higher rainfall, the possibility of dryland farming increased accordingly. Furthermore, in dry years, more irrigation was necessary, thus, a correlation between rainfall and energy saving in agriculture was expected. Accordingly, a multiple choice question on rainfall covered the range between 400 and 700 mm. More than the annual rainfall, the distribution of precipitation during the farming year may have an effect on irrigation; nevertheless, it was not included in the survey as it is not easy to estimate.

In this study, farm ownership was categorized in a multiple choice question in to three aspects; own farm, rent farm or share farm. It was expected that most farmers worked on their own farms. As mentioned before, farm ownership (non- numeric data) would not be used in the ANN model; however, it was examined to understand the effect of ownership on energy use in wheat production.

4.4.1.3 Seed, Fertilizers and Pesticides

Farm inputs have direct effects on energy consumption on farms. Seed, fertilizers, and pesticides were the most important inputs in wheat and other agricultural production. There were several factors, which may influence seed, fertilizers, and pesticides consumption on farms. During the pilot study, several methods were examined to find the best way to collect the amount of seed, fertilizers, and pesticides used. The first challenge was that the wide range of varieties of seeds, fertilizers, and pesticides meant that it was impossible to use multiple choice questions to select the names of inputs. This meant that farmers might forget to include some inputs or make significant mistakes.

Farmers either used their own seed or seed provided by producer companies. The variety of seed depended on the target of the product (milling or feeding), sowing time (spring or autumn), and farming system (irrigated farming or dryland farming systems). Multiple choice questions were provided for farmers to select from the above factors. Specific places were provided for farmers to write the amount of seed per hectare and the name of the cultivar. The only numeric data in the above factors were seed amount (kg/ha); other factors were investigated to examine their effects on energy use.

Enough room was provided for farmers to write the name and amount of fertilizers and pesticides. In face to face interviews, farmers were reminded, in some cases, to write all agrichemical and fertilizer products used on their farms in the 2008-2009 farming year. The basis of energy conversion of nitrate and phosphate in most references are the N and P contained in fertiliser. The percentage of N and P depends on the type of fertilizer; thus, the content of these elements was calculated and entered in a spreadsheet. In the pilot study, it was found that some experienced farmers decided the amount of fertilizers to be used based on P and N on their farms instead of these amounts in fertilizer. Agrochemicals were separated into herbicides, fungicides, and insecticides in a spreadsheet. Pesticide formulae and rates were checked using the New Zealand Novachem Agrichemical Manual (2009).

4.4.1.4 Machinery and Operations

Tractors are the most important machines in modern agriculture. Tractors produce power for running other machines and equipment on farms. They have different features, such as hydraulic 3 point linkage, PTO, and a drawbar for accomplishing a wide range of operations on the farm. Additionally, it is possible to use tractors to transport inputs and outputs in and out of the paddocks. A wide range of brands, models, and tractor power are available and farmers choose them depending on their requirements, background, and financial constraints. Another important factor in choosing tractors and other machinery is the availability of service and maintenance. Usually, the efficiency of machines reduces as they aged; especially, if there is no appropriate service and maintenance; hence, farmers were asked about the age of tractors and machines, to examine its effect on energy consumption. The power of the tractor was another question asked in the survey. Generally farmers use more than one tractor on their farms. Powerful tractors are used for tillage and other heavy operations. The operations of each tractor were used to estimate annual work hours and energy use in the production of the tractors in this study.

Results

For better understanding of the operations, the power and brand of tractors and combines as well as the brand, ground speed and width of equipment were collected. Most farmers knew the power of their combines and tractors and this was used to estimate the mass of tractors and combines. Ownership of tractors, equipment, and combines was another question that was asked in the questionnaire. It was expected most farmers used their own tractors; however, comparing the energy consumption of farmers who owned their tractors and farmers who used contractors was the main target for asking this question. This information helped to estimate energy consumption on farms and could also be used to estimate other agricultural mechanization factors in New Zealand, which were not available in New Zealand for farmers so they use other countries' databases.

Different machinery is used in agricultural operations; these are designed to do a wide range of operations in the farming process from soil preparing to harvesting and even post-harvesting. During the pilot study, the most common machinery and their popular names were found. Some of the agricultural machinery, such as combines and some sprayers and fertilizer spreaders are self propelled. These machines produce their power themselves; however, other equipment need a tractor to pull them. Farmers depend on machine features, experience, and soil condition to select different farming systems or a combination of machines for the best results. For example, some of them might prefer to use a mouldboard plough twice for soil preparing, some of them might use it once and others might not use it at all. More energy is needed for deep and heavy operations; also, these kinds of operation may increase the possibility of erosion and soil compaction.

Total hours of operation per hectare were asked to estimate the proportion of each operation in the total life of tractors, combines and other equipment. This estimation was necessary to calculate human energy, and the proportion of energy required to maintain and repair farm machinery. Width (m) and ground speed (km/h) of machines were asked to estimate field capacity and examine the effect of these factors on energy consumption. The farmers' answers on tractors and equipment were further scrutinized one by one using catalogues and websites.

Another factor solicited in the questionnaire was fuel consumption for various operations. However, most farmers did not have reliable estimates of fuel consumption and most did not encourage these measurements to be done on their farms. Therefore, in order to reduce estimation errors, a fixed rate of fuel consumption was used from the Financial Budget Manual (2008) of Lincoln University to estimate fuel consumption in each operation. (A limited number of on-farm measurements could be done that helped verify the adequacy of the rate of fuel consumption used in this study, as discussed later in Section 4.4.2). Fuel consumption per unit depended on the size of machine, power of the tractor, soil condition, driver skill, driving pattern, shape of paddock, and many more factors. Additionally, in relation to fuel use, the age and ownership of machines were questioned in order to examine their relationship with energy consumption. The ownership of machines was asked to assess if there is a difference when contractors do some farming operations.

It was expected that irrigation would be one of the most important energy consuming operations in irrigated wheat production. The power of the water pumps was related to the depth of the wells, distance between paddock and pump, and the irrigation system. In Canterbury, most farmers used electric pumps; however, the power and energy use of diesel pumps were asked as well as that of electric pumps. Electricity use (kW/h) and fuel consumption (l/h) of pumps, irrigation duration (h/ha), and irrigation frequency were asked in the survey; consequently, it was possible to estimate energy use of irrigation per hectare. Some irrigated farms had been converted to dryland farms, or vice versa, in recent years. For this reason, it is difficult to find boundaries between dryland farming and irrigated farming in Canterbury.

4.4.2 Sampling

There were no suitable statistics to find the number of farmers in Canterbury. According to Statistics New Zealand (2003) there were 2,685 grain, seed and fodder crop land farms in Canterbury; but, it was not clear how many of these farms were wheat producers; in addition, many arable farms had been converted to dairy farms after 2003, a trend that is continuing presently. Furthermore, some farmers, for financial reasons, had started to cultivate new plants instead of wheat in common rotation systems; thus, it was impossible to estimate the total number of wheat farms. Finding 100 samples was the first target in this study. To collect samples (farmers), three different methods were used: face to face interviews, contact through mail, and an online survey. The online survey was the fastest method for participants; however, it was found that most farmers did not have sufficient knowledge of the internet use and only a portion of the farmers could use the internet. Therefore, the focus shifted to the other methods.

To contact farmers, it was necessary to find their addresses and telephone numbers. North, Mid, and South Canterbury Federated Farmers were asked to introduce some farmers. The same request was sent to other research and farming institutes and organisations, such as Foundation for Arable Research (FAR) that have contact with farmers. Unfortunately, most of these institutes were not interested in actually supporting this study; most of them promised to help but nothing eventuated. To solve the problem, different ways to find farmers' addresses and telephone numbers were attempted. For example, farmers' addresses and telephone numbers were found through career pages in newspapers when they advertised jobs on their farms. However, this was very time consuming. Finally, one interested farmer was contacted and was consulted to prepare the short list of farmers in Canterbury.

One by one, farmers were contacted and some of them were happy to be involved in the study; however, when the oil price reduced during the study, their interest waned. Many farmers did not want to be involved in this study; their reasons being: they were too busy, the subject was not of interest to them, they were fed up with student surveys, they liked their privacy, or they did not trust foreign students. Some farmers, after making an appointment and meeting them on their farms, suddenly changed their minds and, without any reasonable explanation did not answer the questions or made some of their answers intentionally inaccurate. This happened several times and this could be due to their concern about the researcher or other factors.

It was attempted to send questionnaires to some farmers by mail. After contacting them and explaining the study, if they agreed to get involved in this study, the questionnaire was sent to them. Around 40 letters were sent to farmers; however, only five of those were returned and only one of those was useable. It was found that data collection in the agriculture sector was a difficult and time consuming process and a face to face interview was the best method. This may be the main reason for using only 3-5 respondents to estimate energy use in agriculture in several studies in New Zealand and other countries.

Initially, several farmers were approached during various field shows, exhibitions, and workshops around Canterbury about involvement in the survey, but only few of them accepted the invitation to fill out the questionnaire and only one of them returned the questionnaire. Also, interviewing farmers in the middle of events was not a suitable way for data collection, as there was a high chance of getting inaccurate answers with no possibility to check the accuracy. The few farmers who showed an interest were requested to introduce the researcher to other farmers in the region and, if they were interested, appointments were made for an interview. It was found that having an introduction from one or two farmers to other farmers helped secure an interview; also, it seemed that educated farmers among these were more likely to agree to an interview.

This process made a network of farmers and it was the best practical way to find respondents. It seemed that using a network was a convenient way to find some interested farmers. However, the network concentrated on a similar group of farmers with similar backgrounds or from the same area; thus, during the data collection process, an attempt was made to reduce these errors by searching for a variety of different farms through various other contacts. As shown in Figure 4.1 the final sample was collected from around the Canterbury. Farms related to universities, institutes, and companies were not included in this study. As these farms did not have specific ownership and usually produced wheat for a specific reasons, such as research, breeding, or seed production, their properties were different from conventional farms.

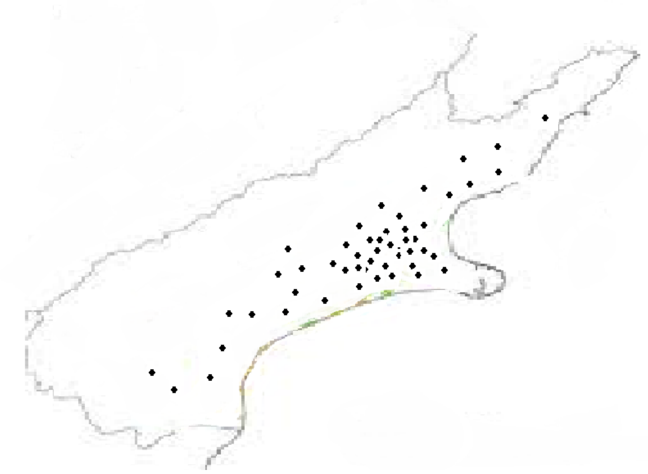


Figure 4-1 Distribution of farmes selected in the study

Face to face interviews were the main method for data collection in this study. The pilot study revealed the difficulty in and importance of finding a representative sample and the need to find the most effective communication method with farmers. The pilot study was very valuable to improve the survey and to find several useful cultural, social, and technical points of conversation that were of interest to farmers in order to have an effective conversation with them. For example, farmers generally had similar issues and technical questions about fuel consumption, carbon tax, and global warming and it was important to give them correct and simple answers, which helped create a friendly environment and encouraged them to answer with interest care and trust.

All appointments were made either during lunch time or after work. Consequently, farmers were either tired or they were not ready for a long interview, which confirmed the design of a short and efficient questionnaire, which seemed to have been done reasonably well. One student colleague suggested involving farmers' wives in the interview. She believed that many farmers' wives helped their husbands to manage their farms and they can provide useful inputs and accurate amounts and numbers. Some farmers were quite accurate and tried to find exact answers from bills, documents, and catalogues; however, some used only rounded estimations. The researcher tried to reduce mistakes by asking the farmers to look at documents and use catalogues, websites, and textbooks. In summary, all possible tools and methods were used to collect data with the highest accuracy, which the researcher believed strongly, was done with the best possible practice considering the practical realties of research on farmers (two filled in questionnaires are shown in Appendix C).

During the survey, an attempt was made to verify some of farmers' answers about farms. For example, the brand and model of tractors, combines, equipment, and pumps were double checked at the farms. It was not possible to attend all farm operations and measure the related factors. Almost all farmers did not encourage field measurements being done on their farms. However, the researcher convinced few farmers and received permission to come to their farms and take some measurements that can be made. So, fuel consumption, ground speed, and the duration of tillage, planting, spraying, fertilizer distribution, and harvesting were measured on a few farms. Fuel consumption was measured by filling the tank twice. As stated before, these provided the confidence in the rates extracted from the Lincoln University Financial Budget Manual (2008) for estimating fuel consumption in various field operations. Another field measurement was yield. The yield was measured by attending the harvesting. Also, one farmer allowed making 12 plots (1*1 m^2) to estimate the wheat production in different paddocks on the same farm. Harvesting of these was done by the researcher who measured their yield at the Lincoln University Field Services Centre. The results confirmed that the yield range used in the survey was adequate for estimating farm yield. These experimental results on yield were not used in the subsequent analyses in this study; however, it was used to estimate the dry weight and proportion of grain and straw of the final product that was useful for estimating the energy ratio. Furthermore, on some farms soil texture was examined by sampling.

As mentioned previously, some farmers used contractors mostly for spraying, fertilizer distribution and harvesting. The contractors were mostly farmers as well; but, there were some companies hired for spraying and fertilizer distribution. Some of these farmers and contractors were contacted and interviewed to find the answers related to their contracting work. Contractors always have more accurate recorded data than farmers, which was used to estimate human energy and machinery energy, such as the width and ground speed of equipment, in corresponding operations.

For a successful data collection process, it was necessary to trust the farmers and they trust the researcher. As mentioned previously, there were a few ways to check their answers, such as personal experience, using catalogues, and farm measurements. One simple limitation was rounding the answers, mostly farm sizes and duration of operations, by farmers, which could affect the final results, correlations, and ANN model. However, such tolerances in agricultural studies are acceptable.

After a long and difficult process, around 50 questionnaires were filled out by farmers. Due to the importance of data accuracy, suspect questionnaires were removed from the study. Farmers' answers were verified carefully and due to wrong or incomplete answers, only 40 questionnaires were used in this study. The importance of the number of farms in the sample was known; however, it was an attempt to avoid any risk that would reduce the accuracy of the database. Most removed questionnaires were filled up in locations away from the farms. For example, they were filled in field shows or exhibitions where farmers were not comfortable, or they were sent by mail. It seemed that the best place to interview farmers was their farms, where they felt secure and had access to documents during face to face interviews.

In summary, the survey for this study was developed based on prior experiences and knowledge and cultural experience gained during pilot study. The farming culture in New Zealand made it harder for the researcher who is an international student to make contact with farmers. Also, the nationality and culture in general created a barrier to be overcome in forming a reliable connection (conversation) with farmers. However, most farmers were helpful and very respectful; for example, they were willing to take time to provide exact data. It was important to create a database with the highest possible accuracy, which would have the ability to be used in other studies; therefore, some questionnaires with suspicious answers were removed from the study. After this difficult and time consuming process, valuable and accurate data were ready for the next steps of the study.

4.4.3 Data Processing

In order to convert different quantitative data to energy and for data processing, it was necessary to design effective spreadsheets. Spreadsheets should provide appropriate spaces for original and calculated data. The final estimations were calculated from conversion coefficients, formulae, and equations in spreadsheets. Data were entered manually into a Microsoft Excel spreadsheet. Microsoft Excel was used for its abilities and facilities for mathematical and statistical calculations and analyses. The main spreadsheet contained all the necessary energy coefficients and was used to calculate energy inputs and outputs for each farm.

From the literature review, equivalent energy inputs were determined for all input parameters. After finishing the survey, for better analysis, some indices and new variables were defined to examine the influence of the interaction of variables on energy use in wheat production. The most important new variables and indices in this study were wheat area/ total farm, crop area/ total farm, average size of wheat paddocks, average size of crop paddocks, tractor power (hp)/farm area (ha), average age of tractors on each farm, and average power of tractors on each farm.

The formulae and equations were entered manually into the main spreadsheet. The inputs, including direct and indirect factors, were placed in approximately 140 columns and 46 columns were used to calculate energy use of different sources and operations. Finally, the energy consumption per hectare for each farm was calculated. The data, formulae, and equations were checked several times to avoid any mistakes or errors. For better analysis, a series of spreadsheets were designed for various aspects of the study and the main spreadsheet was linked to these spreadsheets. For example, in one of the spreadsheets, the final estimations of average energy consumption for energy sources in irrigated farms, dryland farms and all farms were calculated, separately; also, operational energy consumption was calculated in the same spreadsheet. Furthermore, the amount of energy in each operation or energy source, the percentage of that operation or energy source was calculated. In another spreadsheet graphs were drawn. Additional spreadsheets were also designed for statistical calculations and fuel use estimations.

To gain an insight into energy consumption in wheat production, operational (direct) energy including human energy, fuel, and electricity use were employed to calculate energy use for farm operations including tillage, drilling, spraying, fertilizer distributing, irrigating, and harvesting. All energy inputs (direct and indirect) were entered in another spreadsheet that contained direct energy inputs including labour, electricity, and fuel, and indirect energy inputs including fertilizer, pesticides, machinery (production, maintenance and service), and seed. Furthermore, the relationship between farm inputs and outputs were examined. As the farms were of different sizes, an average per hectare was calculated for each input by summing the total amount of a particular input for each farm and dividing the result by the sum total size of all farms. This meant that the averages of the different factors were not averages for those factors on each farm; therefore, larger farms had a relatively higher value in the final average estimations.

In the first step of data analysis, the Pearson product-moment correlation coefficient was used to explore the relationship between different variables. It was the most common measure of correlation; denoted by the letter *r*. The correlation coefficient gives insight into the relationship between two variables and it has been used for comparing and analysing different variables. The correlation coefficient ranges between -1 and +1 where a coefficient of +1 indicates a perfect and positive correlation between two variables. A coefficient of -1 indicates a negative correlation. In contrast, a coefficient of zero indicates no linear relationship between the two variables. In practice, correlation coefficient usually stays between -1 or +1. The correlation coefficient, *r*, is given by the formula:

$$r = \frac{\sum (X - \overline{X})(Y - \overline{Y})}{N\ S_X S_Y} \qquad (4\text{-}4)$$

where $\overline{X}$ and $\overline{Y}$ are the mean of the X and Y values being correlated, S_x and S_y are their standard deviations, respectively, and N is the sample size.

In analysing the relationship between two variables it is important to know, if the correlation coefficient between two variables is significant or not. To establish the significance of correlation, the highest correlation coefficient was obtained from the table of critical values of the Pearson product-moment correlation coefficient. If the highest correlation coefficient for a given number of degrees of freedom is greater or equal to the value in this table, the correlation is significant at the level of significance given. The significant correlation between two variables is important to analyse the relationship between two different variables and it was also used for data reduction in this study.

One of the common problems in correlation is that if the x-y relationship is curvilinear, the r value cannot explain the relationship completely. However, a linear relation can be mistakenly assumed to be the best fit based on the correlation coefficient. In general, it is not advisable to extrapolate the relations beyond the range of the data collected because even if the linear relationship is good within the range of the data, it may be nonlinear outside this range. To reduce these kinds of common mistakes in this study, all graphs for the data that had significant correlations were drawn, and their relationships were examined.

4.4.4 Selection of Variables

For use in the ANN model, it was necessary to select a limited number of relevant and influential variables without any bias; therefore, all information was investigated carefully. There were around 140 original variables, each of which could be a potential input in the final model. The collected data indicated that some inputs can be dropped; for example, 39 farms were managed by owners; therefore, farm ownership was eliminated from the process, or some of the operations were not commonly used; consequently, those machines or operations were eliminated from the analysis as well. Finally 63 columns of inputs and outputs were selected and saved in another spreadsheet. This information was used to draw the graphs and carry out statistical analysis using MS Excel and SPSS software, respectively.

A strong feature of this study was in selecting a few of the best variables from several inputs. In this study, for variable reduction, correlation and principal component analysis (PCA) were used. Initially, variables were selected on the basis of no significant correlation between them but high relationship to energy consumption. Out of the variables that had significant correlations to each other and to energy consumption, the one with the strongest correlation with energy consumption was selected and the other was removed. The selected variables were further reduced by using PCA to select the final most relevant set of variables. Specifically, the PCs were carefully studied to select the uncorrelated inputs based on their coefficients in each PC.

4.5 Neural Network Model Development

ANNs can be successfully trained to describe the influence of energy sources, agricultural operations, and indirect factors on energy consumption in wheat production. The sample size used in this study was 40 farms. Initially, a sample of 30 farms (75%) was randomly selected for training, and the remaining 10 farms (10%) were used for validation. The inputs to the model were the reduced set of inputs found by PCA and an ANN was developed to relate energy consumption (output) to the selected input variables. The selection of the number of inputs and outputs is the first step in developing an ANN.

In this study, several network structures were examined to find the best model using the commercial software package, Peltarion Synapse[1] (Appendix A). Specifically, the influence of (1) the number of hidden layers and neurons, (2) learning algorithm, (3) the type of transfer function in each neuron in the hidden layers and output layer in the model, and (4) type of network structure were studied to approximate the actual energy consumption. Genetic optimizer in Peltarion Synapse software was used to optimize weights, learning rates, and number of neurons. As stated before, Genetic algorithms are based on the biological theory of evolution and involve selection, crossover, and mutation of potential solutions to search for the optimum solutions. Optimization is generally a slow process as large search spaces are explored in the optimisation of each parameter.

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[1] Peltarion Synapse software package is an appropriate tool to design ANN models. Examining different structures and changing most elements in the Peltarion Synapse software are faster than most other modeling software such as Matlab. Furthermore, the software can optimize models using a genetic algorithm and it has a great ability to reduce errors, find the best number of neurons, and optimize weights and learning rates. However, the difficulty to accessing some outputs and the lake of tools to present the graphs and outputs that were necessary for comparing the results of different models, were the most important limitations of this software. The software contained four different operating modes that made up the development of the model including processing, design, training, and post processing (Appendix A).

In the first stage, a simple model with one hidden layer was selected and different learning methods, transfer functions, and other training elements were examined and the model was developed step by step. After initializing the network weights, the training was performed in batch form. Different learning methods, such as Back Propagation, Delta-Bar-Delta, Steepest Descent, Quick Prop, and Gauss–Newton learning methods were tested and the best algorithm was selected to adjust the weights to minimize the mean square error between the actual and predicted outputs.

Peltarion Synapse software provided useful facilities to change various elements in the models. Each model variant was trained for 100 iterations; then, the results, including MSE for training and validation data, were investigated and the best models were saved. Then the models were trained for the next 100 iteration and results were compared for each combination of different model parameters. Several combinations of transfer functions, iteration, learning methods, and numbers of layers created a large number of possibilities. Then, the modelling process extended to multiple hidden layers and several other more complex network structures, such as modular neural networks with a hebbian layer, and the optimisation was repeated.

In summary, the survey was developed carefully, in a step by step manner, to collect as much as information as possible in the easiest way. Total energy consumption was calculated using the most relevant energy conversion coefficient for energy inputs taken from different references. The relationships between the different direct and indirect factors were then examined using the Pearson product-moment correlation coefficient. After data reduction, a group of direct and indirect factors were selected and, based on these variables, and after examining different learning methods, transfer functions and hidden layers, the final ANN model was developed to predict energy consumption under different conditions. In the last step the results from the ANN Model were compared with the Multiple Linear Regression Model.

Chapter 5

Results

The main objectives of this study were the determination and modelling of energy use in wheat production; as a secondary objective, it aimed to examine the relationship between energy consumption and direct and indirect parameters in wheat production as such investigation can provide important insights. A clear initial picture was gained through the collected data and their descriptive statistics: such as maximum, minimum, mean, and standard deviation (SD). For making inferences about population data, the 95% confidence interval was estimated for the most important data.

In the first section of this chapter, the most important factors of wheat production are explained; this information would be useful for other related studies. Specifically, correlations between different factors (direct and indirect) were investigated one-by-one through correlation analysis and graphical illustration. Due to the limited of data, it was difficult to present a lengthy discussion on each parameter and correlation; for this reason, they are explained only briefly. It was noticeable that these parameters would influence energy consumption directly or indirectly and investigating the correlations between different variables and energy consumption was necessary for modelling.

In the second section, energy use in wheat production is explored in detail taking into careful account all relevant direct and indirect inputs and operations. In the final section the artificial neural network (ANN) model development and result are explained. For assessing the performance of the final ANN model, it was compared with a multiple linear regression model, the common modelling method used in agricultural studies.

5.1 Factors Influencing Wheat Production

Several natural, technical, financial, geographical, and, even social factors can influence wheat production and energy use on farms. It was not easy to collect sufficient information on all these factors. However, collecting as much information as possible and analysing the collected information in detail, would give a good view of farms, farmers and farming processes.

In this study, some important direct and indirect factors in wheat production were investigated. In this section, these parameters are explained and their relationships are examined. The tables and figures helped gain a clear view of data and wheat production process in Canterbury; also, the acceptable correlations found between the factors confirmed the reliability of the data collection process. Additionally, this information was used to select input variables for the final ANN model.

5.1.1 Distance from the Nearest Town

Soil fertility, access to water sources, the degree of security and many other factors are important in the development of initial communities (Boserup, 2005). Therefore, it was expected that farms nearer to towns would have better conditions and consequently, higher yield. Thus, it was decided to examine this hypothesis by investigating the effects of distance on energy use, yield and other farm outputs. In this study, distance to farms from the nearest town ranged between 2 and 14 km with average of about 8.8 km. As shown in Figure 5.1, average distance was approximately 7.8-9.8 km from the nearest town with 95% confidence. Increased distance to farms from towns (distance) lead to increased energy consumption in transporting the input and output materials; however, most farms were not far from towns. A town was defined as a place where farmers obtained most of their requirements. However, some important farm inputs, such as fertilizers, machinery, and seed, were sold in special places and farmers obtained these essentials regardless of distance.

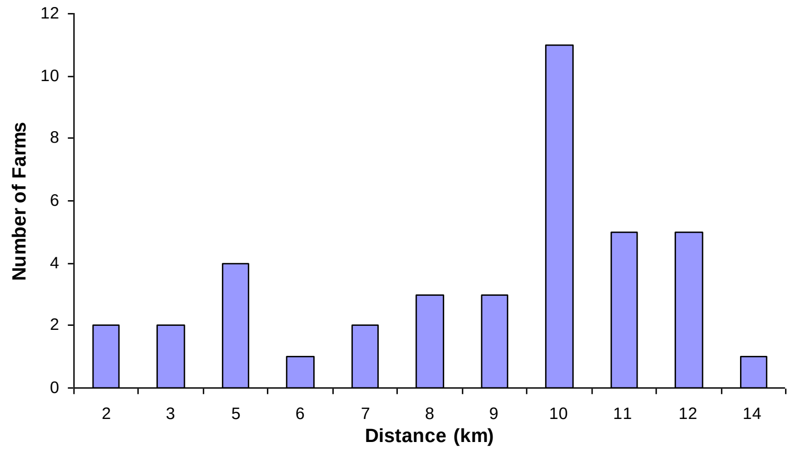


Figure 5-1 Frequency distribution of distance to farms from the nearest town

The results of this study showed that there was no significant correlation between distance and both energy consumption and yield. Consequently, it does not affect yield and energy use in wheat production of the farms in this region. However, distance appeared related to the use of tillage machines. For example, distance was significantly correlated with the number of passes of mouldboard ploughs (r= 0.36).

5.1.2 Farm Conditions

5.1.2.1 Size of Farm, Wheat Area, and Crop Area

The average size of farms in New Zealand and Canterbury was estimated at between 233 ha and 320 ha, respectively (Statistics New Zealand, 2003). The average size of farms in this study was 288.5 ha. Farms ranged from 68 to 880 ha and the average size of farms ranged between 229 and 348 at the 95% confidence interval. Also, as shown in Table 5.1, the average size of crop area and wheat area on farms were 205 and 60 ha, respectively. Table 5.2 shows the correlation between the total farm area, crop area, and wheat area and some other factors. Some of these correlations are explained in this section and others are explained in the next sections.

Table 5.1 Farm conditions in Canterbury

	Maximum (ha)	*Minimum (ha)*	*Mean (ha)*	*SD*	*95% confidence interval*	
					Lower	Upper
Total Farm	880	68	228	184.7	229.4	347.5
Crop Area	850	21	205	150.67	157.2	347.5
Wheat Area	260	6	60	48.5	44.1	74.2

Table 5.2 Correlation between total farm area, crop area, wheat area and other factors

		Total Farm (ha)	*Crop Area (ha)*	*Wheat Area (h)*	*Wheat/Total Index*	*Crop/Total Index*	*Number of Paddocks*	*Number of Wheat Paddocks*	*Average size of Paddocks*	*Yield*	*Annual Rainfall*
Total Farm Area	*r*	1	.69**	.58**	-.25	-.26	.54**	.30	.75**	-.36*	.19
	P value	.	.000	.000	.12	.10	0.0003	.06	.000	.02	.25
Crop Area	*r*	*.69***	*1*	*.87***	*.20*	*.40**	*-.03*	*.46***	*.851***	*.03*	.39*
	P value	*.000*	*.*	*.000*	*.22*	*.01*	*.84*	*.003*	*.000*	*.82*	.01
Wheat Area	*r*	.58**	.87**	1	.51**	.34*	-.11	.55**	.80**	.12	.41*
	P value	.000	.000	.	.001	.03	.49	0.0002	.000	.45	.009

* indicates statistical significance

Farmers select the proportion of each crop depending on the rotation, market, farm conditions, and their knowledge and background. This study showed that there were significant correlations between the total farm area (ha), crop area (ha) and wheat area (ha). Figure 5.2 shows that the size of farm has a significant positive correlation with wheat area (r= 0.58). In addition, as Figure 5.3 shows, there is a strong, significant positive correlation between wheat area and crop area (r= 0.87). The slope of regression line between the wheat area and crop area was statistically significant and was around 0.30. It can be concluded then that the proportion of wheat area on farms was about 30% of crop area. Also, Figure 5.4 shows a significant positive correlation between crop area and total farm area with r= 0.68. The correlation between wheat area and crop area was stronger than the correlation between the crop area and total farm area. This difference between the above correlations meant that farmers, depending on their production, limitations, and markets, selected different proportions of crop areas on their farms;

however, in this crop rotation, wheat usually has a fixed proportion. It was clear that on mixed farms which produced dairy as well as crops, the proportion of wheat area was reduced compared to arable farms. As well as rotation, the price of milk, meat, wool, and other crops would play a role in the proportion of wheat area on farms. It was hypothesised that as the size of the farm increased, the number of paddocks increased. As shown in Figure 5.5, the size of farm was significantly correlated with the number of paddocks (r= 0.54). Figure 5.6 showed that the wheat area was positively correlated with the number of wheat paddocks, with r= 0.55. The correlation between the size of farm and number of paddocks was similar to the correlation between the size of wheat area and number of wheat paddocks. Contrary to expectations, the average size of paddocks and average size of wheat paddocks were similar at approximately 10.6 ha and 10.4 ha, respectively. It can be concluded that farmers did not select larger paddocks for keeping dairy and sheep and they select the paddocks mostly depending on rotation.

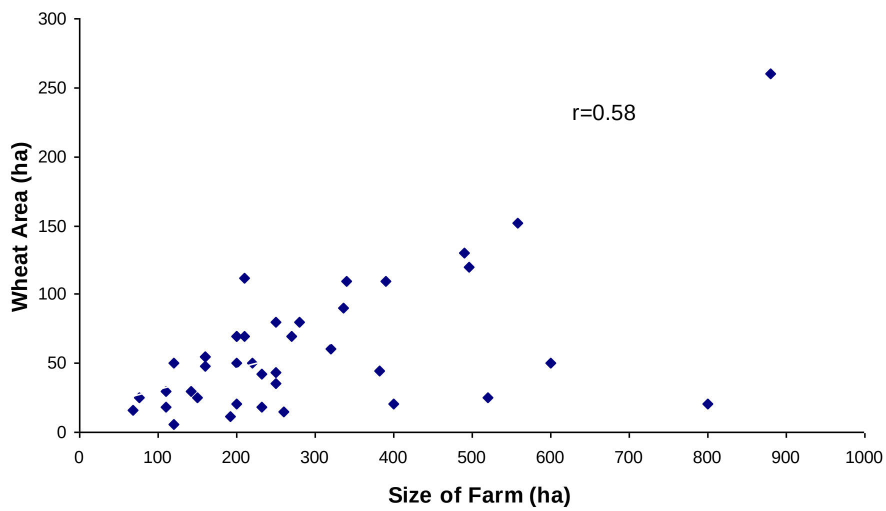


Figure 5-2 Correlation between total farm area and wheat area

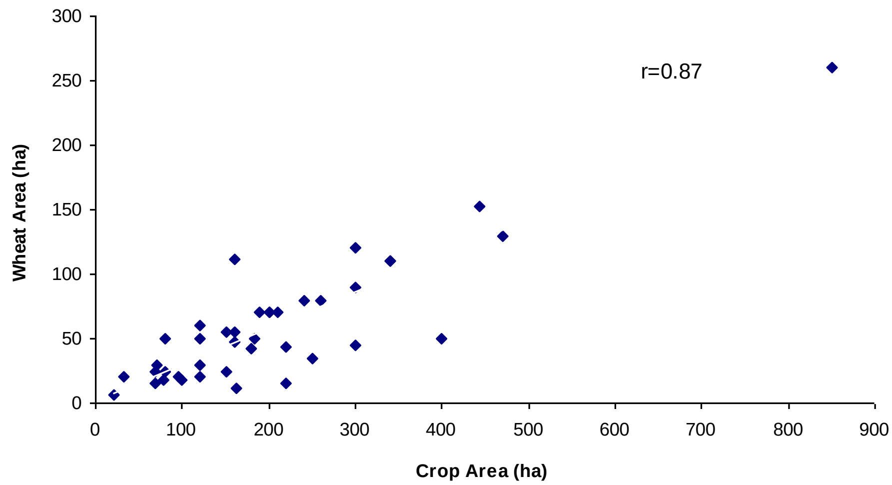


Figure 5-3 Correlation between crop area and wheat area

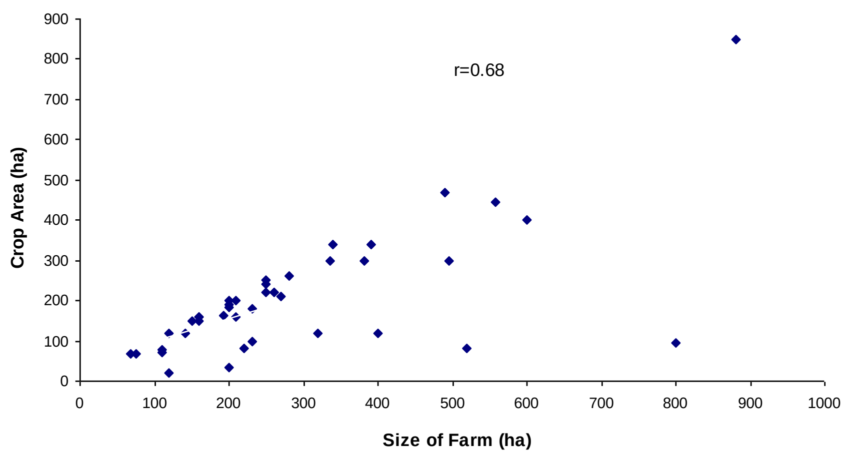


Figure 5-4 Correlation between total farm area and crop area

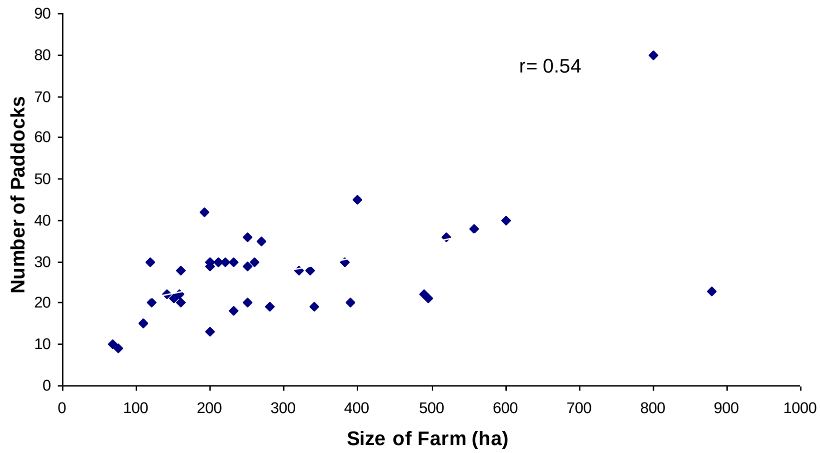


Figure 5-5 Correlation between size of farm and numbers of paddocks

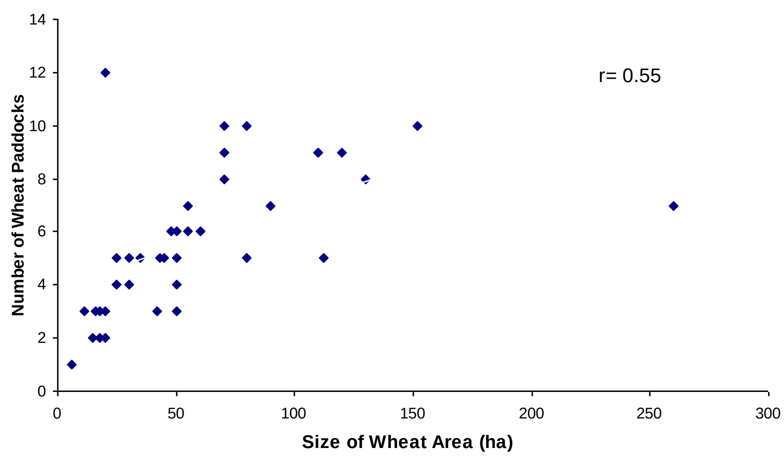


Figure 5-6 Correlation between wheat area and numbers of wheat paddocks

There were significant associations between the size of farm and several other parameters. For example, there was a significant positive correlation between the size of farm and number of sheep (r=0.54). Most arable farmers kept sheep only for a short time for fattening and, therefore, there may be some errors in this estimation. The correlation between the size of farm and number of sheep (Table 5.3) indicated that farmers who had larger farms kept more sheep than others. They have more land residues for feeding; also, keeping sheep was not as time consuming as crop and dairy production. Furthermore, dairy and sheep production would improve soil fertility.

Table 5.3 Correlation between number of livestock and some farm properties

		Total Farm (ha)	*Crop Area (ha)*	*Wheat area (ha)*	*Wheat Area/ Total Farm Index*	*Crop Area/ Total Farm Index*	*Number of Paddocks*
Number of cows	*r*	0.19	-0.27	-0.23	-.40**	-.64**	.35*
	P value	0.24	0.09	0.16	0.01	.00	0.03
Number of sheep	*r*	.54**	-0.06	-0.14	-.35*	-.46**	.77**
	P value	.00	0.71	0.39	0.03	0.003	.00

* indicates statistical significance

Table 5.4 shows the correlations between the size of farm, crop area and wheat area and tractor and combine properties. Some of these correlations are explained in section 5.1.4. There was a negative significant correlation between the size of farm and tractor hp/ha index with r= -0.71. This meant that power per hectare on larger farms, was less than for smaller farms. This difference may be due to better farm management; also, farmers who had larger farms showed a greater preference for allocating some paddocks to keep sheep and cows because livestock production needed less power per hectare than crop production. Additionally, on large farms, due to time limitations, more contractors were used. There were significant positive correlations between the size of farm and both the power of combines and the average power of tractors, with r= 0.38 and r= 0.48, respectively. These indicate that on larger farms, more powerful tractors and combines were used. The two results combined, it can be said that power of tractors and combines increases with farm area but the rate of use of their power is lower on larger farms.

Another interesting result from Table 5.4 was the negative correlation between the age of machinery and size of farm. Similar negative correlations can be seen for both size of crop area and wheat area. These results showed that on larger farms, newer tractors, combine, and equipment were used. For example, the age of tractors and both the crop area (r= -0.36) and wheat area (r=-0.34) were significantly correlated. Also, there were similar negative and significant correlations between age of combines and both the crop area and wheat area, r= -0.39 and r=-0.32, respectively. Similarly, negative correlations were seen between the size of farm and the age of other machinery. The reason may be that the farmers who owned larger farms are in a better financial position to replace their tractors and machinery or tractors and equipment work more than in smaller farms. It is recommended that the negative correlation between the size of farm and the age of machinery be investigated further in future studies.

Table 5.4 Correlations between the size of total farm, crop area, wheat area, and tractor and combine properties

		Number of Tractors	*Average age of tractors*	*Average power of tractor(hp)*	*Tractor hp/ha*	*Power of Combine*	*Age of Combine*
Total Farm	*r*	.32*	-.13	.48**	-.71**	.38*	-.10
	P value	.04	.42	.002	.000	.015	.55
Crop Area	*r*	.33*	-.36*	.73**	-.46**	.67**	-.39*
	P value	.04	.02	.000	.003	.000	.02
Wheat Area	*r*	.24	-.34*	.64**	-.33*	.62**	-.32*
	P value	.13	.03	.000	.039	.000	.04

* indicates statistical significance

It appeared that the average power of tractors on each farm and power of combine was significantly correlated with the size of farm, crop area, and wheat area (Table 5.4). However, these correlations showed that the power of tractors and combines depended more on the size of arable area rather than on the size of farm. For example, Figures 5.7 and 5.8 present the correlations between the size of crop area and both the average power of tractors and power of combine with r=0.73 and r=0.67, respectively. Similarly, the size of wheat area was significantly correlated with both the average power of tractors on each farm and combines with r=0.64 and r=0.62, respectively. However, the size of farm was positively correlated with both the average power of tractors in each farm (r=0.48) and power of combines (r=0.38) with smaller correlation coefficient. As discussed later in this chapter, the new generation of tractors and combines are more powerful; therefore, farmers can improve timelines through driving faster and using wider platforms and equipment.

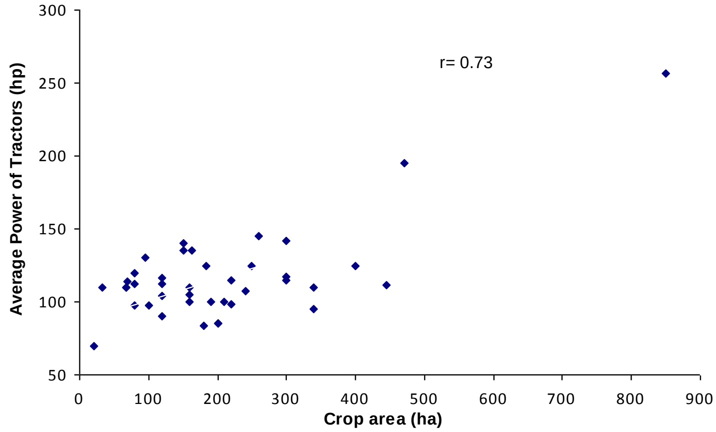


Figure 5-7 Correlation between crop area and average power of tractors

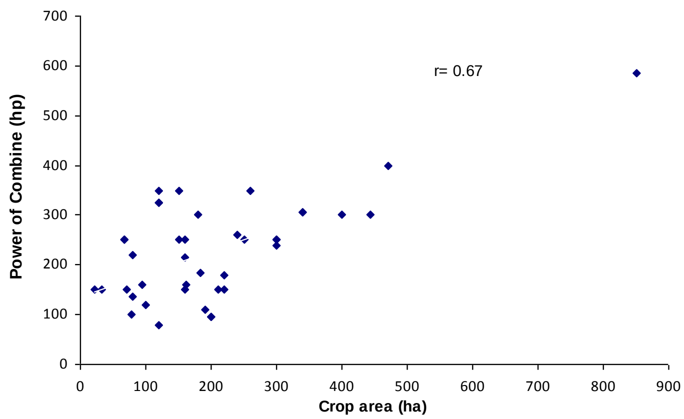


Figure 5-8 Correlation between crop area and power of combine

The size of wheat paddocks ranged between 4 and 37 ha, with an average of about 10.4 ha. The relationship between the average size of paddocks and the wheat area (r= 0.8; Table 5.2) may be due to better and wider machinery and more powerful tractors on larger farms, which helped farmers to manage larger paddocks. Figure 5.9 shows a strong positive significant correlation between the wheat area and average size of wheat paddocks, at r= 0.87. This indicated that farmers followed similar patterns on their farms; meaning that they established larger paddocks and used more powerful tractors and combines with wider equipment and similar rotations and farming patterns.

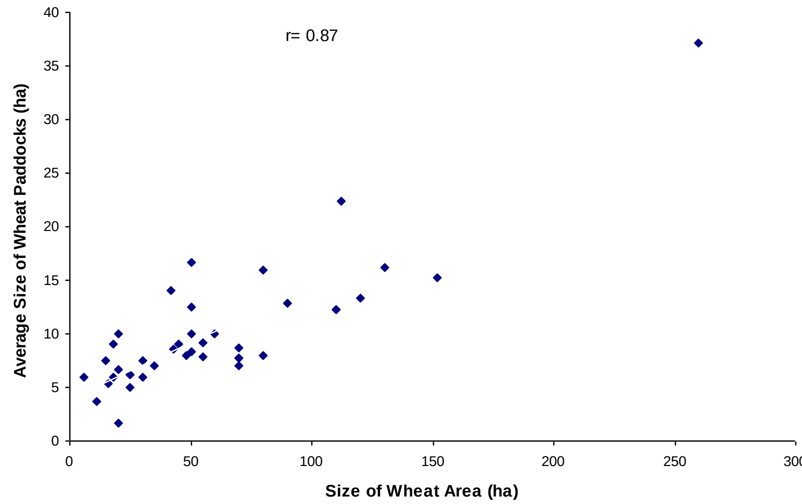


Figure 5-9 Correlation between wheat area and average size of wheat paddocks

Yield was another important parameter that was asked from farmers in the questionnaire and it was the main target of all farms activities. Yield was one of the simplest parameters for comparing farms and farmers. For many farmers, quantity of yield was more important than quality and environmental impacts. They tried to produce more crops by improving techniques and machinery as well as increasing farm inputs. In this study, maximum and minimum yield ranged between 6 and 15 tonnes per hectare, and average yield was estimated around 9.9 tonnes/ha. Average yield in this study was 1.4 tonnes/ha more than the national average yield, in 2007 (Statistics New Zealand, 2008c).

The study showed that yield (tonnes/ha) on larger farms was less than on smaller farms and it was negatively correlated with the size of farm at r= -0.36 (Figure 5.10). Nevertheless, there was no significant correlation between yield and either the size of wheat area or crop area. It was considered whether this can be explained by the fact that as the milk price increased, during 2007 and 2008, farmers naturally focused on dairy more than on arable farming. To test this hypothesis, the wheat area (ha)/total farm (ha) and crop area (ha) /total farm (ha) indices were defined. These two indices represented the proportion of wheat and crop areas for the total farm.

A positive correlation between both the above indices and yield was found and the relationship for wheat of r= 0.53 is shown in figure 5.11. It was clear that in mixed farms, which produced crop and dairy together, the proportion of wheat area was less than in arable farms. This association confirmed that farmers focused on the more beneficial aspects of their farms. Therefore, the proportion of wheat area to the total farm would be more important than the size of wheat area in farm yield analysis. This may be due to different reasons; for example, usually farmers produced crops they have more knowledge about and experience with. In other words, when farmers had experience on wheat (crop) production, the proportion of wheat areas on their farms increased. This would be correct even for arable farms; where farmers produced only crops, the yield and proportion of area dedicated to particular crops the farmers had experience with were higher than those for other crops. This will be an interesting subject for research in future studies.

It was expected that farmers focussed on agricultural products with higher profit margins; for example, as milk price increased, they focussed on dairy more than crops on mixed farms. There was a negative correlation between the yield and numbers of sheep and cows at r= -0.41 and r= -0.38, respectively. These results indicated again that the size of the farm and the proportion of crop area was a key factor to increase the yield in wheat production, and farmers who kept more livestock usually had lower wheat yields than farmers who concentrated on crop production.

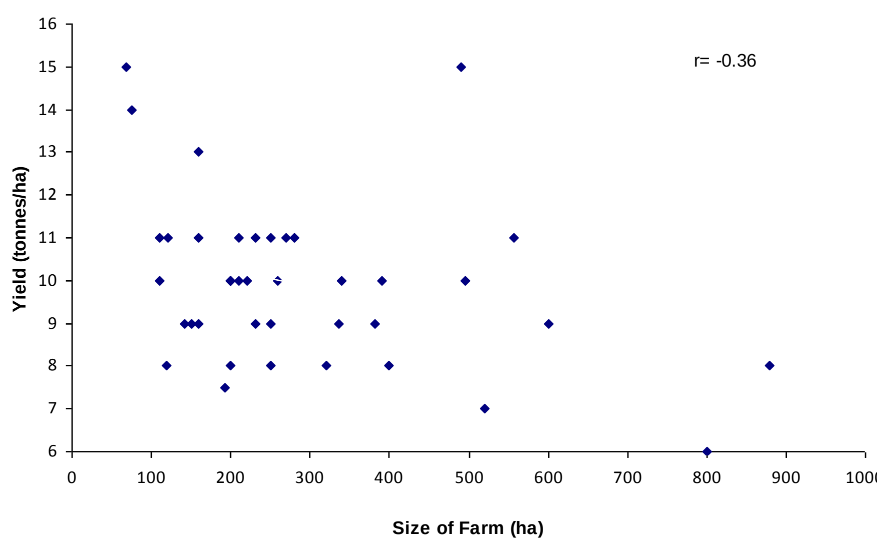


Figure 5-10 Correlation between total farm area and yield

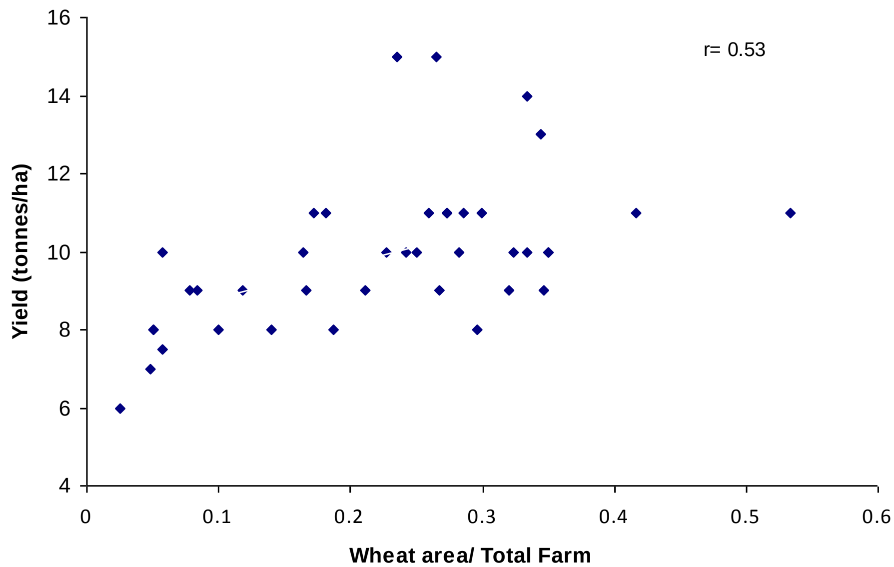


Figure 5-11 Correlation between proporion of wheat area and yield

5.1.2.2 Soil Type

Another important parameter in the questionnaire was soil condition. In this study, soil type (soil texture) was divided into five categories; Sandy (light), Light to Medium, Loamy (Medium), Medium to Heavy, and Clay (heavy). These categories were part of a soil texture classification; however, due to farmers' background, it was referred to as soil structure in the survey. Usually, farmers in Canterbury described the soil of their farms using the name of the area, such as Lincoln or Greenpark. In many cases, soils with different names had similar conditions. Around 57% of farmers suggested that the soil on their farms was loamy-clay and 37% of them said that their soil was loamy. If they were correct, it can be concluded that the soil of 95% of farms was between loamy and loamy-clay.

The relationship between soil type (soil texture) and fungicide consumption was significantly correlated (r= 0.42). This correlation was acceptable because fungi were more active in heavier soils and, through simple search, several articles were found highlighting fungus activity in heavy soils, such as Claus and Filip (1990), Ritz and Young (2004), and Ipsilantis et al. (2009). Additionally, the results of this study showed that in heavier soil, newer tillage machines were used. For example, soil type was significantly correlated with the age of mould ploughs, at r= 0.38. In other words, due to friction and more mechanical resistance, the age of tillage machines in heavier soils was less than that of machines used in lighter soils.

5.1.2.3 Rainfall

Annual rainfall was another parameter that was investigated in this study. Around 70% of farmers estimated the annual rainfall on their farms to be around 600 mm and their estimations ranged from 400 mm to 850 mm, with an average of 628 mm. According to the Lincoln University website, the average rainfall in the Lincoln area in 2007 and 2008 was about 620 mm and this was close to the results of this study. As annual rainfall increased, the demand for irrigation reduced and this influenced farm management. In areas where farmers had water source constraints and rainfall was not enough for dryland farming, more paddocks were used for livestock production. A dryland farming system was preferred in areas with higher precipitation (the threshold annual rainfall for irrigated and dryland farming systems depended on many factors, such as crop, variety, and soil). From the initial analysis, it was found that 30 farms were irrigated and the rest of the10 farms were dryland farms. The irrigated farms in this study used only electric pumps for irrigating the wheat paddocks between 1 and 10 times annually depending on the annual rainfall.

Relationship between annual rainfall and frequency of irrigation had a negative significant correlation, with r= -0.43. This meant that in areas with higher precipitation, irrigation demand is less; thus, farmers needed fewer irrigation facilities for larger areas. Other results confirmed the accuracy of this discussion. For example, annual rainfall was significantly correlated with average size of paddocks (r= 0.46). This indicated that larger size paddocks are established in areas with higher annual rainfall. On irrigated farms, paddock sizes were smaller than on dryland farms to manage the irrigation operations. For example, in irrigated farming, farmers adjust the size and shape of paddocks to suit the irrigators; especially, when centre pivot systems were used. Other results confirmed that the size of farms and paddocks in dryland farming was larger than for irrigated farming. The average size of irrigated and dryland farms was estimated at 273 and 322 ha, respectively, and the average size of paddocks for the two cases was estimated at 9 and 13 ha, respectively.

The results showed that annual rainfall was significantly correlated with the size of crop area (r= 0.39) and the size of wheat area (r= 0.41). This meant that in areas with more annual rainfall, farmers preferred to produce more crops and in areas with less rainfall, farmers preferred to produce other products with less water demand.

5.1.2.4 Farm Ownership

The study showed that 95% of the farmers involved in the survey cultivated on their own farms, one farm (2.5%) was shared and, one farm (2.5%) was rented. A high percentage of farmers who worked on their own farms did not allow on investigation of the relationship between ownership and other parameters.

5.1.3 Social Information

In this study, some simple social information about farmers was collected to examine the relationship between social and technical factors. These kinds of correlations may reduce energy consumption in the long term and help the government make better decisions on energy conservation. In sustainable agriculture, it is crucial to know accurately the factors affecting farming and energy consumption. It is not possible to control or change some of these social factors; however, it is possible to use them for better decision making. Nonetheless, some of the social factors are controllable and it is possible to improve them. Monitoring personal factors and investigating their effects on the farming process in the long term will be an interesting subject for future studies. It is important to note that farmers were always sensitive about personal questions. Prior to this study, an investigation into appropriate social factors was carried out with the help of scientists, some farmers, and someone with experience in contacting farmers. Additionally, to improve data collection, an investigation on farmers' habits, behaviours, and customs was carried out.

Farmers' age, education, and experience were examined in this study as social factors. For detail understanding and use in the model, education was divided into five categories:

primary school, high school, diploma, undergraduate, and postgraduate. The farmers' experience was defined as the years the farmers had worked on farms. The descriptive statistics of the age and experience are presented in Table 5.5.

Table 5.5 Social attributes of farmers in Canterbury

	Mean	*Max*	*Min*	*SD*	95% confidence interval	
					Lower	*Upper*
Age	53	70	32	9.39	49.5	55.5
Experience	32.3	52	12	11.04	28.7	35.8

The average age of farmers was around 53 years and high school was the maximum educational level of approximately 64% of them. No single farmer had a tertiary education. It was difficult to estimate farmers' experience, because the majority of them grew up on farms and they have been involved in agricultural activities since childhood. Table 5.6 shows the correlation between social attributes and some of the technical factors, some of which are explained later.

Table 5.6 Correlation between social attributes and other technical factors

		Age	*Education*	*Experience*	*Number of passes of plough*	*Number of Passes of chisel*	*Number of Passes of Disc*	*Number of Passes of cultivator*	*Number of Passes of Fertilizer Spreader*	*Number of Passes of Sprayer*
Age	*r*	1	-.08	.82**	.45*	-.56**	-.007	.40*	-.28	-.35*
	P value	.	.62	.000	.004	.000	.97	.01	.08	.03
Education	*r*	-.08	1	-.12	-.34*	.02	-.21	-.17	.05	-.01
	P value	.62	.	.44	.03	.92	.20	.29	.74	.96
Experience	*r*	.82**	-.12	1	.31*	-.37*	.10	.29	-.38*	-.40*
	P value	.000	.44	.	.05	.02	.53	.07	.02	.01

Figure 5.12 shows a strong positive significant correlation between farmers' experience and age with r= 0.82. Contrary to expectations, there was no significant correlation between education and both age and experience. This indicated that younger generation farmers were no more educated than old generation farmers and that farmer education does not contribute much to experience.

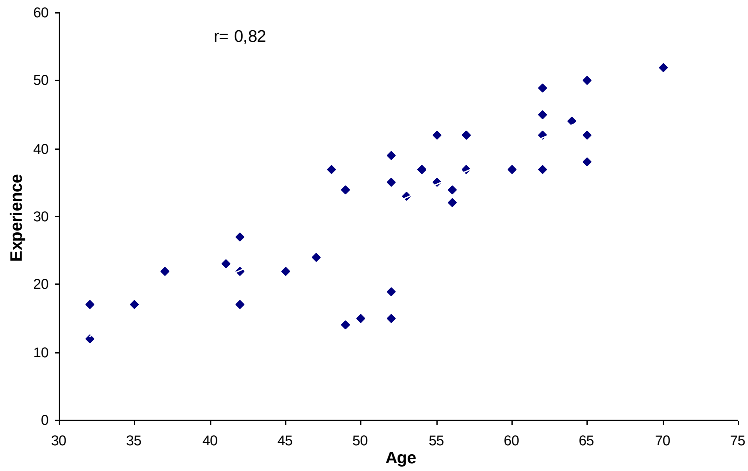


Figure 5-12 Correlation between farmers' age and experience

Surprisingly, there was a negative correlation between the farmers' age and the power of combines (r= -0.36). It meant that the new generation preferred to use more powerful combines. Farmers' age was significantly correlated with the number of passes of mouldboard ploughs (r= 0.45) and number of passes of cultivators (r= 0.40). Also, the results indicated a significant negative correlation between farmers' age and number of passes of chisel ploughs, at r= -0.56. Therefore, the younger farmers might be more risk averse and they accept new technologies and methods more readily than the older farmers. They operated lighter machines for tillage, such as chisel ploughs, to reduce soil compaction and fuel consumption instead of conventional tillage.

There was a negative significant correlation between age and number of passes of sprayer, at r= -0.35. In other words, younger generation farmers sprayed more than older farmers. This means that younger farmers preferred to use agrochemicals more than mechanical methods. Hence, they need more powerful tractors to carry sprayers, as farmers' age was negatively correlated with owning a second powerful tractor (tractor 2), at r= -0.34, which was usually used for spraying. The correlation between the farmers' age and both insecticide consumption and fungicide consumption was not significant; however, both correlations were close to a negative significant association, with P-values of 0.06 and 0.19, respectively.

The results further showed that educated farmers used secondary tillage machines more than primary tillage machines. There was a significant association between education and the number of passes of mouldboard ploughs, at r=-0.34. This indicates that educated farmers accepted new technologies better than other farmers. Education was significantly correlated with insecticide consumption (r=0.35), which must be taken into consideration.

5.1.4 Power Resources

The most important goal of using agricultural machinery is to reduce expenditure, improve timeliness, increase total production, and reduce drudgery in farming activities. Farmers selected appropriate machines to improve the above factors. Also, farmers' background, size of farms, farmers' financial constraints, access to repairs and maintenance, and matching tractors and equipment were important in choosing agricultural machinery. Therefore, the relationships between the technical properties of machines and other factors were investigated carefully.

Tractors and combines were the most important power resources in agriculture. There was an extensive range of brands and models of tractors and combines. In the survey, the most important information about each tractor was collected by interview and the answers were checked on farm. Farmers used at least two tractors on their farms and the number of tractors on farms ranged from two to four per farm. To enable better use in the model and better comparisons, most common tractors were analysed based on their weight, power, age, brand, and model. Tractors were ranked from more powerful (ranked 1) to less powerful (ranked 4) for each farm. Farmers use most powerful tractors for tillage operations and soil preparation. These tractors, due to better traction, are extremely heavy and are not suitable for other operations. Lighter tractors were used for planting, transportation, spraying, fertilizer application, and some secondary tillage.

Table 5.7 shows the average age and power of all tractors and combines; in addition, it presents the average power and average age of tractors on each farm separately. As shown in Table 5.7, the power of tractors ranged from 40 to 320 hp and the power of the combines ranged between 80 and 586 hp. On average, the age of tractors was less than the combines. The average power of tractors on each farm was 115 hp and ranged from 70 to 257 hp. The study showed that approximately 30% of tractors were less than three years old. It means that farmers generally preferred to use new technologies and new machines. The average age of first tractor was 5.8 years and the average age of the second tractor was 11.1 years. During 2007 and 2008, the price of oil and agricultural production increased simultaneously. This increased farmers' interest in using more powerful tractors for tillage operations. Also, a few used combination tillage equipment for tillage and sowing that needed more powerful tractors than the typical equipment. Additionally, Table 5.8 shows the correlations between average age and power of tractors and combines. This showed that new tractors and combines were more powerful than old ones.

Table 5.7 Tractor and combine properties in Canterbury

	Mean	*Max*	*Min*	*SD*	95% confidence interval	
					Lower	*Upper*
Average Power of Tractors (hp) on each Farm	115	257	70	31	105	125
Average age of Tractors on each Farm	10	20.3	2	5	8	11
Average Power of All Tractors (hp)	117	320	40	45	107	126
Average Age of All Tractors	10	35	1	8	7.5	12.5
Power of Combine (hp)	230	586	80	103	197	263
Age of Combine	13	30	1	9	11	16.5

Table 5.8 Correlation between average age and power of tractors and combines

		Average age of Tractors	*Average Power of Tractors (hp)*	*Power of Combine (hp)*	*Age of Combine*
Average Age of Tractors	*r*	1	-.49**	-.39*	.37*
	P value	.	.001	.01	.09
Average Power of Tractors (hp)	*r*	-.49**	1	.72**	-.57**
	P value	.001	.	.000	.000
Power of Combine (hp)	*r*	-.39*	.72**	1	-.61**
	P value	.012	.000	.	.000
Age of Combine	*r*	.37*	-.57**	-.61**	1
	P value	.018	.000	.000	.

Previously, it was shown in Table 5.4 that there were negative significant correlations between the average age of tractors on each farm and the size of crop and wheat areas with r= -0.36 and r= -0.34, respectively. These associations showed that as the size of wheat and crop areas increased, farmers used newer tractors. This may be due to more annual use of tractors in crop production than in the livestock sector, which increased depreciation. Also, it seemed that in recent years, farmers have preferred to use more powerful tractors and farmers with larger crop areas bought newer, more powerful tractors more than others. Figure 5.13 shows a negative significant relationship between the age and power of tractors with r= -0.49.

Figure 5-13 Correlation between the age and power of tractors

As discussed previously, the farmers who were in a better financial position were more interested in replacing old machines with new ones; therefore, a significant positive relationship between the age of tractors and machines was expected. For getting the highest efficiency, appropriate equipment and tractors should be matched. When farmers changed their tractors to get higher efficiencies, they should change other equipment as well, such as mouldboard ploughs, sprayers, grain drillers, and fertilizer distributors. For example, Figure 5.14 shows a positive significant correlation between the average age of tractors on each farm and the age of sprayers (r= 0.37). This correlation illustrated that the use of new tractors forced farmers to match their equipment and tractors. Especially as new generation of sprayers were wider they needed more power to operate.

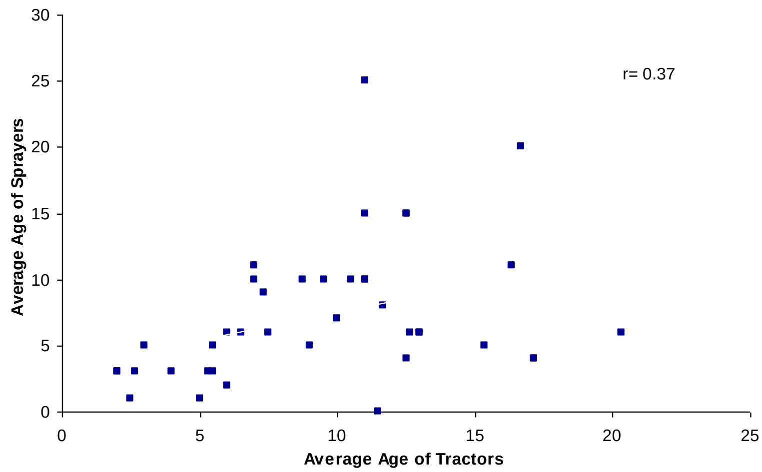


Figure 5-14 Correlation between average age of tractors and age of sprayers

Another example was in Figure 5.15, which showed that the age of combine and tractors were significantly correlated (r= 0.37). This harmony may be due to financial, social, or technical reasons. Similar correlations occurred between the average age of tractors on each farm and age of other equipment, such as grain drillers and sprayers with r= 0.51 and r= 0.37, respectively.

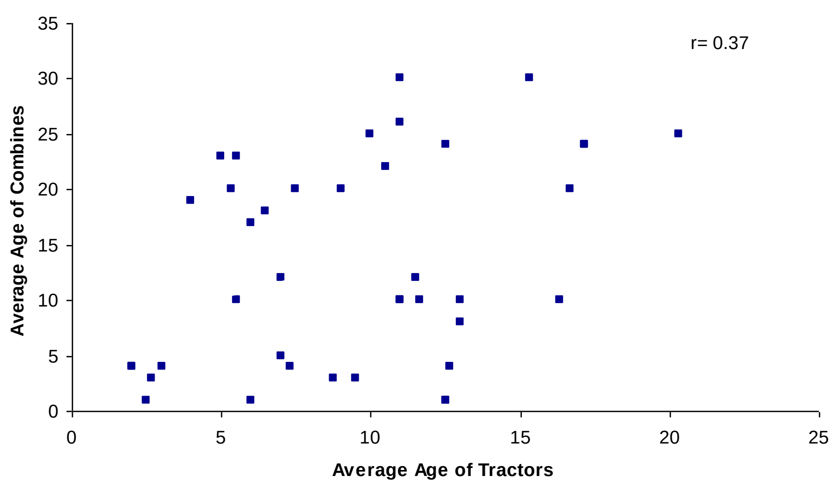


Figure 5-15 Correlation between average age of tractors and age of combines

Farmers used more powerful tractors and wider equipment on larger farms to save time and reduce their expenditure. It was shown in Table 5.4 that the average power of tractors on each farm was significantly correlated with the size of farm and crop and wheat areas with r= 0.48, r= 0.73, and r=0.64, respectively indicating the relative importance of the crop and wheat area components to the total area. Similar correlations have been seen for the power of tractor 1 and tractor 2, except there was no significant relationship between the power of tractor 2 and the size of farm. For example, Figure 5.7 showed that the average power of tractors on each farm was significantly correlated with the size of crop area. The power of combines had a positive significant correlation with the average power of tractors on each farm (r=0.72), as shown in Figure 5.16. These links showed again that farmers who focussed more on crop production used more powerful tractors than other farmers and the proportion of crop and wheat areas were even more important than the size of farm in farm investigations.

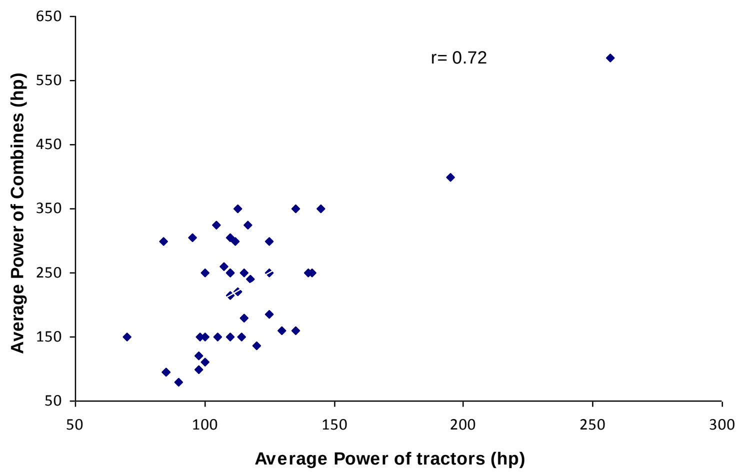


Figure 5-16 Correlation between average power of tractors and average power of combines

In Table 5.4, the tractor hp/ha index indicated the average power of tractors (hp) per hectare (ha). This significantly correlated with the size of farm, crop area and wheat area with r= -0.71, r= -0.46, and r= -0.33, respectively. Figure 5.17 illustrates a significant link between the size of farm and tractor hp/ha index. These correlations demonstrated that on larger farms power per unit was less than on smaller farms. This may be driven by better efficiency, better management, and using contractors; also, as discussed previously, the possibility of keeping livestock on larger farms was more than in smaller farms; therefore, farmers needed less power to manage their farms.

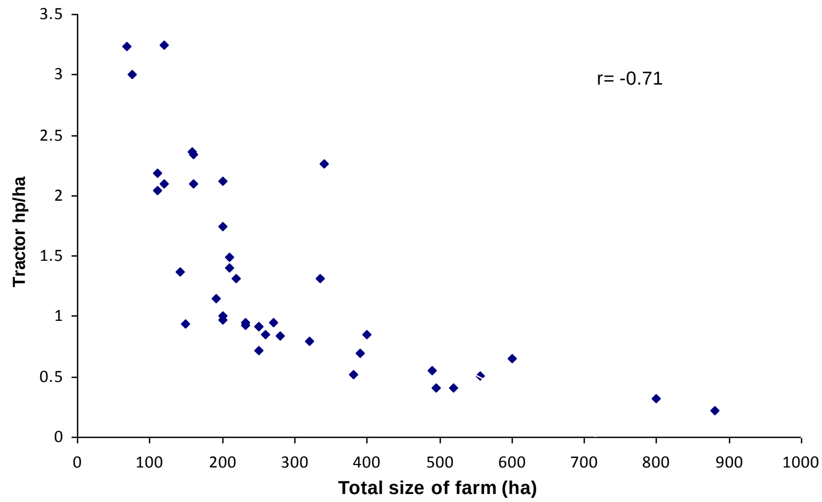


Figure 5-17 Links between the size of farm (ha) and tractor power index (hp/ha)

Moreover, there was a positive significant correlation between the tractor hp/ha index and crop area/total farm index (r= 0.31). Also, as shown in Figure 5.18, there was a positive correlation between tractor hp/ha and wheat area/total farm indices (r= 0.40), which indicated that the proportion of wheat and crop area was important indicators of power use on farms and that the power concentration (fuel consumption) in crop production was more than that in dairy production. The negative significant correlation between tractor hp/ha index and both the size of crop and wheat area and the positive correlation between the tractor power index and the crop and wheat area proportions must be taken into consideration.

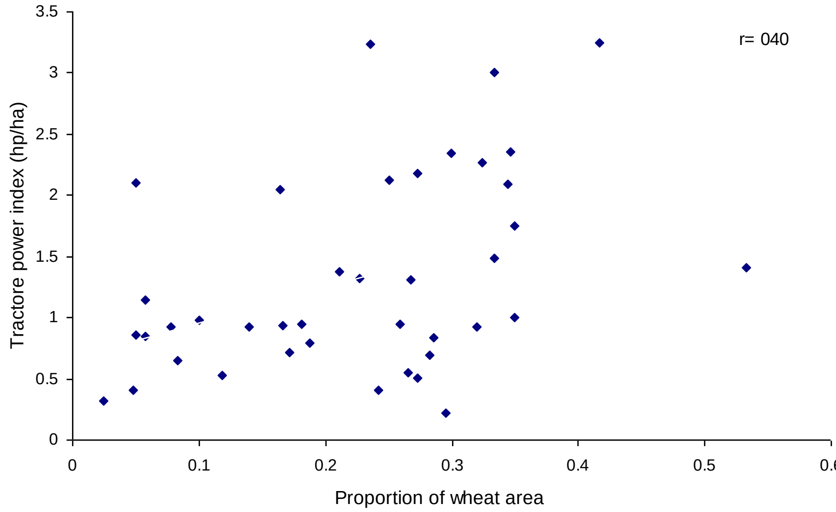


Figure 5-18 Correlation between tractor power index (hp/ha) and proportion of wheat area

As shown in Figure 5.19, there was a positive significant relationship between yield and tractor power (hp/ha) index, with r= 0.48. This indicated that as the power of tractors (mechanization) per hectare increased, the yield also increased, which explained why farmers have preferred to buy more powerful tractors and combines in recent years. Figures 5.18 and 5.19 show together that the proportion of wheat area (crop area), yield, and tractor power per unit area linked strongly together. It seemed that crop specialising and increasing tractor power/ha on farms can increase yield. However, it was necessary to investigate more on the effects of increasing the power on fuel use and energy consumption on farms.

Figure 5.20 shows a negative significant correlation between the power and age of combines (r= -0.61) indicating that new generation combines were more powerful with the ability to work faster with wider platforms than older combines. Again, this correlation confirmed that in recent years, farmers have preferred to use more powerful combines to save valuable and critical time during harvesting operations.

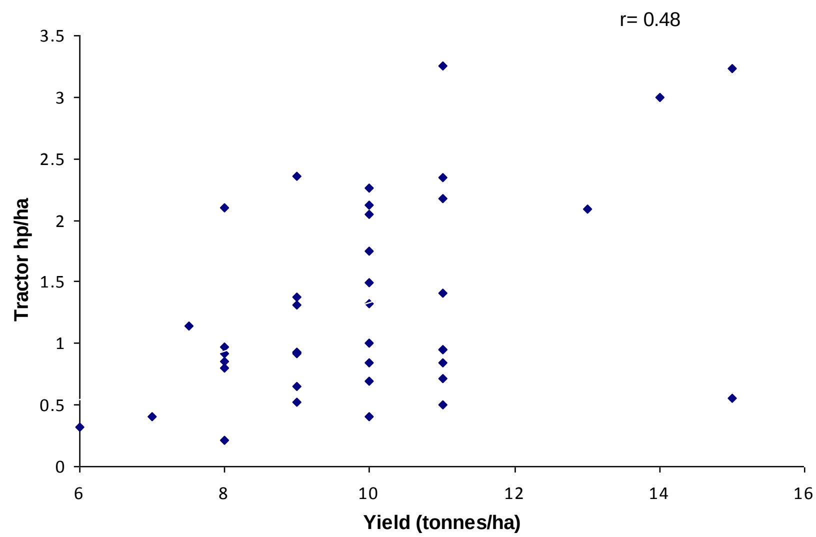


Figure 5-19 Correlation between yield (tonnes/ha) and tractor hp/ha

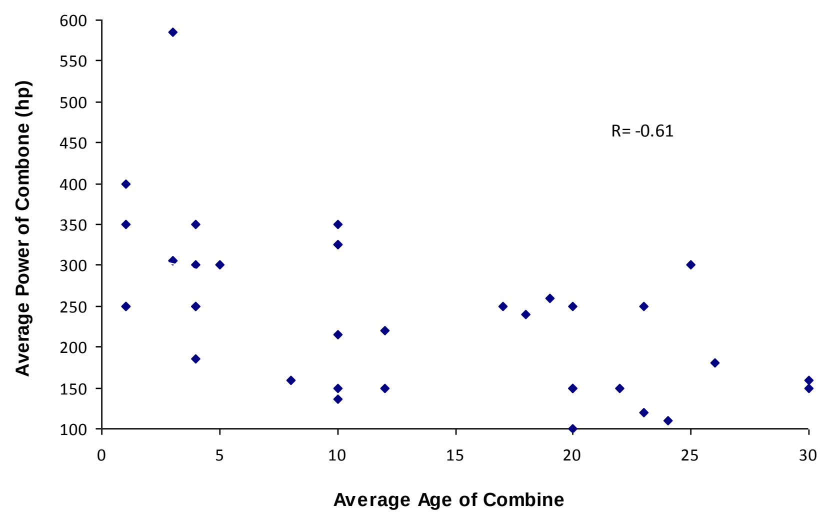


Figure 5-20 Correlation between age and power of combines

5.1.5 Farm Inputs

Fertilizers, pesticides, fuel, and seed were the most important inputs used on farms to increase wheat and other agricultural production (fuel is considered separately, in section 5.1.6). A wide range of fertilizers and pesticides have been used on farms. For better analysis, inputs were classified into N, P, insecticides, fungicides, and herbicides. Farmers used different kinds of nitrogen and phosphate fertilizers (mostly urea and super phosphate) in Canterbury. The amount of nitrogen and phosphate consumption was extracted separately for each farm and Table 5.9 presents the basic statistics on the quantity of fertilizers and pesticides.

Table 5.9 Statistics on the quantity of inputs used in wheat production (kg/ha)

	Mean	*Max*	*Min*	*SD*	95% confidence interval	
					Lower	*Upper*
N	121	203	45	35	243	295
P	36	100	0	26	28	44
Herbicide	1.8	4.2	0	1.2	1.4	2.2
Fungicide	0.8	2.3	0	0.6	0.58	0.96
Insecticide	0.3	3	0	0.7	0.04	0.50
Seed	100	130	75	13	96	104

By using new farming methods and new fertilizer varieties, farmers can reduce fertilizer consumption on their farms. The extensive use of N and P was related to soil condition, crop rotation, method of fertilizer distribution, and farming method. Some farmers followed recent research and applied new fertilizers; so, they managed fertilizer use on their farms more efficiently. Average nitrogen consumption was about 121 kg/ha (270 kg /ha urea) and average phosphate consumption was about 36 kg/ha (180 kg/ha super phosphate). Table 5.9 shows that farmers use herbicides more than insecticides and fungicides. On average, farmers applied around 100 kg of wheat seed depending on the sowing technique, germination rate, and wheat variety. In this study, 12.5% of farmers prepared seeds themselves and others bought them from seed companies. Also, 45% of farmers produced milling wheat and other farmers produced feeding wheat. Furthermore, only 7.5% of farmers produced spring wheat and 92.5% of them preferred to cultivate wheat in autumn.

There was a significant association between nitrogen consumption and crop area (ha)/ total farm (ha) index (r= 0.45), as presented in Figure 5.21. This correlation indicated that as the proportion of crop area increased, N consumption increased; in other words, farms devoted more to crop production consumed more nitrogen than other farms. Also, negative significant correlations between nitrogen use and numbers of cows (r= -0.35) and sheep (r= -0.41) emphasized the accuracy of the above hypothesis that increasing the number of cows and sheep or improving the proportion of dairy would conserve nitrogen use in wheat production. This may be due to rotations where animal manure and urine can provide some nitrogen and nutrients to plants.

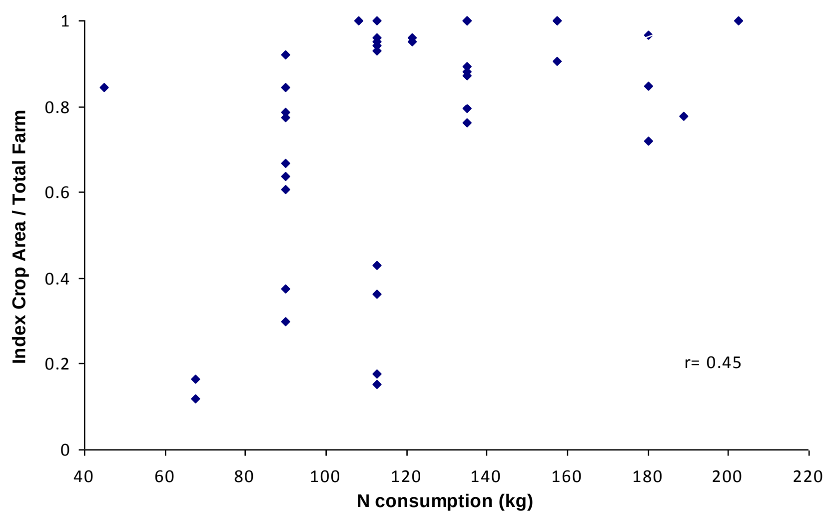


Figure 5-21 Correlation between N consumption and proportion of crop area

The results of this study confirmed the farmer's opinion of the role of nitrogen in crop production. They believed that nitrogen (urea) was one of the most important factors to increase yield, revealed through the positive significant correlation between yield and nitrogen (r= 0.43), as shown in Figure 5.22. It can be concluded that any plan to reduce nitrogen consumption, in current circumstances, would reduce wheat and other agricultural production.

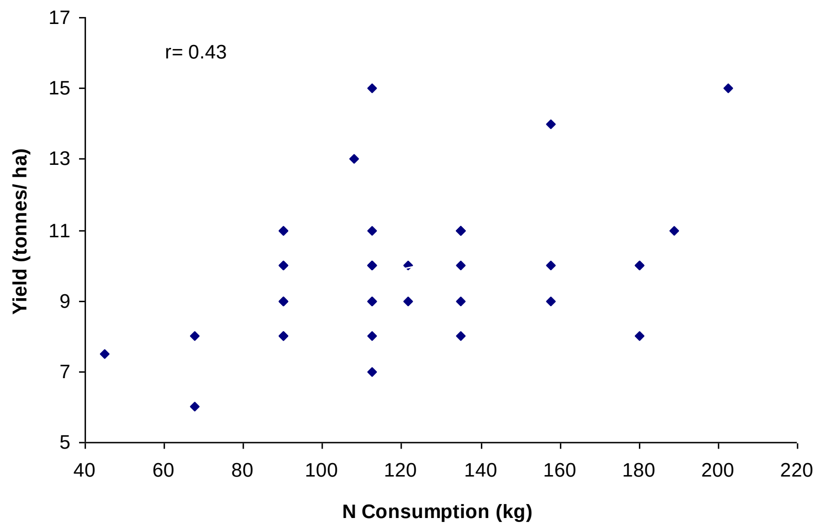


Figure 5-22 Correlation between yield (tonnes/ha) and N consumption

As shown in Figure 5.23, fungicide consumption was significantly correlated with yield (r= 0.59). Maybe, and just maybe, fungi reduced yield more than other pests or they were more active on the farms with higher yield than on other farms. It was noticeable that fungicide consumption in wheat production was extremely low and its effect on yield must be taken into consideration.

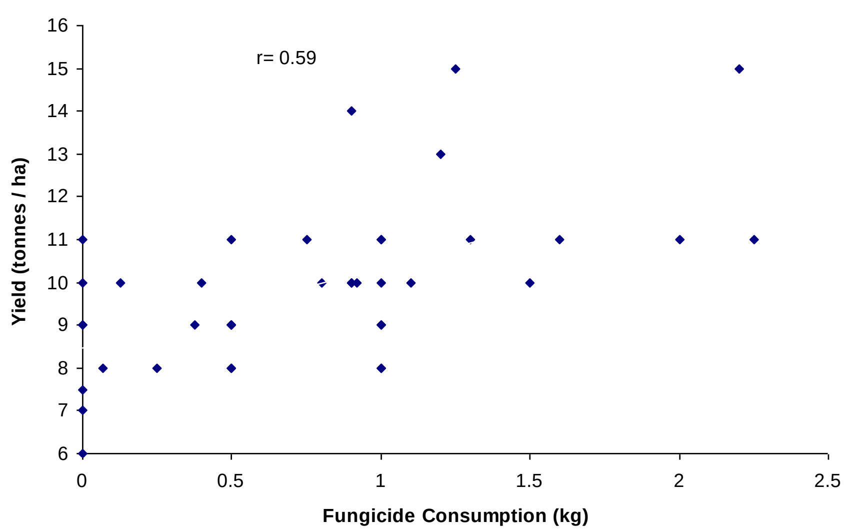


Figure 5-23 Correlation between yield (tonnes/ ha) and fungicide consumption

As shown in Figure 5.24, annual rainfall was significantly correlated with seed consumption (r= -0.53), meaning that as the moisture content of the soil increased, germination increased.

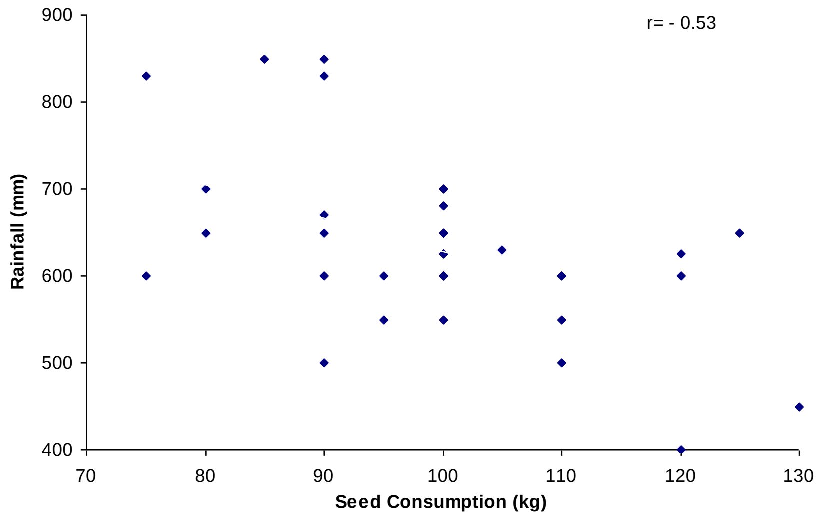


Figure 5-24 Correlation between seed consumption and annual rainfall

5.1.6 Fuel

Fuel is one of the most important inputs in agricultural production; therefore, it was investigated separately. As shown in Table 5.10, on average, 65.3 l/ha of diesel was consumed in wheat production in Canterbury. Table 5.11 illustrates average fuel consumption in different operations. For better understanding, farm operations were classified into five categories; tillage, drilling, fertilizer distributing, spraying, and harvesting. In developing countries with lower degree of mechanization, fuel consumption was less than in developed countries. Nonetheless, diesel powered pumps are used in irrigation in developing countries more than electric powered pumps and this increased the proportion of fuel used; however, in Canterbury most farmers used electric pumps for irrigation. These differences should be noted when comparing results of this study with other studies.

Table 5.10 Statistics of fuel consumption (l/ha)

	Mean	*Max*	*Min*	*SD*	95% confidence interval	
					Lower	*Upper*
l/ha	65.3	96	36	11.9	62.1	68.5

Table 5.11 Fuel consumption (l/ha) in different operations

	Tillage	Drilling	Fertilizer Distributing	Spraying	Harvesting	Total
l/ha	30	5	9	4	18	65
%	45	8	13	5	28	100

As shown in Table 5.11 and Figure 5.25, tillage was ranked first with 45% of total fuel consumption. Between the different tillage operations, ploughing and other primary and heavy operations used more fuel. As farmers are encouraged to use new methods and machinery, such as combination tillage machines, fuel consumption will decrease leading to better soil conservation. In Canterbury, different patterns of tillage were used on farms from conventional tillage to no tillage. Farmers use mouldboard ploughs and field cultivators more than other tillage machines and two thirds of farmers used these two pieces of equipment together or with other equipment. Compared with other tillage operations, mouldboard ploughs and field cultivator operations were more correlated with fuel consumption. For example, there was a strong positive correlation between fuel consumption and numbers of passes of mouldboard ploughs and cultivators with r= 0.63 and r= 0.51, respectively. As shown in Figure 5.26, as the number of passes of cultivator increased, total fuel consumption increased.

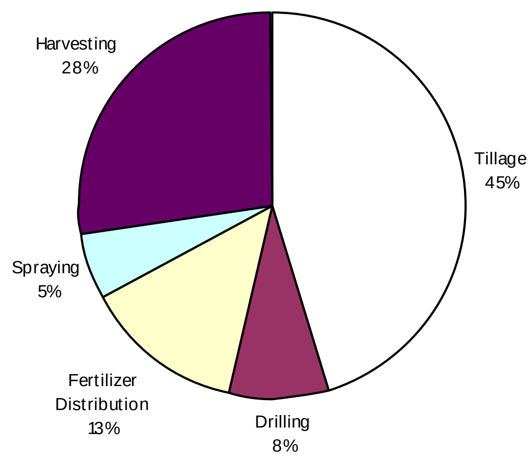


Figure 5-25 Proportion of total fuel consumption in various operations in wheat production

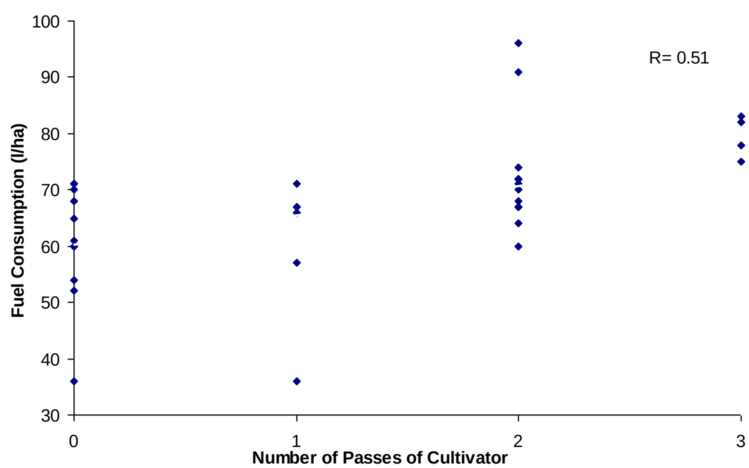


Figure 5-26 Correlation between fuel consumption and number of passes of cultivator

Figure 5.27 presents that fuel consumption is significantly correlated with farmer's education (r= -0.36), which shows farmers with higher education consumed less fuel on their farms (as mentioned before, farmer's education was divided into five categories: primary school, high school, Diploma, undergraduate, and postgraduate). This makes sense, because educated farmers may accept new methods and technologies more readily than others and that would reduce fuel consumption in wheat (and other crop) production. Education can show only part of farmers' knowledge; however, experience, attendance in technical workshops, and personal ability to analyse different events on farms are other factors that may affect farmers' decisions. As shown in Table 5.12, average fuel used in irrigated and dryland farming systems were 64.9 and 66 l/ha, respectively. This showed that the fuel consumption in dryland farming and irrigated farming systems was similar.

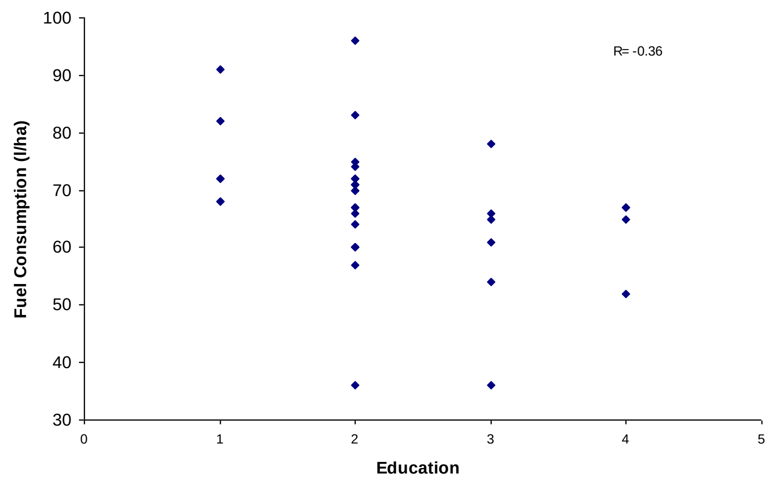


Figure 5-27 Correlation between fuel consumption and level education

Table 5.12 Quantity and percentage of fuel consumption in different operations in different farming systems

	Tillage		*Drilling*		*Fertilizer Distributing*		*Spraying*		*Harvesting*		*Total*
	l/ha	%	l/ha	%	l/ha	%	l/ha	%	l/ha	%	l/ha
Irrigated	29	44.9	6.2	9.5	8.3	12.7	3.3	5.1	18	27.8	64.9
Dryland	30.3	45.9	4.3	6.5	9.3	14.4	3.9	5.9	18	27.3	66

5.2 Energy

On average, energy consumption in wheat production in Canterbury was about 22,566 MJ/ha (Table 5.13); 36% was direct energy in the form of diesel, at 3,121 MJ/ha, and electricity at 4,870 MJ/ha (Table 5.14). Fertilizer ranked the highest with 47% of total (10,651 MJ/ha), and electricity ranked second with 22% (4,870 MJ/ha). Table 5.14 and Figure 5.28 present the amount and percentage of all energy sources in wheat production. As shown, fertilizers, especially urea, were the most important energy source in wheat production.

Table 5.13 Statistics of energy consumption (MJ/ha)

	Mean	*Max*	*Min*	*SD*	95% confidence interval	
					Lower	*Upper*
MJ/ha	22,566	36,230	11,497	6,125	20,608	24,524

Table 5.14 Energy sources in wheat production (MJ/ha)

	Human	*Seed*	*Fertilizer*	*Pesticides*	*Electricity*	*Machinery*	*Fuel*	*Total*
MJ/ha	6	1,266	10,651	911	4,870	1,741	3,121	22,566
%	0.03	6	47	4	22	8	14	100

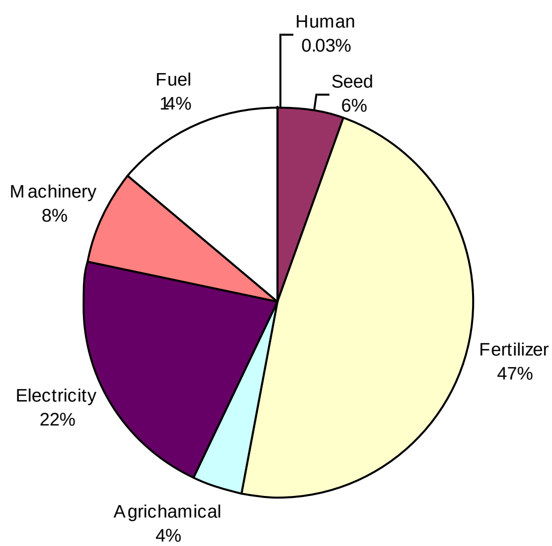


Figure 5-28 Proportion of total energy use in wheat production

For better understanding, the energy consumption in wheat production was investigated separately for irrigated farming and dryland farming systems. Table 5.15 and Figure 5.29 show the energy sources in wheat production on irrigated and dryland farming. Average energy consumption on irrigated and dryland farms was 25,600 and 17,500 MJ/ha, respectively. In both irrigated and dryland farming systems, fertilizer ranked as the highest energy consumer with 40% and 66%, respectively. The main difference between energy consumption in irrigated systems and dryland systems came from electricity that was mostly used in irrigation. Thus, in wheat production, fertilizer was by far the most important source of energy in both systems; electricity came second in irrigated system. On dryland farms, fuel came second and it comes third on irrigated farms. Therefore, for energy conservation, it is necessary to focus more on fertilizer, electricity, and fuel consumption than other factors.

Table 5.15 Energy sources in wheat production in irrigated and dryland farming (MJ/ha)

	Indirect Energy				*Direct Energy*			
	Seed	*Fertilizer*	*Pesticide*	*Machinery*	*Human*	*Electricity*	*Fuel*	*Total*
Irrigated	1329(5%)	10193(40%)	1045(4%)	2169(9%)	8(0.03%)	7762(30%)	3099(12%)	25,600
Dryland	1160(7%)	11430(66%)	689(4%)	1018(6%)	4(0.02%)	0	3156(18%)	17,458

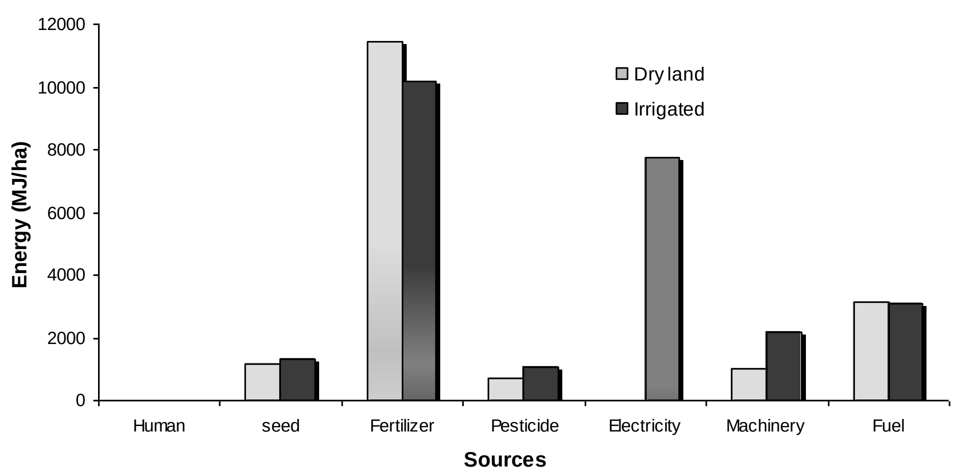


Figure 5-29 Sources of energy consumption in wheat production in dryland and irrigated farming

One of the most revealing results of this study was the positive significant correlation between yield and energy consumption in wheat production (r= 0.47), as shown in Figure 5.30. This indicated that for increasing yield, more energy should be spent. It may be mostly due to irrigation and fertilizer use, which prepared better conditions for plants. Therefore, finding a balance between energy consumption and agricultural production would be necessary for achieving the goals of environmental conservation and higher agricultural production. Finding solutions to reduce tension between production, environment and income should be one of the most important topics to study.

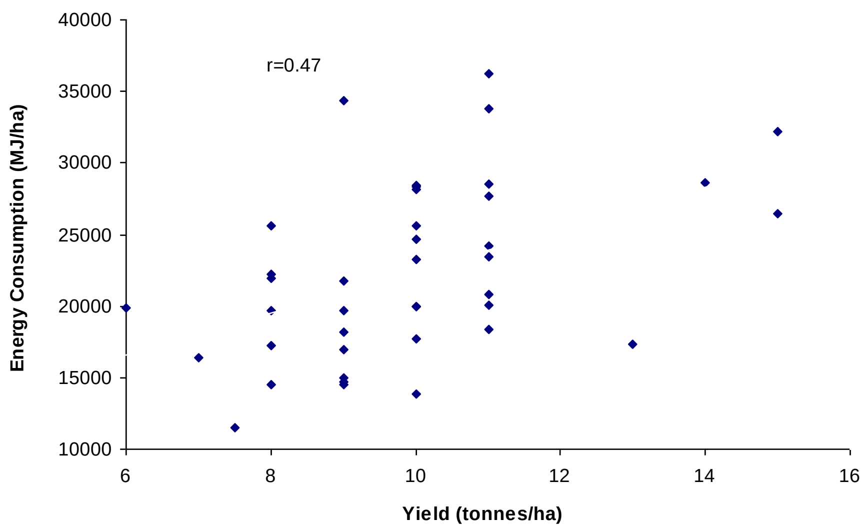


Figure 5-30 Correlation between energy consumption (MJ/ha) and yield (tonnes/ha)

As shown in Figure 5.31, there was a strong positive correlation between nitrogen use and energy consumption (r= 0.54). This was mostly due to the high proportion of energy used in fertilizer application. In other words, reducing nitrogen use, mostly urea, may cut energy consumption significantly. Also, as mentioned before, and shown in Figure 5.22, urea use reduction would reduce wheat production and farmers' income.

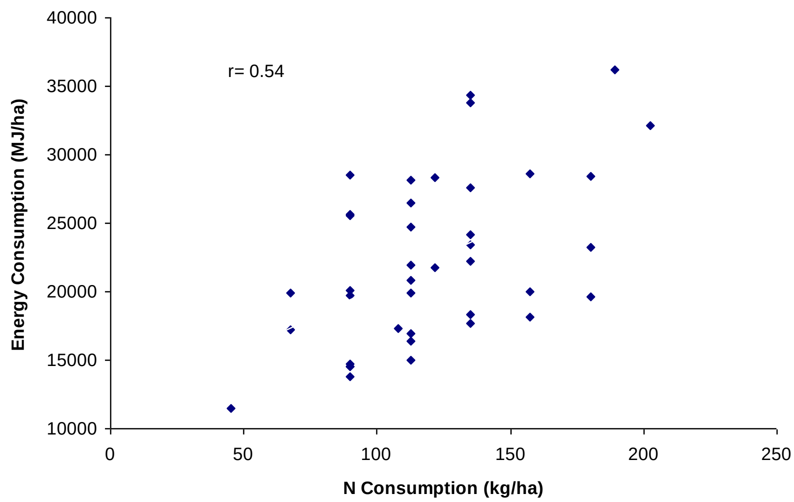


Figure 5-31 Correlation between energy consumption (MJ/ha) and nitrogen consumption (kg/ha)

Figure 5.32 presents a positive significant correlation between energy consumption and the number of passes of sprayer (r= 0.36). On average, energy use in spraying was around 3% of total energy consumption. Usually, on farms with higher yield, there were greater numbers of pests and, hence, increased applications of pesticides. There was a significant correlation between fungicide consumption and yield (r= 0.59). It was noticeable that the proportion of energy involved in fungicide use was only about 0.7% of the total. As presented previously, results showed that in heavier soils where there were more fungi than in lighter soils, more tillage was needed for soil preparation, and, due to higher friction and draw bar resistance, the age of equipment was less than those used in lighter soils. These facts may contribute to the indirect significant correlation between energy consumption and number of sprayer passes. It was important to note that for the above reasons, reducing fungicide consumption cannot reduce energy use on farms significantly and these correlations happen in a cascading fashion.

The proportion of electricity use was around 22% of total energy; also, irrigation frequency, irrigation duration (h/ha), and pump power (kW h/ha) affected electricity use more than other factors. Therefore, a correlation was expected between energy consumption and these aspects related to irrigation. This study showed that energy use was significantly correlated with irrigation frequency (r= 0.70) (Figure 5.33), irrigation duration (h/ha) (r= 0.65), and pump power (kW h/ha) (r=0.52).

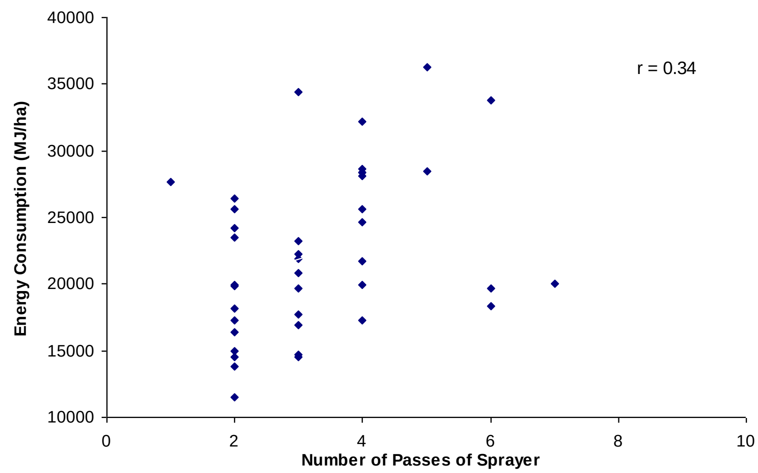


Figure 5-32 Correlation between energy consumption (MJ/ha) and number of passes of the sprayer

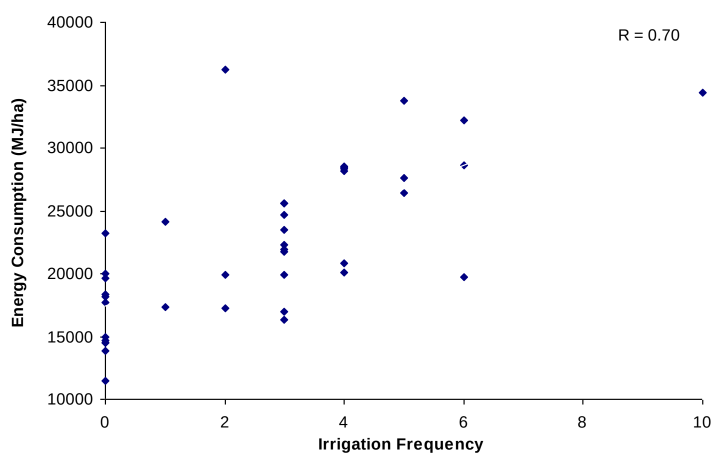


Figure 5-33 Correlation between energy consumption (MJ/ha) and irrigation frequency

In this study, the direct (operational) energy consumption included fuel, electricity, and humans and these were investigated as a group. Table 5.16 and Figure 5.34 present energy used in each operation in both dryland and irrigated farming systems. On average, operational energy consumed in wheat production was about 7,997 MJ/ha. Most differences between dryland farming and irrigated farming comes from electricity use in irrigation and it appeared that there was no significant difference in direct (operational) energy use between other operations in dryland and irrigated farming systems.

Table 5.16 Operational energy consumption in wheat production and total operational energy on irrigated and dryland farming systems (MJ/ha)

	Tillage	*Drilling*	*Fertilizer Distribution*	*Spraying*	*Harvesting*	*Irrigation*	*Total*
Irrigated	1,395(13%)	296(3%)	396(4%)	159(1%)	862(8%)	7,762(71%)	10,870
Dryland	1,451(46%)	206(7%)	456(14%)	186(6%)	861(27%)	0	3,153
Total farms	1,416(18%)	262(3%)	418 (5%)	169(2%)	862(11%)	4,870(61%)	7,997

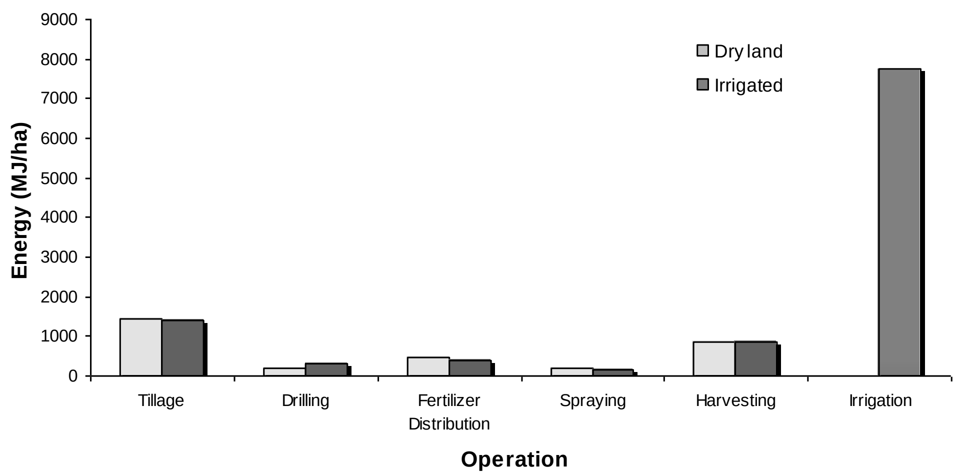


Figure 5-34 Operational energy consumption in wheat production in irrigated and dryland farming systems (MJ/ha)

Proper timing of fertilizer application, appropriate use of tractors and equipment, optimization of irrigation, and improving farmers' skills can lead to substantial energy conservation in wheat production. To gain an insight into energy consumption on farms, the indirect energy consumption including pesticides, fertilizers, seeds, and machinery were investigated as a group. As shown in Figure 5.35, there was a positive significant correlation between indirect energy and yield (r= 0.44). This confirmed the role of fertilizer on crop production. However, a significant correlation was not found between direct (operational) energy consumption and yield. This also indicates the possibility of reductions in fuel and electricity use with minimum yield reductions. Under current conditions, it is hard to encourage farmers to reduce fertilizer use on their farms because reducing fertilizer, especially N fertilizer, reduces their production and net benefits. It appears that the best solution will be using more efficient methods to reduce fuel use, more efficient irrigation systems, and more efficient N fertilizers.

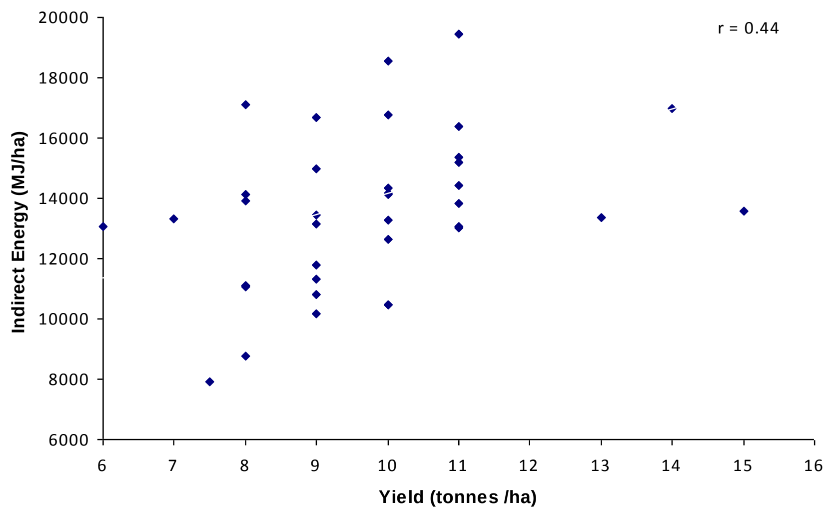


Figure 5-35 Correlation between indirect energy consumption (MJ/ha) and wheat production (tonnes/ha)

Figure 5.36 presents a positive significant correlation between indirect energy use and proportion of wheat area (r= 0.35). A similar significant correlation was seen between indirect energy use and proportion of crop area (r= 0.33). This showed that indirect energy use in wheat production increased on farms with higher proportions of wheat and crop. In other words, farmers who focus on crop production consume more fertilizer and pesticides, which may be due to keeping fewer sheep and cows. Animal manure and urine can improve soil fertility and reduce fertilizer demand; however, it was not easy to find the main reasons for these correlations and it needs more investigation.

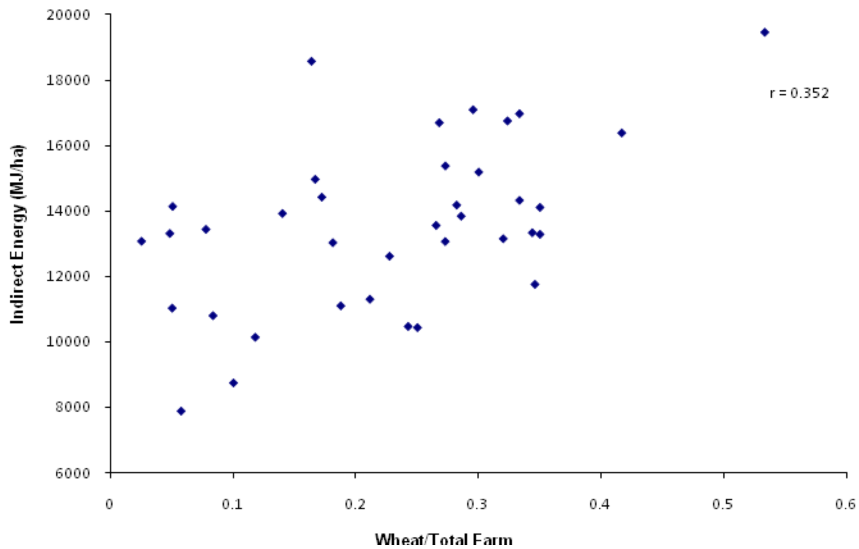


Figure 5-36 Correlation between indirect energy consumption (MJ/ha) and proportion of wheat area

5.3 The Modelling Process for Predicting Energy Use

Predicting the outcomes for different conditions and scenarios is one of the first steps of managing future events. However, having to use a large number of complex variables to predict outcomes make it very complex leading to large errors margins. However, choosing and using the best methods for agricultural processes and farming conditions would reduce agricultural expenditures and environmental impacts; therefore, modelling can be a valuable asset for improving farming processes.

The main target of this study was to help scientists and farmers gain new perspectives on farming and to compare different agricultural inputs and farming methods to find optimum solutions for different farming conditions. This can also help scientists know which technical and social factors influenced wheat production and energy consumption. The second objective of the study, presented in this section, is to develop neural network models to predict energy consumption in different farming situations as this has the potential to reduce farmers' expenditure and environmental impacts using direct and indirect factors. After selecting the appropriate variables, multiple linear regression and

ANN models were developed and compared to test the ANN model's ability to predict energy consumption in wheat production.

5.3.1 Variables

Finding appropriate variables was the first step of model creation. After initial input reduction, based on an extensive study of correlation analysis, 19 variables were selected for further reduction using PCA. These were: crop area (ha), wheat area (ha), crop area/ total farm index, wheat area/ total farm index, number of paddocks, numbers of wheat paddocks, farmer's age, farmer's education, nitrogen consumption (kg), phosphate consumption (kg), fungicide consumption (kg), amount of seed (kg), irrigation frequency, power of combine (hp), number of passes of sprayer, number of passes of ploughs, number of passes of discs, and number of sheep.

After the PCA, five variables from the PCs with the threshold cumulative variance of around 72% were selected to use as variables in the ANN model. These were: the size of crop area (ha), farmer's education, nitrogen consumption (kg), phosphate consumption (kg), and irrigation frequency. These variables were not significantly correlated to each other but significantly correlated with energy consumption. Estimating these input variables was easy and farmers had a clear idea about them. Consequently, the final model will be able to predict energy use with minimum estimation error.

5.3.2 Multiple Linear Regression Model

For predicting energy consumption in wheat production, multiple linear regression and ANN methodologies were developed. Regression modelling was tested first for predicting energy consumption. Multiple Linear Regression (MLR) had been extensively used in experimental evaluations in agricultural with positive expected linear effects and negative quadratic effects (Colwell, 1994). Normally a simple model with the highest r^2 is designed through a combination of forward, backward, and stepwise regression adjustments. Terms are retained in the final model if they are significant at $p=0.05$ (Alvarez, 2009).

In the first step, the relationship between energy consumption and the 5 variables - the size of crop area (ha), farmer's education, nitrogen consumption (kg), phosphate consumption (kg), and irrigation frequency - was tested with simple linear regression using the r^2 value as a decision criterion. Then, a multiple linear regression model was developed for predicting the energy consumption as:

$$Y=a_0+a_1V_1+a_2V_2+\cdots+a_nV_n+\epsilon \qquad (5\text{-}1)$$

where a_0-a_n are the regression coefficients, V_0-V_n are the independent variables, and ϵ is error.

The model in Eq. 5-1 is in a linear form to represent linear relationships of the dependent variable with the independent variables. For better comparison with the ANN model, 25% of samples were randomly selected for verification and 75% of samples were used for training (i.e. model development). After running the model, predictions on validation data were estimated. A multiple linear regression accounted for around 74% of the variation in validation data. Figures 5.37 and 5.38 compare the predicted energy consumption in wheat production for training and validation data, respectively. The figures show that the correlations between the actual and predicted energy consumption in wheat production for training and validation data were similar at 0.82 and 0.86, respectively. The final RMSE for validation data was 4,963 MJ/ha.

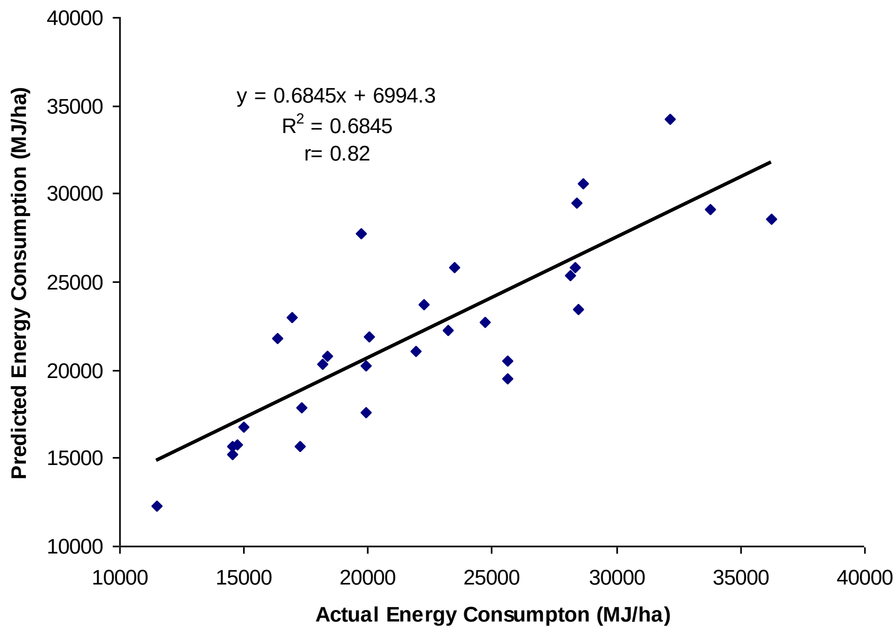


Figure 5-37 Correlation between the actual and the multiple linear regression model predicted energy consumption (MJ/ha) for training data

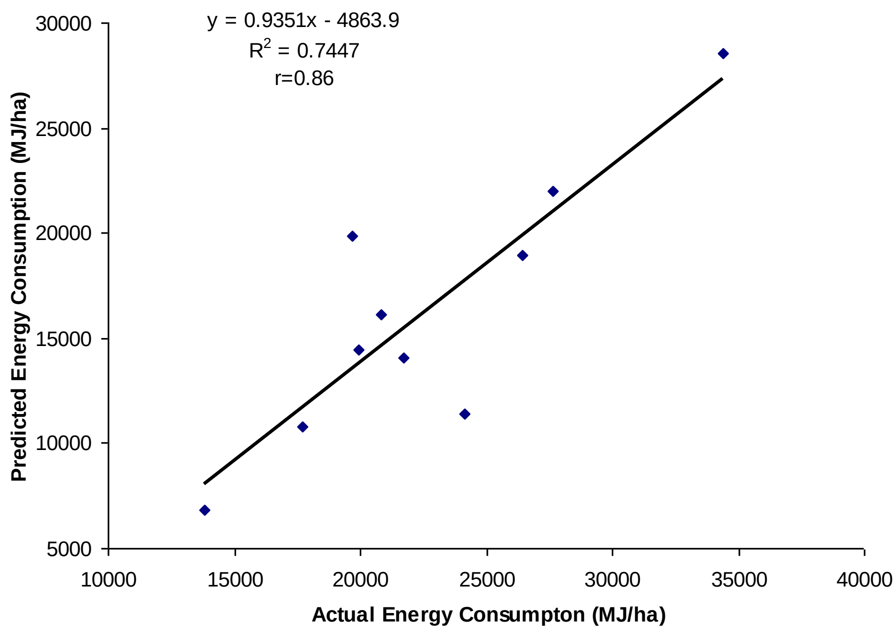


Figure 5-38 Correlation between the actual and the multiple linear regression model predicted energy consumption (MJ/ha) for validation data

5.3.3 Neural Network Model

The neural networks were trained with energy consumption as output and the five input variables - size of crop area (ha), farmer's education, nitrogen consumption (kg), phosphate consumption (kg), and irrigation frequency. The inputs and outputs were scaled to the range [0 1] to bring all variables to the same range. As detailed in Chapter 3, different network structures, the number hidden neurons and hidden layers, neuron activation functions, and learning algorithms were tested with the aid of Genetic Algorithm (GA) optimization.

Due to the large number of possible combinations of attributes, training process was slow and very time consuming. Few examples of promising models are presented in Appendix B. Finally, a modular network with two hidden layers was found to be the best for the data. In the modular network structure, the model is characterized by a series of independent neural networks after the input layer, that operate on the inputs to achieve some subtasks of the task the network is expected to perform (Figure 5.39). These subtasks were trained separately and their outputs were summed in the output layer. This structure of the model made it possible for the network to simultaneously use different activation functions in the same layer. More details of the model are given in the following discussion.

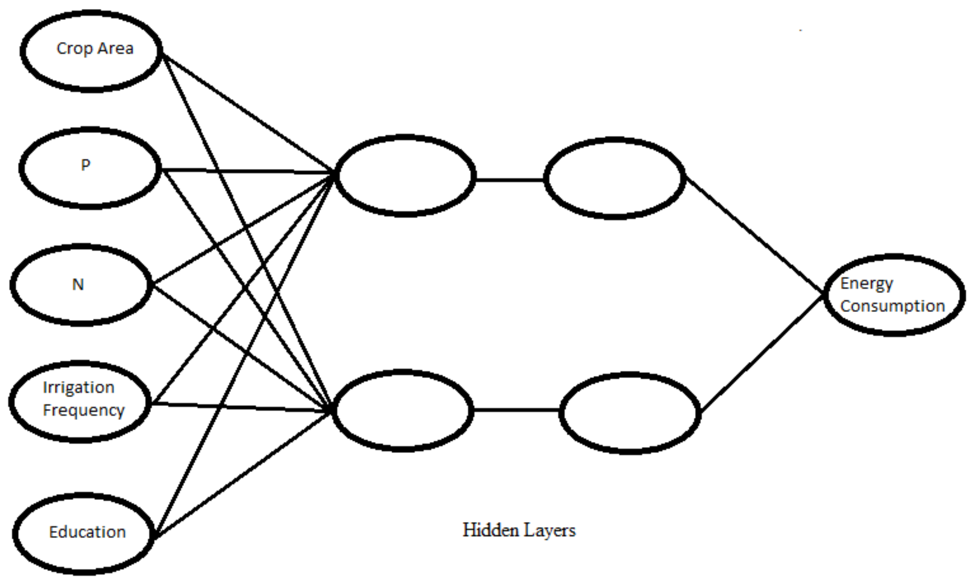


Figure 5-39 Topology of a feed forward neural network for calculating energy consumption

After selecting the modular network, it was further trained to refine the network structure. Specifically, the appropriate activation functions, such as hyperbolic tangent (tanh), logistic, Gaussian Bell, linear, and Sine functions, as well as the number of neurons in each layer were optimised using GA. The possibility of using different combinations of these functions and neurons in the modular ANN model increased the complexity in finding the final appropriate model. In the final model, the linear function was applied for input layer, logistic function was selected for the output layer and the first hidden layer, and hyperbolic tangent function was used in the second hidden layer. The general format of these activation functions are given in Table 3.3. Learning algorithms were also tested on the modular network and the Quick Prop learning method provided better performance than other learning methods. The Quick Prop was fast in reducing errors and finding the best model. As previously explained in Chapter 3, Quick Prop implicitly uses the second derivative of error to adjust weights.

Figure 5.40 shows some other details of the modular network and training with the focus on number of neurons in each layer. After the first layer, the modular network is separated into two parts. The number of neurons in the first and second layers of the top part was optimized using the genetic algorithm optimizer that indicated 2 and 17 neurons for first and the second hidden layers, respectively. In the second part, the number of neurons was optimized to be 18 and 17 for the first and second hidden layers, respectively. The results were combined at the output layer using a logistic function to produce the final output, the energy consumption. The box below (data terminator) the network shows the error vs number of iterations (epochs) graph used during training.

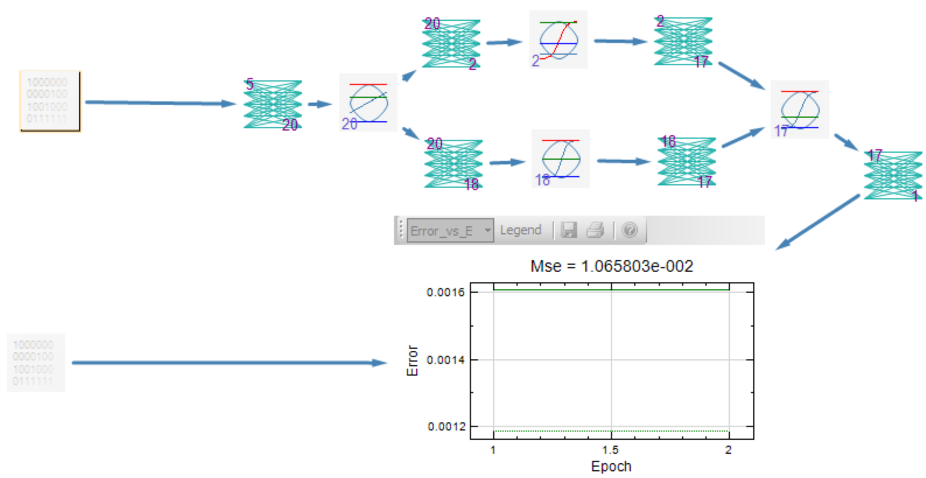


Figure 5-40 Structure of the modular network and number of neurons in each layer

The ANN model achieved the best results with a scaled[1] MSE= 0.0106 after 100 batch iterations. The actual RMSE of the final ANN model was estimated to be 1230 MJ/ha on validation data. This was the lowest RMSE between a number of ANN models examined and developed in this study. As shown in Figures 5.41 and 5.42, energy consumption estimated by the ANN accounted for 81% and 91% of the actual variability in energy use in training and validating data, respectively. The correlation between the observed and predicted energy consumption was very high with coefficients of 0.90 (training) and 0.96 (validation). Comparison between ANN model and multiple linear regression models showed that the correlation between the actual and predicted energy consumption in the ANN model was much higher than in the linear regression model for both training and validation data; furthermore, RMSE (square root of MSE) of the ANN model on validation data was much lower than that of the linear regression model (Table 5.17). For the validation data, the ANN model provided an r of 0.96 as opposed to 0.86 from multiple linear regression model (Figure 5.42).

[1] Simple range scaling is a normalized method, which fixes the minimum and maximum values for the normalized variable to ±1

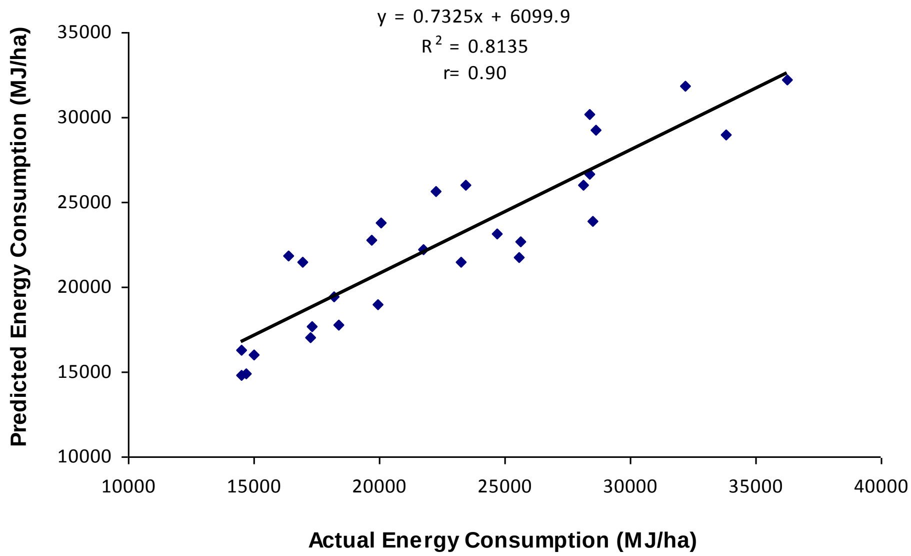


Figure 5-41 Relationships between the observed and ANN model predicted energy consumption (Training data)

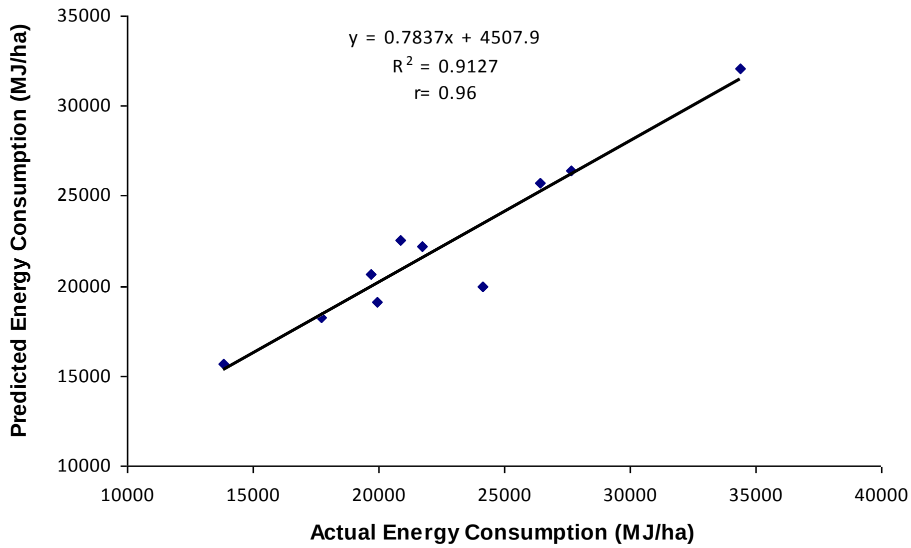


Figure 5-42 Relationships between the actual and ANN model predicted energy consumption (Validation data)

Table 5.17 RMSE and R^2 of training and validation of the multiple linear regression model and the ANN model

	Linear		*ANN*	
	training	validation	training	validation
R^2	0.68	0.77	0.81	0.91
RMSE	2,485	4,963	1,896	1,230

The Peltarion Synapse software allowed estimation of the sensitivity of the output to changes in each independent variable (sensitivity analysis). It ran the system for each variable and recorded how much the output changed due to the dithering of each input variable. In other words, it showed how much the output changes, if an input variable changed within a range; this was a measure of how important an input was in the model. It is not correct to say that sensitivity equals importance but is an indication of relative importance of a variable.

However, for the results from the sensitivity analysis to be reliable, input variables must be as independent as possible. Otherwise, multicollinearity in the data can produce different network relationships, depending on the initial random weight values used in the neural network. For uncorrelated data, any random initial set of weights would lead to the same final weights (i.e. the same relationship between inputs and outputs); such network can show correct sensitivity between inputs and outputs. The careful data pre-processing in this study fallowed by PCA-based input reduction was an attempt to obtain the most influential uncorrelated inputs for the model. Therefore, the sensitivity results presented here should be reliable.

As shown in Figure 5.43, the sensitivity study of the model showed that irrigation frequency (40%) was the most important factor contributing to the model. This was followed by N consumption (31%), size of crop area (16%), Farmers' education (10%), and P consumption (2%). Thus irrigation frequency, nitrogen consumption, and size of crop area contributed (87%) to predicted energy consumption in this model more than the other two variables. It was noticeable that estimating these three factors was easy and it would reduce the estimation error.

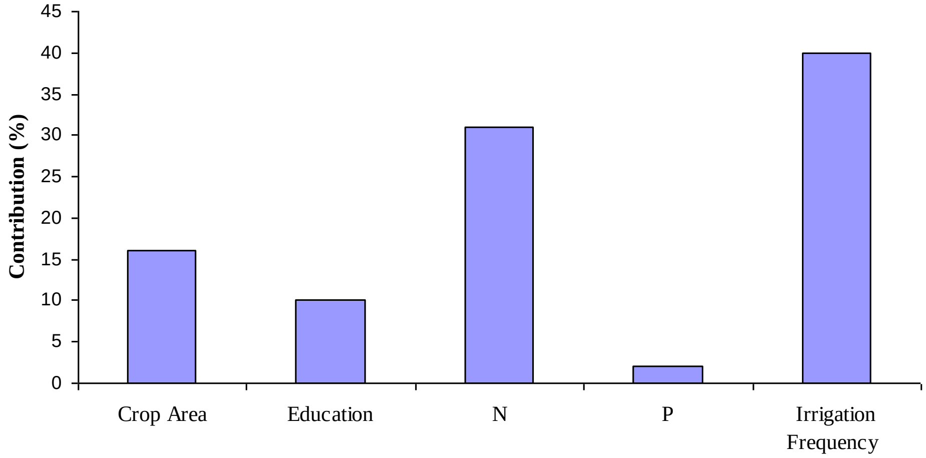


Figure 5-43 Contrribution of different variables to the output of the ANN model for energy consumption in wheat production

Figures 5.44 and 5.45 show the ANN prediction on training and validation data, respectively, along with 95% confidence limits. There are four lines in each plot: network output, desired output and the high and low bounds of the confidence interval. The grey area shows the region within which the correct answer lies within the chosen confidence level of 95%. As shown in Figure 5.44, the final model predicted energy consumption with error margins of around ±6000 MJ/ha for the training data and an error margin of around ±2970 MJ/ha for the validation data (Figure 5.45) and the predictions for both data sets are within the 95% interval. This means that there is only a 5% chance that the predicted errors will be more than ±2970 MJ/ha.

Figure 5-44 Predicted, observed and the 95% Confidence Interval for energy consumption based on the artificial neural networks model (training data)

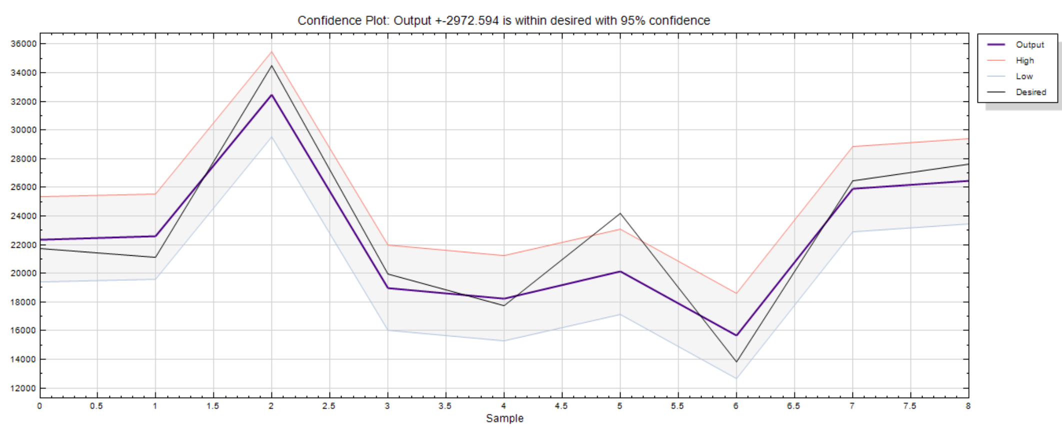


Figure 5-45 Predicted, observed and the 95% Confidence Interval for energy consumption based on the artificial neural networks model (validation data)

The above confidence calculations would be fine, if the error distribution is normally distributed with zero mean indicating that error in the model is due to random effects. Figure 5.46 shows that the errors on the validation data are indeed normally distributed and it confirmed the validity of energy use estimation. The graph of the error distribution was an extremely powerful tool that allowed finding problematic cases where the system has performed poorly. If the errors are not distributed normally, the problem should be investigated and sometime the data that made it skewed would be removed from the study.

The Figure 5.47 shows a very useful testing tool of Pelrarion Synapse software called Probe. It allows a quick way to run the model for various setting on the input variables in order to obtain predictions for a desired set of values for the input variables. This way, a user can interact with the model to investigate various options for inputs and see how energy consumption is affected by them. As shown in Figure 5.47, the left pane shows the input variable and the values can be changed manually. The output of the probe, energy consumption, is shown in the right pane. In the bottom right is a plot that continuously sampled the output as the values of inputs changed.

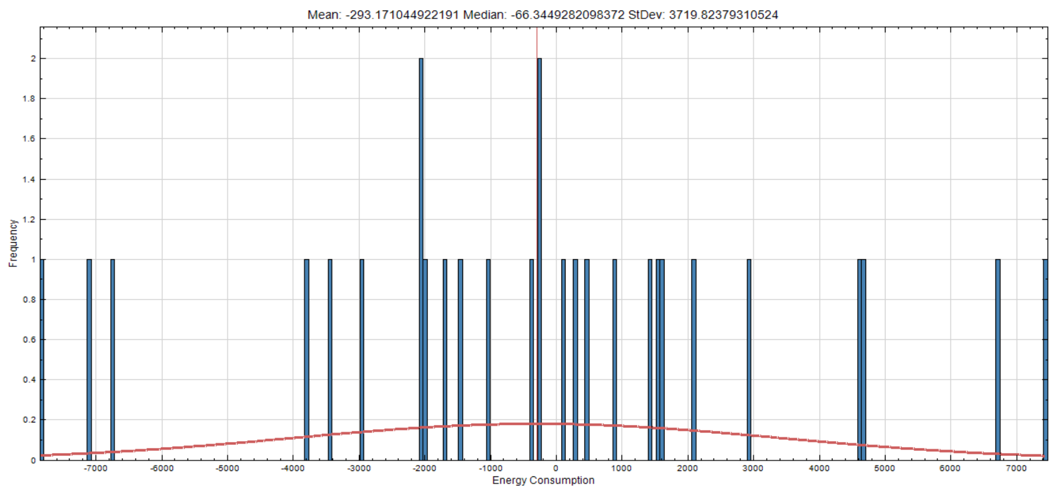


Figure 5-46 Distribution from the errors on the validation data

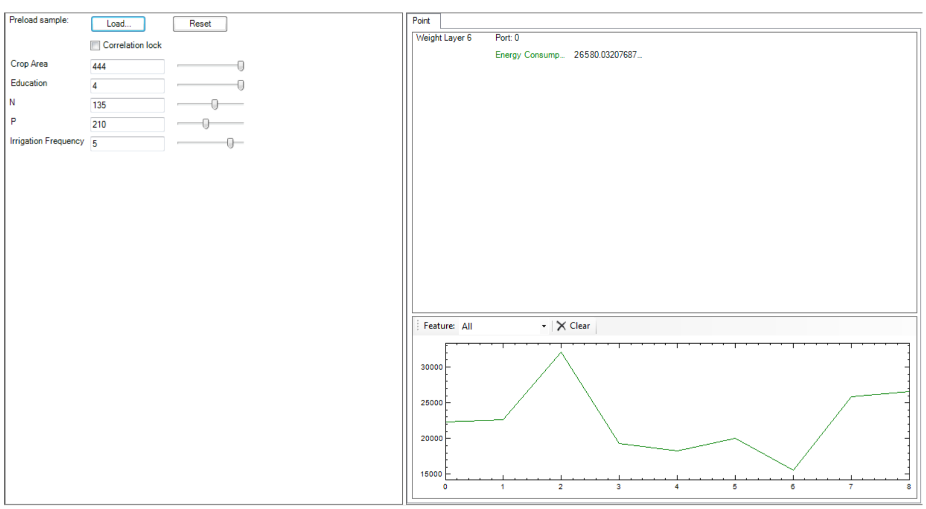


Figure 5-47 Prediction system using five input variables

As discussed before, several uncontrolled factors influence energy consumption in wheat production; therefore, the result of this study is very useful and important. The final model can predict energy use in wheat production with acceptably small error. It is noticeable that most variables in the model can be altered, for example, N, P, irrigation frequency and in some cases crop area. This gives indicators and directions for improving energy efficiency in wheat production in future. Some variables in the final model are fixed and cannot be changed, and they show the farming conditions such as crop area and farmer's education. For example, farmer's education would affect energy consumption indirectly. Therefore, the next step (in future studies) should be to explore in detail the links between input variables and energy consumption in wheat and other agricultural production.

This model can estimate energy use per hectare in wheat production. Farmers can estimate and compare energy use on their farms easily. They can explore the factors that have more potential to reduce energy use on their farms. Additionally, decision makers and scientists can estimate energy use in different regions of Canterbury and they can investigate the effects of different energy inputs on energy consumption in wheat production. For example, it is possible to predict the effect of N use reduction on energy consumption or to compare farms with similar conditions but different level of farmer's education.

Chapter 6

Discussion

Due to data shortages and low levels of multi-disciplinary research, energy consumption in agriculture sector has received little attention from scientists and decision makers. However, the link between energy use in agriculture and environmental impacts, on one hand, and increasing food demand, on the other, have raised the level of importance of energy studies in agriculture. Determination of the energy consumption of different inputs on farms was the first step in the analysis of energy consumption in agricultural production.

Comparisons of results from different studies would be quite useful for finding appropriate research methods and techniques and validate research outcomes. In the agriculture sector, especially in energy studies, results should be judged cautiously; as found in this study, different protocols used and the different environmental conditions of the studies meant that many studies were not able to be compared. Additionally, many energy studies on crop production did not mention the protocol boundaries, or details of the methods. Few studies on energy in wheat production in New Zealand were available, but due to limitations stated above it was not easy to compare them with this study. As discussed previously, no research was found on neural network modelling of energy consumption in wheat and other agricultural production.

6.1 Primary Analysis

6.1.1 Direct and Indirect Farm Inputs

Farming is a profession and farm management is a key factor targeted in programmes for reducing energy consumption in agriculture. Inefficient management and lack of experience can waste significant amounts of fertilizer, fuel, and other farm inputs. At the beginning of this study, the researcher of this thesis strongly believed that estimating direct and indirect factors and investigating their effects on each other, yield, energy consumption, and even CO_2 emissions, should be the next step in improving agricultural production with minimum impact on the environment and farmers' incomes. It was important to note that inappropriate use of farm inputs not only increased farmers' expenditure but contributed to negative environmental impacts.

Increased wheat production in New Zealand has been achieved through extensive use of various direct inputs, such as fertilizer, fuel, agrichemicals, electricity, and farm machinery. In addition, there were several indirect parameters which may influence the efficiency of the direct factors. Farm conditions, social aspects, and technical factors influenced energy consumption as well as wheat production. The results of this study showed that there was a complex series of links (known and unknown) between indirect and direct parameters based on yield and energy consumption. The database produced in this study provided a good opportunity to investigate the effects of different direct and indirect factors on each other and on wheat production. The accepted links between the direct and indirect factors, such as the link between the age of tillage machines and soil texture, showed the accuracy of the data collection process. There were many expected correlations between different parameters as discussed in Chapter 5 and they confirmed the accuracy and reliability of the survey and data collection method.

Fungicide consumption was a good example of a low proportion, high correlation, and complex link between different parameters. Exploring these links was not the main target of this study; however, it would be helpful for farmers and decision makers to have a clear view of farm activities to make informed decisions. For example, the results showed that wheat production depended heavily on N fertilizers. Therefore, reducing fertilizer consumption can lead to reduced wheat production. Any plan to reduce fertilizer use on farms could reduce farmers' income; consequently, farmers may resist reducing fertilizer use on their farms. As another example, the results showed that the proportion of the wheat area (crop area) had more effect on energy use and wheat production than the total farm area. This relation should be investigated further as a new hypothesis in agricultural management.

There were some differences between the average estimation of some factors in this study and previous studies. For example, Fairweather & Mulet-Marquis (2009) estimated the average age of farmers, in 2006, to be around 44.1 years, which was less than estimated in this study. They mentioned that the average age of farmers in NZ was increasing; however, dairy farmers were younger than other farmers. In addition, it seemed that they estimated the average age of all people involved on farm activities but in this study the estimation was only for farm owners. However, in most cases, the differences were acceptable.

As mentioned previously, the link between different technical and social factors in wheat production would be an excellent subject for future studies. Also, if the database is developed over time, it could help better understand the dynamics of change between census periods, and the models enable good predictions of future changes based on the present condition.

6.1.2 Fuel Consumption

Fuel was one of the most important energy inputs in agricultural production; therefore, it was investigated separately in this study. As mentioned in the literature review, as oil price increased, farmers selected agricultural products with minimum fuel use. Thus, if oil prices increased and agricultural production prices did not change to reflect the increase in oil prices, more arable farms would be converted to dairy farms in Canterbury. Consequently, wheat production in Canterbury would reduce and more wheat would need to be imported. If the same scenario happened globally, we should be concerned about providing enough food for the global population. Moreover, if the agricultural production prices increased at the same rate as oil prices, more people will find it difficult to obtain sufficient food.

Using appropriate tractors and equipment and expert management would be key factors in fuel conservation in agricultural production. Due to different farming systems, farm conditions, and machinery, it was difficult to compare results from different studies. For example, due to the use of diesel pumps for water pumping in many developing countries, the fuel use in those countries was somewhat higher than in other countries.

For example, Safa & Tabatabaeefar (2008) estimated fuel consumption in wheat production in Iran at 598 l/ha in irrigated farming (most fuel consumption in irrigation) and 74 l/ha in dryland farming. Even in the same operation, several factors would influence fuel consumption. So comparing the results of different studies without comparing farm conditions and other factors was not useful.

In this study, the average fuel consumption in wheat production was estimated at 65 l/ha and average fuel use in irrigated and dryland farming systems were estimated at 65 and 66 l/ha, respectively. Barber (2004) estimated fuel use in irrigated and dryland wheat farming at 85 and 71 l/ha, respectively. The difference came from the different fuel consumption rates that were used in the studies. In this study, fuel consumption rates were obtained from the Financial Budget Manual (2008) and Barber (2004) used rates from the McChesney (1981) reports. As shown in Table 3.1 (Wells used fuel consumption rates from McChesney), in some operations there were significant differences between the two estimates. These differences may be due to different methods, machines, and farm conditions. Also, Barber (2004) used only two case studies for estimating fuel use in irrigated farming systems and one case study for dryland farming systems. However, in this study, thirty irrigated farms, and ten dryland farms were investigated and this could have reduced the estimation error. Additionally, it was expected that improvements in technology since the earlier study would reduce fuel consumption in farm operations. It was noticeable that Barber (2004) did not mention the area of farms in his case studies; consequently, it was difficult to further investigate his results.

On average, new tractors and combines were more powerful allowing farmers to use wider equipment. It was expected that using wider machinery and new technology such as precision farming by the younger generation farmers would reduce fuel consumption in wheat production.

6.2 Energy Consumption

It was important to note that concentrating on only one factor, such as fertilizer or fuel, cannot affect the appropriate energy use reductions in crop production. It was important to look at a farm as a complex network, containing several technical, social, and financial parameters. Some of these parameters may have positive or negative direct or indirect effects on each other and energy consumption. Management was a key factor to reduce energy use on farms. Improving operational efficiency and using new methods and technologies can significantly enhance energy conservation on farms.

For estimating energy consumption in wheat production, selecting the correct number of samples, designing an appropriate survey, measuring the direct and indirect inputs, and selecting accurate conversion coefficients were the key points. Some differences in other studies came from selecting different conversion coefficients. Additionally, as explained previously, data collection with sufficient number of samples was a complex and quite time consuming process. Therefore, designing a flexible survey and selecting the right method for data collection can improve the accuracy of the final results.

The lack of standard protocols to estimate the energy consumption on farms resulted in some difficulty in comparing different studies. Estimating national energy equivalents (conversion coefficients) and updating them after a period of time would increase the accuracy of final energy estimations. An international protocol should clearly identify the inputs and boundaries; also, it should define the standard method for data collection. The protocol should be flexible, taking into account social, technical, and financial limitations. For example, in some studies, post-harvesting processes and transportation have been estimated as energy inputs and not in others. Also, comparing a fully mechanized farming system with traditional farming based on human labour would be very difficult.

The energy consumption in wheat production was estimated at 22,566 MJ/ha. The main source of energy was fertilizer consumption (especially urea) with 10,651 MJ/ha (47%), which was by far the most important source of energy. Electricity (22%) was the second most important source of energy in wheat production while fuel (14%) ranked third. The energy consumption for wheat production in irrigated farming systems and dryland farming systems was estimated at 25,600 and 17,458 MJ/ha, respectively. The main source of energy in both systems was fertilizer with around 10,193 MJ/ha and 11,430 MJ/ha for irrigated farming and dryland farming, respectively.

Fertilizer management, particularly in relation to the use of urea to reduce indirect energy requirements in fertilizer manufacture, the method and timing of fertilizer distribution and the amount of fertilizer use must be taken into consideration. Using controlled release nitrogen fertilizers and appropriate rotations can also reduce fertilizer consumption. Appropriate plans for reducing fertilizer use on farms not only deliver financial benefits to the farmers, but also importantly, can reduce environmental impacts. The high proportion of the total energy consumption by fertilizers would increase the concern about NO^+ emissions and water pollution in the future. Due to a significant correlation between N use and yields, reducing N consumption on farms would reduce wheat production. From the results of this study, it appeared that animal urine and manure were applied instead of N on mixed farms; however, the environmental effects of using animal urine and manure should be investigated.

Some studies about energy consumption in wheat production were available; however, due to different technological levels and environmental conditions, the lack of basic information, and the use of different energy conversion coefficients, comparing those results with this study was difficult. For example, Safa & Tabatabaeefar (2002) estimated energy use in irrigated and dryland farming for wheat production in Iran at around 45,970 and 17,106 MJ/ha, respectively; however, Safa et al. (2010) estimated energy use in irrigated and dryland farming in the same area around 51,587 and 12,543 MJ/ha, MJ/ha, respectively. The most important difference between these two studies was the severe drought during the second study, which increased fuel and electricity consumption for irrigation. However, during the time between the two studies, many old diesel pumps incorporated in the first study have been converted to electric pumps, thus saving energy on many irrigated farms. Consequently, understanding such details is essential when judging and comparing different energy studies, but these are not always available from journal articles. For example, Singh and Mittal (1992) estimated energy consumption in irrigated and dryland wheat production in India at around 18,881 and 5,458 MJ/ha, respectively. However, comparing their result with this study involving different farming systems and technology was pointless. As another example, in New Zealand, Nguyen (1995) compared energy use in wheat production on conventional and biodynamic farms. Due to different study bases, again, comparison of the results would not be beneficial.

Barber (2004) estimated energy consumption in irrigated and dryland farming in wheat production in New Zealand at around 34,150 and 20,190 MJ/ha, respectively. The amount and percentage of Barber's (2004) estimations for dryland farms were not far from the results of this study. However, there was a significant difference between the results of the two studies for energy use on irrigated farms. The most important difference in Barber's estimation and the result of this study for irrigated farming was electricity use in irrigation. Barber estimated electricity use in wheat production at around 16,000 MJ/ha; however, estimate in this study is approximately 7,700 MJ/ha. Barber (2004) did not mention the area of his two case studies or the irrigation systems; therefore, it was difficult to investigate his results. Electricity use on farms depended on several factors, such as climate, irrigation system, depth of well and soil type and it may even change in different years due to different amounts and distribution of precipitation. Incidentally, in this study, there were some farmers who used more electricity than Barber's (2004) estimation. As discussed before, thirty farms were investigated in this study to estimate energy consumption on irrigated farms and this number of case studies would have increased the accuracy of results.

Pimentel et al. (2002) carried out one of the most detailed studies of energy use on farms in the US. He estimated 15,000 MJ/ha energy use for winter wheat production in dryland farming. As discussed previously, several factors influenced the final energy use estimation, such as environmental factors, conversion coefficients, and farming method. However, Pimentel's (2002) estimations were not far from the results of this study.

On average, operational energy consumption found in this study was 7,997 MJ/ha. This was much higher in irrigated farming systems than in dryland farming systems.

Operational energy consumption was 10,870 MJ/ha on irrigated farms and 3,153 MJ/ha on dryland farms. The major difference was due to irrigation operations consuming 71% of the total operational energy consumption in irrigated farming. Tillage ranked high in both systems. It ranked first (46%) in dryland farming and second (13%) in irrigated farming. There was no significant difference between energy consumption of tillage operations and other operations in the two systems. In other words, farmers used similar operations, methods, and farming patterns in both irrigated and dryland farming systems.

6.3 Neural Network Model

The second main objective of this study was to design a model to predict energy consumption using different direct and indirect parameters. In creating a practical model, the number of samples and data collection method play a large role. Varied environmental/farming conditions and farmers' background make each farm unique; therefore, the number of samples and accurate data are critical in modelling studies in agriculture. Without a sufficiently large sample and accurate data, models cannot accurately predict energy use in agricultural production; this has reduced the interest of scientists in energy studies, especially modelling agricultural production. No study on modelling energy consumption in wheat and other agricultural production was found to compare the results of this study. Due to different conversion coefficients and environmental and farm conditions, models can have dissimilar outcomes.

Using a large number of correlated inputs can give results with minimum error; but the final model becomes unnecessary complex and unstable as the correlated inputs introduce redundancy into the model. Therefore, selecting a small number of independent inputs can lead to a more robust model. This study emphasized the complexity of the relationships between different parameters in wheat production (agriculture). Consequently, before any modelling study in agriculture, the relationship between different variables should be explored cautiously. In this study, it was attempted to select the minimum number of uncorrelated variables and variables that were easy to estimate and calculate. Consequently, the estimation error of the model would be minimised. To this end, the most important direct and indirect factors and their correlation were investigated carefully. After an initial data pre-processing involving correlation analysis followed by PCA, five uncorrelated technical and social factors were selected as input variables to the ANN and these were N, P, irrigation frequency, crop area, and farmer's education.

Using genetic algorithms to optimise the network structure and neuron activation functions in conjunction with a search for the best training algorithm, it was possible to find a two layer modular neural network with high performance. Here, we reported the best ANN model found in this study. This ANN model can predict energy use in wheat production in Canterbury with acceptable accuracy (±2970 MJ/ha). The final ANN model showed the possibility of using direct and indirect technical factors combined with social attributes to predict technical parameters such as energy consumption in the agriculture sector. It would be advantageous to design future studies on modelling energy use in agriculture based on these results.

As discussed previously in Chapters 4 and 5, some variables influenced energy use directly; whereas; others showed indirect links to it. Similarly, out of the five variables used in the ANN model, some were directly linked to energy and others seemed to influence energy consumption indirectly. For example, the size of crop area and farmers' education, two variables used in the ANN model, had indirect links to energy. In other words, they did not have a direct cause and effect relationship with energy consumption. The size of crop area and education would indicate part of farmers' professional practice. To reduce energy use, prominent links should be recognised and carefully investigated in an extensive study.

The other three variables in the ANN model, N and P consumption and irrigation frequency, had direct correlations with energy consumption in wheat production. Irrigation frequency as well as irrigation system affected energy consumption through electricity use and its reduction can reduce energy use directly. Reduction of the use of N and P would also reduce energy consumption on farms. These three therefore were important variables in the ANN model. The direct effect of N, P, and electricity on energy consumption would be interesting to focus on to reduce energy use on farms.

However, as mentioned in section 5.3.3, the contribution of N and irrigation frequency were the highest in the ANN model and P use featured relatively low in the model. Thus, exploring the network of links between these variables would improve the utility of the final model.

It was expected that the ANN model would predict energy use in wheat production better than other modelling methods. A Multiple Linear Regression (MLR) model, a common modelling method in agricultural studies, was established. Comparison of results (r, r^2, and MSE) of the ANN model with the linear regression model showed that the ANN model performed remarkably better than MLR in predicting energy consumption. It is possible that ANN models in other agricultural studies could provide better estimations with minimum errors.

The final model was capable of predicting energy use on a single farm or in a specific region. This will help farmers estimate energy use on their farms and compare it with other farms. It would also help decision makers to have a better view of energy use in wheat production.

Compared to other sectors, in the agriculture sector, uncontrolled factors had more influence on the final products. Therefore, comparing energy consumption of the same agricultural products in different years, without an understanding of the environmental parameters, would not be very beneficial. These differences could even change the structure and results of the models; therefore, each model could work only for a particular area and for a short period of time. Therefore, models should be updated with new data, which could possibly alter the model structure, input variables and the results.

Chapter 7

Conclusions and Recommendations

In this study, a wide range of farming parameters was investigated to determine and model energy consumption in wheat production. The most important results of this study were presented and discussed in Chapters 5 and 6. In this Chapter, the conclusions of this study are discussed briefly.

7.1 Fuel Consumption

Fuel consumption was related to several direct and indirect factors. In this study, it was hypothesised that investigating these factors further would be important to reduce fuel consumption on farms. This study showed that fuel consumption in both irrigated and dryland farming followed similar patterns and tillage in both systems ranked as the highest fuel consuming activity. Given the findings of this study, the main conclusions are as follows:

-Tillage ranked the highest, with 45% of total fuel consumption. Mouldboard ploughs and field cultivators were used more than other equipment in tillage and fuel use in mouldboard ploughs was more than in other tillage operations. Using new techniques and machinery instead of mouldboard plough operations can significantly reduce fuel consumption on farms. In addition, reducing the number of tractor passes on farms can also reduce fuel consumption significantly.

- During 2007 and 2008, the price of oil and agricultural production increased simultaneously. This increased farmers' interest in using more powerful tractors for agricultural operations and a few of them used a combination of machines for tillage and sowing. It seemed that oil price had an important role in encouraging farmers to improve their technology. However, due to the direct link between the price of oil and the price of agricultural production, it is not recommended to push farmers to reduce fuel and nitrogen use by increasing taxes or using other price manipulation methods.

- The study showed that there were some significant correlations between social factors and technical factors, which would be useful for fuel conservation in agriculture. For example, new generation of farmers preferred to use more powerful tractors, or the number of passes of some machinery was significantly correlated with farmer's age. From the results, it appeared old farmers preferred to use more conventional tillage than new tillage methods.

- Educated farmers had accepted new methods and machines to reduce fuel use in farm operations. Therefore, it would be beneficial to encourage farmers to employ educated farm managers or consultants on their farms. Improving knowledge and awareness of new technologies would be the best way to encourage new generation farmers to reduce fuel consumption in future.

7.2 Energy Consumption

Given the findings of this study, the most significant areas for improving overall energy efficiency on wheat farms in Canterbury region are as follows:

- In wheat production, fertilizer was by far the most important source of energy and electricity was the second most important source. Fuel came second on dryland farms and third on irrigated farms. Therefore, it is necessary to focus more on fertilizer, electricity, and fuel consumption than the other factors. Fertilizers, mainly nitrogen, have a significant influence on energy consumption, accounting for 47% of total energy consumption.

- Electricity consumption on irrigated farms, mostly for irrigation, is the most important difference in energy consumption between irrigated and dryland farms in wheat production.

- Comparison of the correlations between wheat production and direct and indirect energy sources showed that it could be possible to reduce the direct (operational) energy sources, especially electricity and fuel, using better technology and management and with minimum yield reduction. However, reducing some indirect energy sources, such as nitrogen fertilizers and pesticides, would significantly reduce yields.

7.3 Neural Network Model

For the first time, in this study, an ANN model was designed to predict energy consumption in wheat production. Additionally, this study was the first to include several indirect factors, such as social factors and farm conditions. The final model was developed based on a modular neural network with two hidden layers that can predict energy consumption based on farm conditions (size of crop area), social factors (farmers' educational level), and energy inputs (N and P use, and irrigation frequency). The main conclusions from the ANN model developed to predict energy use in wheat production are as follows:

- The final ANN model can predict energy use in Canterbury wheat farms with an error margin of ± 2970 MJ/ha. This size of error in agricultural studies with several uncontrolled factors was quite acceptable. Furthermore, comparison between the ANN model and Multiple Linear Regression model (MLR) (the most common model in agricultural studies) showed that the ANN model can predict energy consumption better than the MLR model.

- The ANN model showed that it was possible to reduce energy use in wheat production by affecting direct and indirect parameters. Improving the model to predict the energy consumption of all farm products can provide more practical results for decision makers. It was clear that changing some of the effective variables in the short term was impossible; however, the model can help scientists and decision makers find the best direction for energy reductions in the future.

- The result of this study showed the ability of ANN model to predict energy consumption in wheat production by using heterogeneous data. Use of dissimilar variables, such as farm conditions and social factors, would improve the ability of decision makers to look at the problem from different perspectives. Furthermore, it would open new doors for scientists to investigate agricultural and environmental topics using a combination of direct and indirect technical and social parameters.

7.4 Suggestions for Future Research

From the results of this study, the most important recommendations for future studies are as follows:

- Increasing the number of samples and testing more variables for a longer period of time, at least five years, can help analyse trends in energy consumption in agricultural production in different regions under different conditions. In doing so, it is important to bear in mind that the correct method for data collection plays a critical role in this type of studies. Continuing this study over a period of time would help compare oil prices, wheat and other crop prices, and their effects on energy consumption and technology use on farms. For example, following energy consumption in the sample of farms of this study would be interesting to understand which factors influence energy use over a period of time. Additionally, it can indicate which operations and energy sources are more potential targets for reductions in energy consumption. Investigating the effects of changes in farmers' behaviour on energy use on their farms would be useful for predicting different scenarios in the future.

- Exploring further links and correlations (known and unknown) between different parameters would be an interesting subject for future studies. Exploring the links between wheat production, crop rotations, and other factors should be taken into consideration by an expert team. Studies focussing on the wheat and crop areas and their proportion to the total farm area as well as social factors and their effects (direct and indirect) on energy and fuel use are highly recommended.

- Investigating the effects of keeping livestock on other agricultural products and energy use will be an interesting subject for future studies. Fattening sheep, especially in winter, was common on Canterbury arable farms. Sheep can improve soil fertility (reduce fertilizer demand); however, they can increase soil compaction (increase fuel consumption in tillage operations); therefore, the role of keeping sheep and other livestock should be explored carefully.

- Choosing and using matched tractors and equipment and selecting the right operation at the right time can reduce the direct use of diesel and petrol; better equipment and reduction of tractor passes on farms can significantly reduce fuel consumption, farm expenditure, and soil compaction. The effect of more powerful tractors and larger equipment on fuel and energy consumption should be investigated in the future. New tractors and machinery are more energy efficient; however, they needed more energy to produce, service, and maintain.

- The method of operation must be studied further and guidance must be given to managerial staff. Furthermore, farmers have to learn that the use of several operations, for example, in soil preparation, increases fuel consumption and has adverse environmental impacts, such as erosion and soil compaction. Using new farming equipment and methods would reduce fuel consumption and environmental impacts considerably.

- As mentioned in the literature review, new irrigation systems had higher efficiencies; however, due to the shape and size of paddocks, some irrigators do not match the paddocks. Comparing the energy use of different irrigators based on the shape and size of paddocks, and designing a practical model, would be a practical subject to study in future.

-Estimating national energy conversion coefficients would increase the accuracy of the results. To achieve this aim, different sciences, such as chemistry, physics, engineering, transport, and social sciences should be involved and several studies should be done. After estimating the energy conversion coefficients, expert teams should monitor these as well as energy use in the most important agricultural products. Comparison of the results of these investigations, locally and globally, would be helpful for energy conservation in future.

- Establishment of an international protocol to estimate energy use in agricultural production would be a great step towards sharing and comparing different results.

Estimation of national energy consumption for different agricultural production and comparing results from other countries would be helpful for the adoption of different farming systems globally. Additionally, this comparison can find the most important barriers to reduce energy use on farms in each country and globally.

-Determination of financial parameters, such as the prices of different crops and livestock and oil prices, for a period of time, and investigation of their effects on energy use in agricultural production would improve the ANN model's ability to predict energy consumption under different conditions. Additionally, it can help scientists to investigate the effect of a wide range of parameters on energy consumption.

- Development of an ANN model to estimate energy use of all products on each farm would help find the most energy efficient combination of different agricultural products (rotations) and agricultural operations under different conditions. To develop this complex model, several farms must be involved and their production and operations must be investigated carefully.

- Develop models to predict fuel consumption, CO_2 emission, and wheat and other agricultural production using the same methods as above. For these investigations, it is possible to use the same database used for energy consumption. Modelling fuel consumption, CO_2 emission, yield, and energy consumption based on social and technical parameters would open new doors to advance agricultural modelling.

- It is possible that most farmers, upon understanding the importance of energy in agricultural production and being involved in a simple and professional survey, would like to engage in such more comprehensive study. The establishment of a network of farmers in different regions and with different backgrounds and monitoring their energy use behaviour in different environmental and economic conditions would be a useful and practical study for the future of New Zealand agriculture. It can also provide practical databases for scientists to study energy and other related topics.

References

Abadia, R., Rocamora, C., Ruiz, A., & Puerto, H. (2008). Energy efficiency in irrigation distribution networks I: Theory. *Biosystems Engineering*, *101*(1), 21-27.

Al-Ghandoor, A., Jaber, J. O., Al-Hinti, I., & Mansour, I. M. (2009). Residential past and future energy consumption: Potential savings and environmental impact. *Renewable and Sustainable Energy Reviews, 13*(6-7), 1262-1274.

Alfoldi, T., Niggli, U., Spiess, E., & Messon, J. M. G. (1994). *Input and Output of Energy for Different crops in Bio-dynamic*. Paper presented at the 3rd ESA congress.

Alvarez, R. (2009). Predicting average regional yield and production of wheat in the Argentine Pampas by an artificial neural network approach. *European Journal of Agronomy, 30*(2), 70-77.

ASAE. (2003). ASAE D496.2, FEB2003, Agricultural Machinery Managment Data: St. Joseph, Mich.: American Society of Agricultural and Biological Engineers (ASAE)

ASAE. (2009). ASAE D497.6, June 2009, Agricultural Machinery Managment Data: St. Joseph, Mich.: American Society of Agricultural and Biological Engineers (ASAE)

Ashhab, M. d. S. S. (2008). Fuel economy and torque tracking in camless engines through optimization of neural networks. *Energy Conversion and Management, 49*(2), 365-372. doi:10.1016/j.enconman.2007.06.005

Ashrafi Zadeh, S. R., & Kushwaha, R. L. (2006). *Development of a Tillage Energy Model Using a Simple Tool*. Paper presented at the CSBE/SCGAB 2006 Annual Conference, Edmonton Alberta. Canada.

Aunan, K., Berntsen, T., & Seip, H. (2000). Surface Ozone in China and its Possible Impact on Agricultural Crop Yields. *AMBIO: A Journal of the Human Environment*, *29*(6), 294–301

Aydinalp, M., Ismet Ugursal, V., & Fung, A. S. (2002). Modeling of the appliance, lighting, and space-cooling energy consumptions in the residential sector using neural networks. *Applied Energy, 71*(2), 87-110. doi:10.1016/s0306-2619(01)00049-6

Azadeh, A., Ghaderi, S. F., & Sohrabkhani, S. (2007). Forecasting electrical consumption by integration of Neural Network, time series and ANOVA. *Applied Mathematics and Computation*, *186*(2), 1753-1761. doi:10.1016/j.amc.2006.08.094

Azadeh, A., Ghaderi, S. F., & Sohrabkhani, S. (2008). Annual electricity consumption forecasting by neural network in high energy consuming industrial sectors. *Energy Conversion and Management*, *49*(8), 2272-2278. doi:10.1016/j.enconman.2008.01.035

Baik, O. D., Marcotte, M., Sablani, S. S., & Castaigne, F. (2001). Thermal and physical properties of bakery products. *Critical Reviews in Food Science and Nutrition, 41*, 321-353.

Bailey, J. A., Gordon, R., Burton, D., & Yiridoe, E. K. (2008). Energy conservation on Nova Scotia farms: Baseline energy data. *energy, 33*(7), 1144-1154.

References

Baker, C. J., Saxton, K. E., Food and Agriculture Organization of the United Nations., & C.A.B. International. (2007). *No-tillage seeding in conservation agriculture* (2nd ed.). Rome, Wallingford, Oxfordshire, UK: FAO ; CABI.

Banks, F. E. (2007). *The political economy of world energy : an introductory textbook*. New Jersey: World Scientific.

Barber, A. (2004). *Seven Case Study Farms: Total Energy & Carbon Indicators for New Zealand Arable & Outdoor Vegetable Production*: AgriLINK New Zealand Ltd.

Barber, A., & Glenys, P. (2005). *Energy Use and Efficiency Measures For the New Zealand Arable and Outdoor Vegetable Industry*. Auckland: Climate Change Office and Energy Efficiency and Conservation Authority.

Barber, A., & Benge, J. (2006). *Total Energy Indicators: Benchmarking Green, Green Organic and Gold Kiwifruit Orchards*: The AgriBusiness Group.

Baruah, D. C., & Bora, G. C. (2008). Energy demand forecast for mechanized agriculture in rural India. *Energy Policy, 36*(7), 2628-2636.

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), 6957-6965.

Biofuels in Brazil : realities and prospects. (2007). [Brazil]: Ministry of External Relations.

Borg, S. (1981). A discriminating monopolist model of natural gas markets over the period 1960-1966. *Applied Energy, 9*(2), 153-158. doi:10.1016/0306-2619(81)90051-9

Boserup, E. (2005). *The conditions of agricultural growth : the economics of agrarian change under population pressure*. New Brunswick, NJ: Aldine Transaction.

Bowers, C. G. J. (1985). Southeastern tillage energy data and recommended reporting. *Transactions of the ASAE, 28 (3)*, 731-737.

Boyle, G. (2004). *Renewable energy* (2nd ed.). Oxford ; New York: Oxford University Press in association with the Open University.

Boyle, G., Everett, B., & Ramage, J. (2003). *Energy systems and sustainability*. Oxford [England]: Oxford University Press in association with the Open University.

Breiman, A., & Graur, D. (1995). Wheat Evaluation. *Israel J Plant Sci, 43*, 58-95.

Campbell, C. J. (2005). *Oil crisis*. Brentwood, Essex: Multi-Science Publishing.

Centre for Advanced Engineering. (1996). *Energy efficiency : a guide to current and emerging technologies*. Christchurch, N.Z.: Centre for Advanced Engineering, University of Canterbury.

CIGR. (1999). *CIGR Handbook of Agricultural Engineering. International Commission of Agricultural Engineering*. St. Joseph, MI: American Society of Agricultural Engineers.

Claus, H., & Filip, Z. (1990). Effects of clays and other solids on the activity of phenoloxidases produced by some fungi and actinomycetes. *Soil Biology and Biochemistry, 22*(4), 483-488. doi:10.1016/0038-0717(90)90182-y

Coley, D. A. (2008). *Energy and climate change : creating a sustainable future*. Chichester, West Sussex ; Hoboken, NJ: John Wiley.

Colwell, J. D. (1994). *Estimating fertilizer requirements : a quantitative approach*. Wallingford: CAB International.

References

Conforti, P., & Giampietro, M. (1997). Fossil energy use in agriculture: an international comparison. *Agriculture, Ecosystems & Environment, 65*(3), 231-243.

Da Rosa, A. V. (2005). *Fundamentals of renewable energy processes*. Amsterdam ; Boston: Elsevier Academic Press.

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.

Dawson, S. M. (1978). *Energy requirements of inputs to agriculture in New Zealand*: Lincoln College.

DeGregori, T. R. (2001). *Agriculture and modern technology : a defense* (1st ed.). Ames: Iowa State University Press.

Dell, R., Rand, D. A. J., & Royal Society of Chemistry (Great Britain). (2004). *Clean energy*. Cambridge [England]: Royal Society of Chemistry.

Devi, R., Singh, V., Dahiya, R. P., & Kumar, A. (2009). Energy consumption pattern of a decentralized community in northern Haryana. *Renewable and Sustainable Energy Reviews, 13*(1), 194-200.

EECA. (1996). *Situation Assessment Report on the National Energy Efficiency and Conservation Strategy*. Wellington, New Zealand: Energy Efficiency and Conservation Authority (EECA).

EECA. (1998). *Situation Assessment Report on the National Energy Efficiency and Conservation Strategy*. Wellington, New Zealand: Energy Efficiency and Conservation Authority (EECA).

EECA. (2006). *Situation Assessment Report on the National Energy Efficiency and Conservation Strategy*. Wellington, New Zealand: Energy Efficiency and Conservation Authority (EECA).

EECA. (2007). *Situation Assessment Report on the National Energy Efficiency and Conservation Strategy*. Wellington, New Zealand: Energy Efficiency and Conservation Authority (EECA).

EIA. (2009). New Zealand energy profile. Energy Information administration, Official Energy Statistics fron US Goverment:

El Bassam, N. (2010). *Handbook of bioenergy crops : a complete reference to species, development and applications*. London ; Washington: Earthscan.

El.Ashry, M. T. (2006). Clean Energy and Sustainable Development. *Environmental Policy and Law, 35*(2), 92-94.

Elias, A. A. (2008). Energy efficiency in New Zealand's residential sector: A systemic analysis. *Energy Policy, In Press, Corrected Proof*

Environment., E. (2009). New Zealand energy & environment business week (Vol. 6, pp. 1). Christchurch, N.Z.: Media Information http://www.nzenergy-environment.co.nz/

Fairweather, J., & Mulet-Marquis, S. (2009). Changes in the age of New Zealand farmers: Problems for the future? *New Zealand Geographer, 65*(2), 118-125. doi:10.1111/j.1745-7939.2009.01154.x

Fang, Q., Hanna, M. A., Haque, E., & Spillman, C. K. (2000). Neural Network Modeling Of Energy Requirments, For Size Reduction Of Wheat. *ASAE, 43(4): 947-952*

FAO. (2000a). *World Agriculture: Towards 2015/2030, Technical Interim Report*. Rome.

References

FAO. (2000b). *CURRENT WORLD FERTILIZER TREND AND OUTLOOK TO 2005/2006*. Rome.

FAO. (2002). *Crop and Drops: Making in Best Use of Water for Agriculture.*: Food and Agriculture Organization, United Nations, Rome , Italy.

FAO. (2008). http://faostat.fao.org/: http://faostat.fao.org/

FAR. (2009). *Far cultival evaluation, autumn sown wheat & barley 2008/2009*. Lincoln, Canterbury: Foundation for Arable Research.

Ferraro, D. O. (2009). Fuzzy knowledge-based model for soil condition assessment in Argentinean cropping systems. *Environmental Modelling & Software, 24*(3), 359-370.

Fluck, R. C. (1992). *Energy in World Agriculture* (Vol. 6): Elsevier, Amsterdam.

Fluck, R. C., & Baird, C. D. (1980). *Agricultural energetics*. Westport, Conn.: AVI Pub. Co.

Fouquet, R. (2008). *Heat, power and light : revolutions in energy services*. Cheltenham: Edward Elgar.

Gajri, P. R., Arora, V. K., & Prihar, S. S. (2002). *Tillage for sustainable cropping*. New York: Food Products Press.

Geem, Z. W., & Roper, W. E. (2009). Energy demand estimation of South Korea using artificial neural network. *Energy Policy, 37*(10), 4049-4054. doi:10.1016/j.enpol.2009.04.049

Gerin, P. A., Vliegen, F., & Jossart, J.-M. (2008). Energy and CO2 balance of maize and grass as energy crops for anaerobic digestion. *Bioresource Technology, 99*(7), 2620-2627.

Ghobadian, B., Rahimi, H., Nikbakht, A. M., Najafi, G., & Yusaf, T. F. (2009). Diesel engine performance and exhaust emission analysis using waste cooking biodiesel fuel with an artificial neural network. *Renewable Energy, 34*(4), 976-982.

Gillingham, K., T, Smith, S. J., & Sands, R., D. (2008). Impact of bioenergy crops in a carbon dioxide constrained world: an application of the MiniCAM energy-agriculture and land use model. *Mitigation and Adaptation Strategies for Global Change, 13*, 675-701.

Grastina, L., Temple, S., & Diana, b. (1995). Energetic Analysis of Four Farming System During the Conversion from Conventional to Organic Farming System In the Sacramento Valley- California. *Rivista di Agronomia, 29*

Grisso, R. D., Kocher, M. F., & Vaughan, D. H. (2004). Predicting tractor fuel consumption. *Applied Engineering in Agriculture, 20*(5), 553-561.

Hagan, M., Demuth, H., & Beale, M. (2002). *Neural network design*: Boston, USA: PWS Publishing Company.

Haldenbilen, S., & Ceylan, H. (2005). Genetic algorithm approach to estimate transport energy demand in Turkey. *Energy Policy, 33*(1), 89-98. doi:10.1016/s0301-4215(03)00202-7

Hall, C. A. S., Cleveland, C. J., & Kaufmann, R. (1986). *Energy and resource quality: the ecology of the economic process*. New York, United State: John Wiley and Sons,New York, NY.

Hatirli, S. A., Ozkan, B., & Fert, C. (2006). Energy inputs and crop yield relationship in greenhouse tomato production. *Renewable Energy, 31*(4), 427-438.

References

Haykin, S. S. (2009). *Neural networks and learning machines* (3rd ed.). New York: Prentice Hall/Pearson.

Heinzow, T., & Tol , R. S. J. (2003). Prediction of crop yields across four climate zones in Germany: an artificial neural network approach. *Centre for Marine and Climate Research, Hamburg University, Hamburg.,*

Helm, D. (2002). Energy policy: security of supply, sustainability and competition. *Energy Policy, 30*(3), 173-184.

Himanen, V., Nijkamp, P., Reggiani, A., & Raitio, J. (1998). *Neural networks in transport applications*. Aldershot, Hants, England ; Brookfield, Vt.: Ashgate.

Hood, C., James, C., & Victoria University of Wellington. Institute of Policy Studies. (2007). *Making energy work : a sustainable energy future for New Zealand*. Wellington [N.Z.]: Institute of Policy Studies.

Hornacek, M. (1979). Energetic analysis of 14 agricultural practices. *Etude du Centre National d'Etude et d'Expérimentation de Machinisme Agricole, France, 457*

Hornik, K., Stinchocombe, M., & White, H. (1989). Multilayer feedforward networks are universal approximators. *Elsevier Science Ltd. Oxford, UK, UK, 2*(5)

Hsu, C.-C., & Chen, C.-Y. (2003). Regional load forecasting in Taiwan--applications of artificial neural networks. *Energy Conversion and Management, 44*(12), 1941-1949. doi:10.1016/s0196-8904(02)00225-x

Hu, J.-L., & Kao, C.-H. (2007). Efficient energy-saving targets for APEC economies. *Energy Policy, 35*(1), 373-382.

Hu¨lsbergen, K. J., & Kalk, W. D. (2001). *Energy balances in different agricultural systems – can they be improved?* . Paper presented at the The International Fertiliser Society

IPCC. (2001). *CLIMATECHANGE 2001: THE SCIENTIFIC BASIS*. Cambridge (UK): Intergovernmental Panel on Climate Change, UNIVERSITY OF CAMBRIDGE.

Ipsilantis, I., Karpouzas, D. G., Papadopoulou, K. K., & Ehaliotis, C. (2009). Effects of soil application of olive mill wastewaters on the structure and function of the community of arbuscular mycorrhizal fungi. *Soil Biology and Biochemistry, 41*(12), 2466-2476. doi:10.1016/j.soilbio.2009.09.003

Jaccard, M. K. (2005). *Sustainable fossil fuels : the unusual suspect in the quest for clean and enduring energy*. Cambridge, UK: Cambridge University Press.

Javeed Nizami, S., & Al-Garni, A. Z. (1995). Forecasting electric energy consumption using neural networks. *Energy Policy, 23*(12), 1097-1104. doi:10.1016/0301-4215(95)00116-6

Jebaraj, S., & Iniyan, S. (2006). A review of energy models. *Renewable and Sustainable Energy Reviews, 10*(4), 281-311. doi:10.1016/j.rser.2004.09.004

Jiang, N., Sharp, B., & Sheng, M. (2009). New Zealand's Emissions Trading Scheme. *New Zealand economic papers, 1*(43)

Juang, C.-F., Cheng, C.-N., & Chen, T.-M. (2009). Speech detection in noisy environments by wavelet energy-based recurrent neural fuzzy network. *Expert Systems with Applications, 36*(1), 321-332. doi:10.1016/j.eswa.2007.10.028

Kalogirou, S. A. (2000). Applications of artificial neural-networks for energy systems. *Applied Energy, 67*(1-2), 17-35. doi:10.1016/s0306-2619(00)00005-2

Kalogirou, S. A. (2001). Artificial neural networks in renewable energy systems applications: a review. *Renewable and Sustainable Energy Reviews, 5*(4), 373-401. doi:10.1016/s1364-0321(01)00006-5

Kalogirou, S. A., & Bojic, M. (2000). Artificial neural networks for the prediction of the energy consumption of a passive solar building. *energy, 25*(5), 479-491. doi:10.1016/s0360-5442(99)00086-9

Karkacier, O., & Gokalp Goktolga, Z. (2005). Input-output analysis of energy use in agriculture. *Energy Conversion and Management, 46*(9-10), 1513-1521.

Karkacier, O., Gokalp Goktolga, Z., & Cicek, A. (2006). A regression analysis of the effect of energy use in agriculture. *Energy Policy, 34*(18), 3796-3800.

Kavaklioglu, K., Ceylan, H., Ozturk, H. K., & Canyurt, O. E. (2009). Modeling and prediction of Turkey's electricity consumption using Artificial Neural Networks. *Energy Conversion and Management, 50*(11), 2719-2727. doi:10.1016/j.enconman.2009.06.016

Kelly, G. (2007). Renewable energy strategies in England, Australia and New Zealand. *Geoforum, 38*(2), 326-338.

Kermanshahi, B., & Iwamiya, H. (2002). Up to year 2020 load forecasting using neural nets. *International Journal of Electrical Power & Energy Systems, 24*(9), 789-797. doi:10.1016/s0142-0615(01)00086-2

Kitani, O. (1999). *CIGR handbook of agricultural engineering*. St. Joseph, MI: American Society of Agricultural Engineers.

Kitani, O., Toda, T., & Roy, K. (1998). *Energy and Environment in Agricultural Engineering Research.* Paper presented at the International Agricultural Engineering Conference, Bangkok, Thailand.

Kizilaslan, H. (2008). Input-output energy analysis of cherries production in Tokat Province of Turkey. *Applied Energy, In Press, Corrected Proof*

Kobayashi, K., & Salam, M. U. (2000). Comparing simulated and measured values using mean squared deviation and its components. *Agronomy Journal, 92*(2), 345-352.

Koga, N., Tsuruta, H., Tsuji, H., & Nakano, H. (2003). Fuel consumption-derived CO2 emissions under conventional and reduced tillage cropping systems in northern Japan. *Agriculture, Ecosystems & Environment, 99*(1-3), 213-219. doi:10.1016/s0167-8809(03)00132-4

Kole, C. (2006). *Cereals and millets*. Berlin ; New York: Springer.

Kreith, F., & Burmeister, G. (1993). *Energy Managment & Conservation*. Denver: National Conference of State Legislature.

Kronstad, W. E. (1998). *Agricultural development and wheat breeding in the 20th century*. Paper presented at the the 5th International Wheat Conference, Ankara, Turkey, Developments in Plant Breeding.

Kuesters, J., & Lammel, J. (1999). Investigations of the energy efficiency of the production of winter wheat and sugar beet in Europe. *European Journal of Agronomy, 11*(1), 35-43. doi:10.1016/s1161-0301(99)00015-5

Lal, R. (2004). Carbon emission from farm operations. *Environment International, 30*(7), 981-990. doi:10.1016/j.envint.2004.03.005

Landsberg, P. T. (1977). A simple model for solar energy economics in the U.K. *energy, 2*(2), 149-159. doi:10.1016/0360-5442(77)90041-x

Lincoln University. (2008). *Financial budget manual*. Lincoln, N.Z.: Dept. of Farm Management and Rural Valuation, Lincoln College.

Linker, R., Seginer, I., & Gutman, P. O. (1998). Optimal CO2 control in a greenhouse modeled with neural networks. *Computers and Electronics in Agriculture, 19*(3), 289-310. doi:10.1016/s0168-1699(98)00008-8

Linko, P., & Zhu, Y. (1991). Neural network programming in bioprocess variable estimation and state prediction. *Journal of Biotechnology, 21*(3), 253-269. doi:10.1016/0168-1656(91)90046-x

Liu, J. (2009). A GIS-based tool for modelling large-scale crop-water relations. *Environmental Modelling & Software, 24*(3), 411-422.

Lynch, B. J. (2008). *Energy security : the foreign policy implications*. Wellington [N.Z.]: New Zealand Institute of International Affairs.

Mader, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). Soil Fertility and Biodiversity in Organic Farming. *Science, 296*(5573), 1694.

Mallon, K. (2006). *Renewable energy policy and politics : a handbook for decision-making*. London ; Sterling, VA: Earthscan.

Manaloor, V., & Sen, C. (2009). *Energy Input Use and CO2 Emissions in the Major Wheat Growing Regions of India.* Paper presented at the International Association of Agricultural Economists Conference,, Beijing, China.

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), 2336-2339.

Manos, B., Begum, M. A. A., Kamruzzaman, M., Nakou, I., & Papathanasiou, J. (2007). Fertilizer price policy, the environment and farms behavior. *Journal of Policy Modeling, 29*(1), 87-97. doi:10.1016/j.jpolmod.2006.05.002

Manual., N. Z. N. A. (2009). New Zealand Novachem agrichemical manual (pp. v.). Christchurch [N.Z.]: AgriMedia

Marchetti, C. (1977). Primary energy substitution models: On the interaction between energy and society. *Technological Forecasting and Social Change, 10*(4), 345-356. doi:10.1016/0040-1625(77)90031-2

Martinez.Alier, J. (1990). *Ecological economics : energy, environment, and society* Oxford, UK

Maugeri, L. (2010). *Beyond the age of oil : the myths, realities, and future of fossil fuels and their alternatives*. Santa Barbara, Calif.: Praeger.

Mayumi, K. (1991). Temporary emancipation from land: from the industrial revolution to the present time. *Ecological Economics, 4*(1), 35-56. doi:10.1016/0921-8009(91)90004-x

McChesney, I. G. (1981). *Field Fuel Consumption of Tractors*: Joint Centre for Environmental Sciences, Lincoln College, University of Canterbury.

McChesney, I. G., & Joint Centre for Environmental Sciences (N.Z.). (1979). *Energy use on hill country sheep and beef farms near Cheviot, North Canterbury*. [Christchurch, N.Z.]: Joint Centre for Environmental Sciences.

McChesney, I. G., & Joint Centre for Environmental Sciences (N.Z.). (1983a). *Electricity demand for irrigation*. [Lincoln, N.Z.]: Joint Centre for Environmental Sciences, University of Canterbury and Lincoln College.

McChesney, I. G., & Joint Centre for Environmental Sciences (N.Z.). (1983b). *Liquid fuel demand in New Zealand agriculture*. Christchurch, N.Z.: Joint Centre for Environmental Sciences, University of Canterbury and 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*, 141-153.

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*. Lincoln College: Joint Centre for Environmental Sciences.

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), 211-219.

McLaughlin, N. B., Drury, C. F., Reynolds, W. D., Yang, X. M., Li, Y. X., Welacky, T. W., & Stewart, G. (2008). Energy Inputs for Conservation and Conventional Primary Tillage Implements in a Clay Loam Soil. ASABE:

MED. (2004). *New Zealand Energy Data File, Ministry of Economic Development*. Wellington, New Zealand: Ministry of Economic Development.

MED. (2007). *New Zealand energy strategy to 2050 : powering our future : towards a sustainable low emissions energy system*. Wellington [N.Z.]: Ministry of Economic Development.

MED. (2009). *New Zealand Energy Quarterly - June quarter 2009*. Wellington: Ministry of Economic Development.

Meisterling, K., Samaras, C., & Schweizer, V. (2009). Decisions to reduce greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat. *Journal of Cleaner Production, 17*(2), 222-230. doi:10.1016/j.jclepro.2008.04.009

Melesse, A. M., & Hanley, R. S. (2005). Artificial neural network application for multi-ecosystem carbon flux simulation. *Ecological Modelling, 189*(3-4), 305-314. doi:10.1016/j.ecolmodel.2005.03.014

Meul, M., Nevens, F., Reheul, D., & Hofman, G. (2007). Energy use efficiency of specialised dairy, arable and pig farms in Flanders. *Agriculture, Ecosystems & Environment, 119*(1-2), 135-144. doi:10.1016/j.agee.2006.07.002

Mielenz, J. R. (2009). *Biofuels : methods and protocols*. New York, NY: Humana Press.

Mills, R. M. (2008). *The myth of the oil crisis : overcoming the challenges of depletion, geopolitics, and global warming* Westport, Conn: Praeger.

Ministry of Commerce., & Eden Resources Ltd. (1993). *Renewable energy opportunities for New Zealand : executive report*. [Wellington, N.Z.]: The Ministry.

Ministry of Economic Development. (2006). *New Zealand Energy Data File, Ministry of Economic Development*. Wellington, New Zealand: Ministry of Economic Development.

Ministry of Transport. (2007). *Sustainable Transport: Uodate of New Zealand Transport Strategy*. Retrieved. from.

Mitchell, D. O., Ingco, M. D., & Duncan, R. C. (1997). *The world food outlook*. Cambridge ; New York: Cambridge University Press.

Mohandes, M. A., Rehman, S., & Halawani, T. O. (1998). A neural networks approach for wind speed prediction. *Renewable Energy, 13*(3), 345-354. doi:10.1016/s0960-1481(98)00001-9

Mohtasebi, S. S., Behroozi Lar, M., Safa, M., Chaichi, M. R. (2008). Comparison of Direct and Indirect Energy Coefficients for Seeding and Fertilizing in Irrigated Wheat Production. *World Applied Sciences, 3*(3), 353-358.

Mukherji, A. (2007). The energy-irrigation nexus and its impact on groundwater markets in eastern Indo-Gangetic basin: Evidence from West Bengal, India. *Energy Policy, 35*(12), 6413-6430.

Murphy, J. D., & Power, N. M. (2008). How can we improve the energy balance of ethanol production from wheat? *Fuel, 87*(10-11), 1799-1806.

NAS. (1977). *World food and nutrition study*. Washington, D.C: National Academy of Sciences.

Nemecek, T., von Richthofen, J.-S., Dubois, G., Casta, P., Charles, R., & Pahl, H. (2008). Environmental impacts of introducing grain legumes into European crop rotations. *European Journal of Agronomy, 28*(3), 380-393.

Nersesian, R. L. (2007). *Energy for the 21st century : a comprehensive guide to conventional and alternative sources*. Armonk, N.Y.: M.E. Sharpe, Inc.

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*, 163-172.

Nguyen, M. L., Haynes, R. J., & Goh, K. M. (1995). Nutrient budgets and status in three pairs of conventional and alternative mixed cropping farms in Canterbury, New Zealand. *Agriculture, Ecosystems & Environment, 52*(2-3), 149-162.

Odum, E. C., Scott, G., Odum, H. T., & Joint Centre for Environmental Sciences (N.Z.). (1981). *Energy and environment in New Zealand*. [Christchurch, N.Z.]: Joint Centre for Environmental Sciences, University of Canterbury.

Odum, H. T. (1994). *Ecological and general systems : an introduction to systems ecology* (Rev. ed.). Niwot, Colo.: University Press of Colorado.

Odum, H. T., & Odum, E. C. (1976). *Energy basis for man and nature*. New York: McGraw-Hill.

Oikawa, T. (1995, 11-14 December). *What is an Ecological Cause of Ongoing Large-Scale Deforestation?* Paper presented at the the Traditional Technology for Environmental Conservation and Sustainable Development in the Asian-Pacific Region, Tsukuba Science City, Japan.

Outlaw, J. L., Collins, K. J., & Duffield, J. A. (2005). *Agriculture as a producer and consumer of energy*. Wallingford, Oxfordshire, UK ; Cambridge, MA, USA CABI Pub.,.

Ozkan, B., Akcaoz, H., & Fert, C. (2004). Energy input-output analysis in Turkish agriculture. *Renewable Energy, 29*(1), 39-51.

Pachepsky, Y. A., Timlin , D., & Varallyay, G. (1996). Artificial Neural Networks to Estimate Soil Water Retention from Easily Measurable Data. *Soil Science Society of America, 60*, 727-733

Parten, C., Hartson, C., & Maren, A. (1990). *Handbook of neural computing applications*: San Diego, CA (USA); Academic Press Inc.

Patterson, M. G. (2006). Development of ecological economics in Australia and New Zealand. *Ecological Economics, 56*(3), 312-331.

Patterson, W. C. (1991). *The energy alternative : changing the way the world works*. London: Optima.

Pearson, R. G., & Joint Centre for Environmental Sciences (N.Z.). (1976). *Energy analysis*. [Lincoln]: Joint Centre for Environmental Sciences.

Pearson, R. G., & Joint Centre for Environmental Sciences (N.Z.). (1977). *Energy in agriculture : a bibliography*. Canterbury [N.Z.]: Joint Centre for Environmental Sciences, Lincoln College.

Pellizzi, G. (1992). Use of energy and labour in Italian agriculture. *Journal of Agricultural Engineering Research, 52*, 111-119.

Pellizzi, G., Guidobono Cavalchini, A., Lazzari, M., & Commission of the European Communities. (1988). *Energy savings in agricultural machinery and mechanization*. London ; New York: Elsevier Applied Science.

Pimentel, D. (2009). Reducing Energy Inputs in the Agricultural Production System. *Monthly Review, 61*(3), 92.

Pimentel, D., & Patzek, T. D. (2005). Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower *Natural Resources Research, 14*(1), 65-76.

Pimentel, D., & Pimentel, M. (2008). *Food, energy, and society* (3rd ed.). Boca Raton, FL: CRC Press.

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., Doughty, R., Carothers, C., Lamberson, S., Bora, N., & Lee, K. (2002). *Energy inputs in crop production: comparison of developed and developing countries*: Boca Raton, FL, CRC Press.

Pimentel, D., Marklein, A., Toth, M. A., Karpoff, M. N., Paul, G. S., McCormack, R., & Kyriazis, J. K., T. (2009). Food Versus Biofuels: Environmental and Economic Costs *Human Ecology, 37*(1), 1-12.

Pimentel, D., Gardner, J., Bonnifield, A., Garcia, X., Grufferman, J., Horan, C., Schlenker, J., & Walling, E. (2007). Energy efficiency and conservation for individual Americans *Environment, Development and Sustainability, 11*, 523-546.

Raja, R., Sooriamoorthi, C., Kanniappan, P., & Ramachandran, T. (1997). Energy planning and optimisation model for rural development—a case of sustainable agriculture. *Int J Energy Res, 21*, 527–548.

Ramanathan, R. (2005). An analysis of energy consumption and carbon dioxide emissions in countries of the Middle East and North Africa. *energy, 30*(15), 2831-2842.

Randolph, J., & Masters, G. M. (2008). *Energy for sustainability : technology, planning, policy*. Washington, D.C.: Island Press.

Reijnders, L., & Huijbregts, M. A. J. (2009). *Biofuels for road transport : a seed to wheel perspective*. London: Springer.

Riethmuller, G. (1989). *Draft Requirements of Tillage Equipment in the Western Australian Wheatbelt*. Paper presented at the Conference on Agricultural Engineering 1988: An Australasian Conference to Celebrate the Australian Bicentennial.

References

Ritz, K., & Young, I. M. (2004). Interactions between soil structure and fungi. *Mycologist, 18*(2), 52-59. doi:10.1017/s0269-915x(04)00201-0

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*. Wooster: Ohio Agricultural Research and Development Center.

Rosegrant, M. W., Agcaolli-Sombilla , A., & Perez, N. (1995). Global Food Projections to 2020: implications for investment *2020 vision discussion papers, 5*

Rutherford, J. P., Scharpf, E. W., & Carrington, C. G. (2007). Linking consumer energy efficiency with security of supply. *Energy Policy, 35*(5), 3025-3035.

Ruttan, V. W. (1993). *Research to Meet Crop Production Needs: Into the 20th Century*. Paper presented at the International Crop Science Congress.

Safa, M., & Tabatabaeefar, A. (2002). *Energy Consumption in Wheat Production, IACE 2002,Wuxi, China.* Paper presented at the IACE 2002, Wuxi, China.

Safa, M., & Tabatabaeefar, A. (2008). Fuel Consumption in Wheat Production in Irrigated and Dry Land Farming. *World Journal of Agricultural Sciences, 4*(1), 89-90.

Safa, M., Mohtasebi, S. S., Lar, M. B., & Ghasemi-Varnamkhasti, M. (2010). Energy consumption in production of grains prevalent in Saveh, Iran. *African Journal of Agricultural Research, 5*(19), 2637-2646.

Samarasinghe, S. (2007). *Neural networks for applied sciences and engineering : from fundamentals to complex pattern recognition*. Boca Raton, FL: Auerbach.

Sartori, L., Basso, B., Bertocco, M., & Oliviero, G. (2005). Energy Use and Economic Evaluation of a Three Year Crop Rotation for Conservation and Organic Farming in NE Italy. *Biosystems Engineering, 91*(2), 245-256. doi:10.1016/j.biosystemseng.2005.03.010

Sauerbeck, D. R. (2001). CO2 emissions and C sequestration by agriculture – perspectives and limitations *Nutrient Cycling in Agroecosystems, 60*, 253-266.

Saunders, C., Barber, A., & Taylor, G. (2006). *Food miles : comparative energy/emissions performance of New Zealand's agriculture industry*. [Lincoln] N.Z.: Agribusiness & Economics Research Unit, Lincoln University.

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), 286-296.

Sfetsos, A. (2000). A comparison of various forecasting techniques applied to mean hourly wind speed time series. *Renewable Energy, 21*(1), 23-35. doi:10.1016/s0960-1481(99)00125-1

Shapouri, H., Duffield, J. A., & Wang, M. (2004). The energy balance of corn ethanol revisited. *Transactions of the ASAE, 46*(4), 959-968

Shoemaker, R., McGranahan, D., & McBride, W. (2006). Agriculture and rural Communities Are Resilient to High Energy Coasts. *Feature, 4*(2), 17-21.

Siemens, J., & Bowers, W. (1999). *Machinery management: how to select machinery to fit the real needs of farm managers*.

Sims, R. E. H. (2004). *Bioenergy options for a cleaner environment : in developed and developing countries* (1st ed.). Oxford: Elsevier Science.

Sims, R. E. H., Raxworthy, C., Henderson, P., Martin, G. A., McChesney, I. G., & Wells, C. M. (1996). *Primary production (Part 4). In: Energy Efficiency: A guide to* *current and emerging technologies. Volume 2, Industry and Primary Production*: Centre for Advanced Engineering, University of Canterbury.

Singh, H., Mishra, D., & Nahar, N. M. (2004). Energy use pattern in production agriculture of a typical village in arid zone--Part III. *Energy Conversion and Management, 45*(15-16), 2453-2472.

Singh, H., Singh, A. K., Kushwaha, H. L., & Singh, A. (2007). Energy consumption pattern of wheat production in India. *energy, 32*, 1848-1854.

Singh, S., & Mittal, J. (1992). *Energy in Production Agriculture*. Mittal Publishing Company: Mittal Publishing Company.

Smil, V. (1991). *General energetics : energy in the biosphere and civilization*. New York: Wiley.

Smil, V. (1994). *Global ecology : environmental change and social flexibility*. London ; New York: Routledge.

Smil, V. (2008). *Energy in nature and society : general energetics of complex systems*. Cambridge, Mass.: The MIT Press.

Snyder, C. S., Bruulsema, T. W., Jensen, T. L., & Fixen, P. E. (2009). Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agriculture, Ecosystems & Environment, 133*(3-4), 247-266. doi:10.1016/j.agee.2009.04.021

Soetaert, W., & Vandamme, E. J. (2009). *Biofuels*. Chichester, U.K.: Wiley.

Sözen, A. (2009). Future projection of the energy dependency of Turkey using artificial neural network. *Energy Policy, 37*(11), 4827-4833. doi:10.1016/j.enpol.2009.06.040

Sözen, A., & Ali Akçayol, M. (2004). Modelling (using artificial neural-networks) the performance parameters of a solar-driven ejector-absorption cycle. *Applied Energy, 79*(3), 309-325. doi:10.1016/j.apenergy.2003.12.012

Sözen, A., & Arcaklioglu, E. (2007). Prediction of net energy consumption based on economic indicators (GNP and GDP) in Turkey. *Energy Policy, 35*(10), 4981-4992. doi:10.1016/j.enpol.2007.04.029

SSSA. (1997). *Glossary of Soil Science Terms*. Medison, WI: Soil Science Society of America.

Stanhill, G. (1984). Introduction to the role of energy in agriculture. *Energy and Agriculture, Springer-Verlag, Berlin,* I1–7.

Statistics New Zealand. (1999). *A Regional Profile, NEW ZEALAND, CANTERBURY*. Wellington, New Zealand: Statistics New Zealand.

Statistics New Zealand. (2003, June 2003). *Hectares Used and Farms by Land Use by Region*. Wellington: Statistics New Zealand.

Statistics New Zealand. (2004). *WATER, Monetary Stock Report*. Wellington, NZ: Statistics New Zealand.

Statistics New Zealand. (2007a). *Physical Stock Account for Water*. Welington: Statistics New Zealand.

Statistics New Zealand. (2007b). *Water Physical Stock Account 1995–2005*. Welington: Statistics New Zealand.

Statistics New Zealand. (2008a). *Agricultural Production Statistics: June 2007 (Provisional) Grain crops - Media Release, Increased yields from wheat and barley harvests* Wellington: Statistics New Zealand.

Statistics New Zealand. (2008b). *Energy and the Economy: 1997–2006*. Wellington, NZ: Statistics New Zealand.

Statistics New Zealand. (2008c). *Agricultural Production Statistics (Final): June 2007*. Wellington: Statistics New Zealand.

Statistics New Zealand. (2009). *Subnational Population Estimates: At 30 June 2009*. Wellington, New Zealand: Statistics New Zealand.

Stern, M. O. (1977). A policy-impact model for the supply of depletable resources with applications to crude oil. *energy, 2*(3), 257-272. doi:10.1016/0360-5442(77)90030-5

Stewart, R. E. (1979). *Seven Decades That Changed America : A History Of The American Society Of Agricultural Engineers 1907-1977* St. Joseph, MICH: ASAE.

Stout, B. A. (1990). *Handbook of energy for world agriculture*. London; New York: Elsevier Science Pub. Co.

Stout, B. A., & Best, G. (2001). Effective Energy Use and Climate Change: Needs of Rural Areas in Developing Countries. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development, 3*

Tester, J. W. (2005). *Sustainable energy : choosing among options*. Cambridge, Mass.: MIT Press.

Tzilivakis, J., Warner, D. J., May, M., Lewis, K. A., & Jaggard, K. (2005). An assessment of the energy inputs and greenhouse gas emissions in sugar beet (Beta vulgaris) production in the UK. *Agricultural Systems, 85*(2), 101-119. doi:10.1016/j.agsy.2004.07.015

UNESCO. (2001). *Securing the Food Supply*: World Water Assessment Programme. United Nations Education Scientific and Cultural Organization. Paris.

USDA. (2008). *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005*. Washington, D.C: United States Department of Agriculture (USDA).

Velde, P., Barré, P., & Velde, B. (2010). Man and Agriculture: Manipulating Soil – Plant Interactions. In *Soils, Plants and Clay Minerals* (pp. 255-303): Springer Berlin Heidelberg.

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), 5803-5813. doi:10.1016/j.enpol.2009.08.046

Warren, J. P. (2007). *Managing transport energy : power for a sustainable future*. Oxford: Open University, Oxford University Press.

WCED. (1987). *Our Common Future*: World Commission on Environment and Development.

Webb, J., O'Brien, C., & Colville, Z. (2002). *Energy Physical Stock Account, 1992-2001*. Christchurch: Statistics New Zealand.

Wells, C. (2001). *Total energy indicators of agricultural sustainability : dairy farming case study* (No. 0478079680 (pbk.)). Wellington [N.Z.]: Ministry of Agriculture and Forestry.

Witney, B. (1988). *Choosing and using farm machines*. Harlow, Essex, England, New York: Longman Scientific & Technical ; Wiley.

Xing, L., & Pham, D. T. (1995). *Neural Networks for Identification, Prediction, and Control*: Springer-Verlag New York.

Yu, L., Wang, S., & Lai, K. K. (2008). Forecasting crude oil price with an EMD-based neural network ensemble learning paradigm. *Energy Economics*, *30*(5), 2623-2635. doi:10.1016/j.eneco.2008.05.003

Yusaf, T. F., Buttsworth, D. R., Saleh, K. H., & Yousif, B. F. CNG-diesel engine performance and exhaust emission analysis with the aid of artificial neural network. *Applied Energy*, *87*(5), 1661-1669. doi:10.1016/j.apenergy.2009.10.009

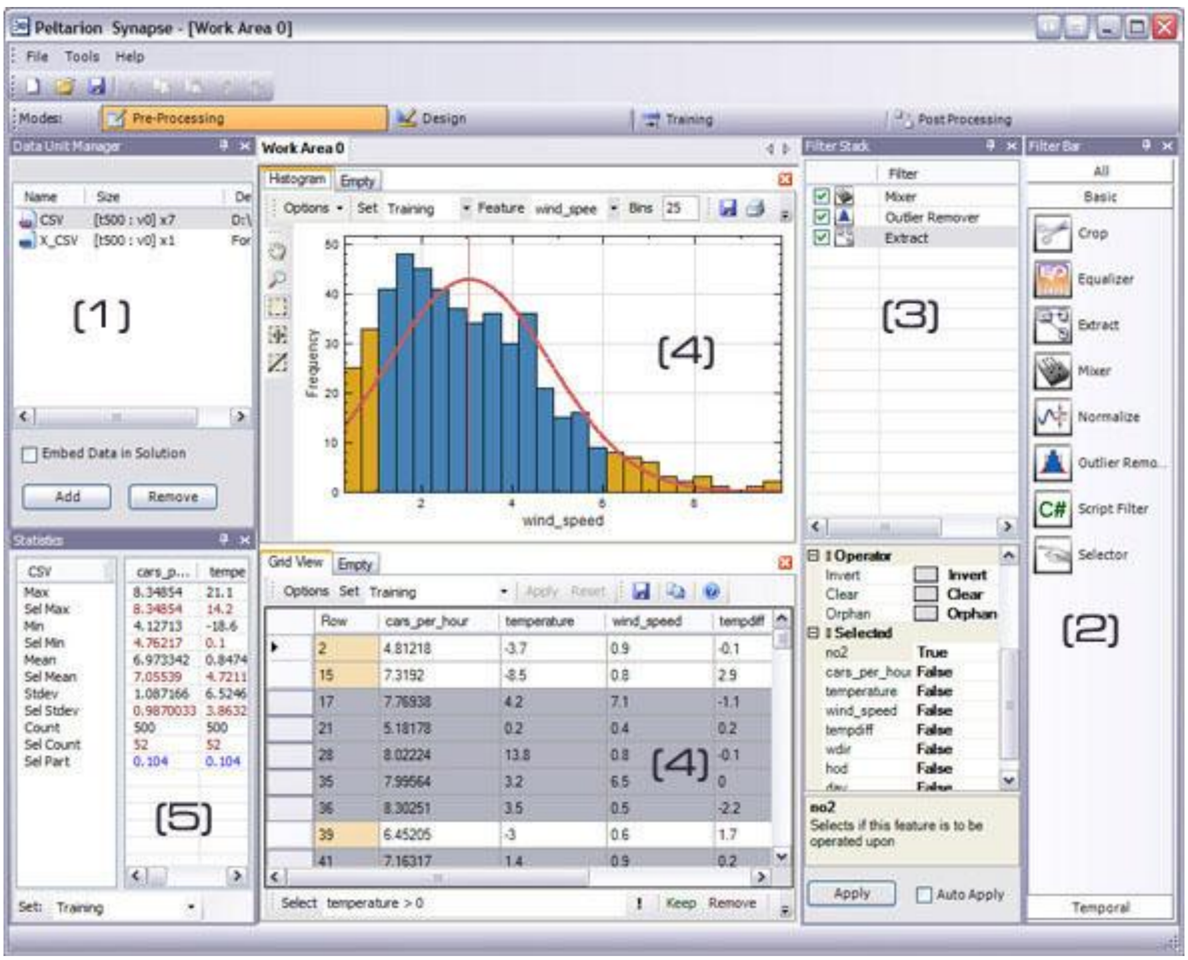
Ziesemer, J. (2007). *ENERGY USE IN ORGANIC FOOD SYSTEMS*. Rome: Natural Resources Management and Environment Department, Food and Agriculture Organization of the United Nations.

Appendix A

A brief introduction to Peltarion Synapse Neural Networks development environment

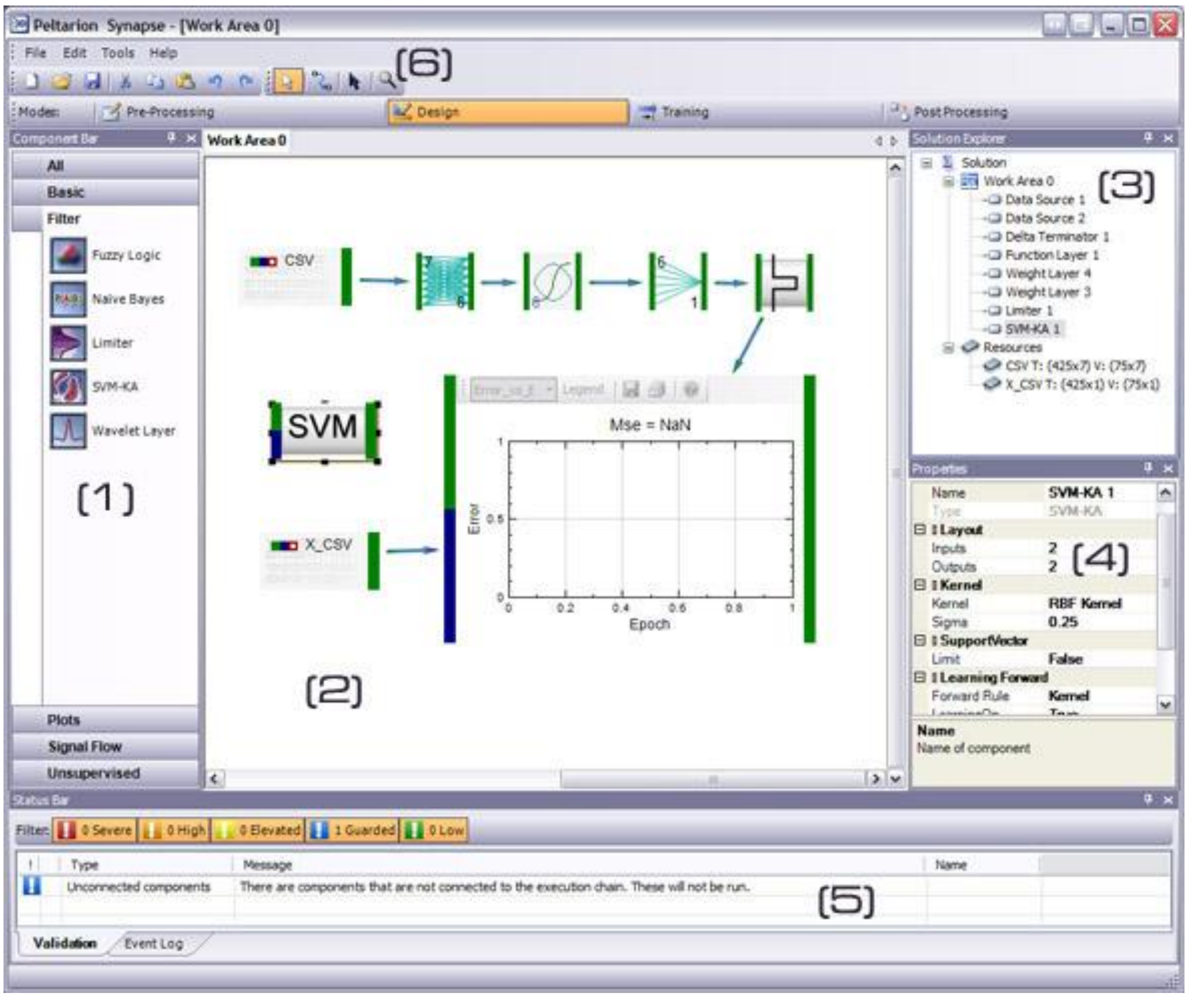
<u>First Mode: *Pre-Processing*</u>

This mode is used to add the file to the Data Unit Manager, explore the data, and remove outliers. It contains five parts: 1) Data unit manager, 2) Filter bar, 3) Filter stack, 4) Visualiser, and 5) Statistics pane.



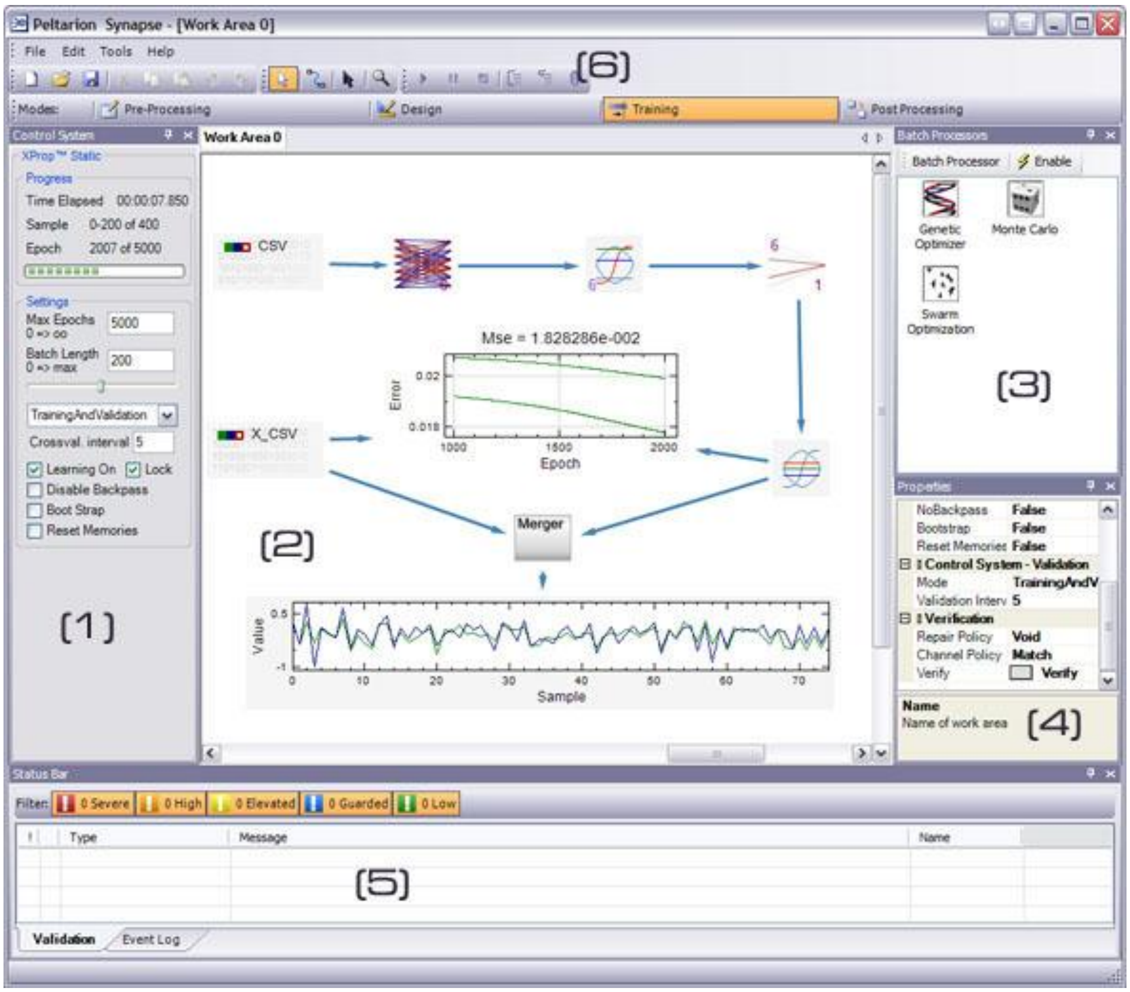
<u>Second Mode: *Design*</u>

The model and its structure is developed in the Design Mode and it contains: 1) Component bar, 2) Work Area, 3) Solution explorer, 4) Setting browser, 5) Validation pane, and 6) Mouse Tools



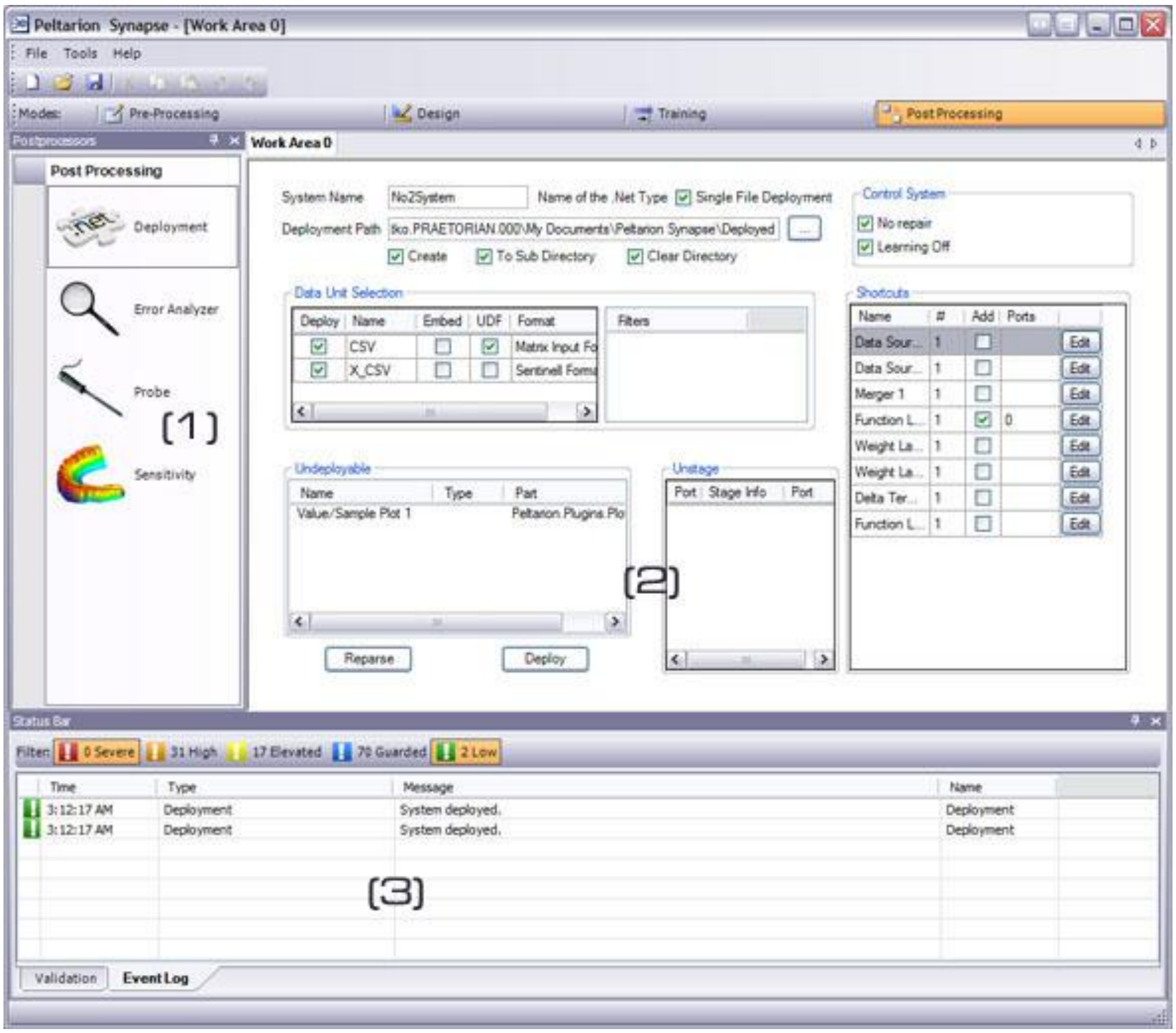
<u>Third Mode: *Training*</u>

The training mode is used to adapt the system. It is visually similar to the Design Mode and it contains: 1) Control System Pane, 2) Work Area, 3) Batch Processor Pane, 4) Settings Browser, 5) Validation / Event Log pane, and 6) Control Buttons.



<u>Fourth Mode: *Post-Processing*</u>

The Post-processing mode is dedicated to the analysis of an already trained model and preparation of such a model for end use. It can be used to test the trained model and take measurements, to get an idea of how well it actually performs, and if it meets the requirements. It contains: 1) Postprocessor Bar, 2) Work Area, and 3) Validation /Log Pane.

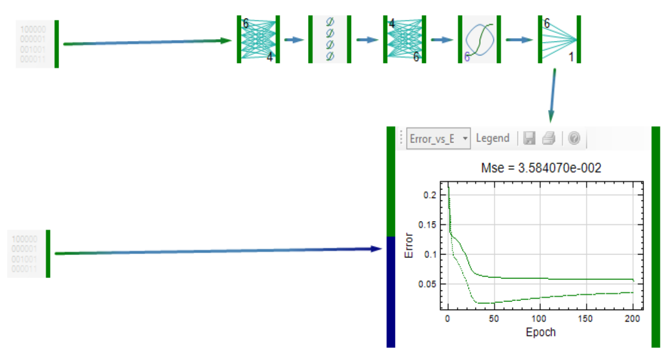


Appendix B

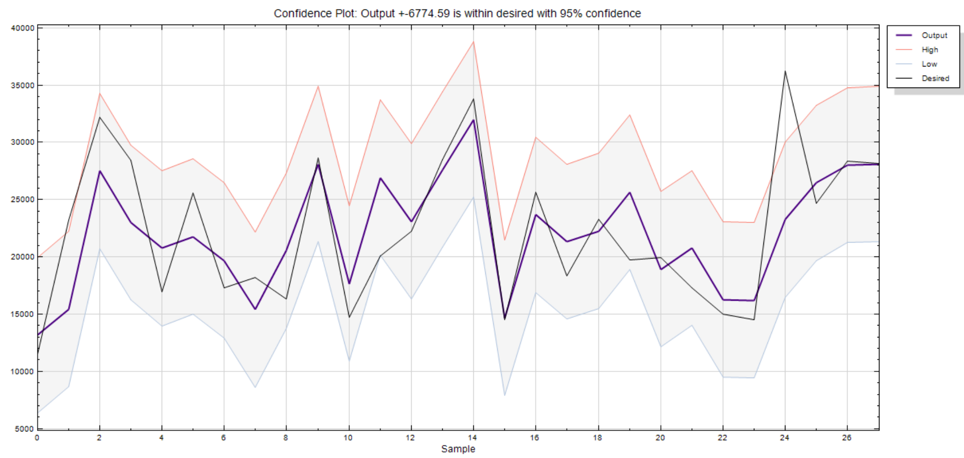
To develop the ANN model in this study several ANNs were tested and as examples, two of them and their results are shown here.

1- MLP two layer

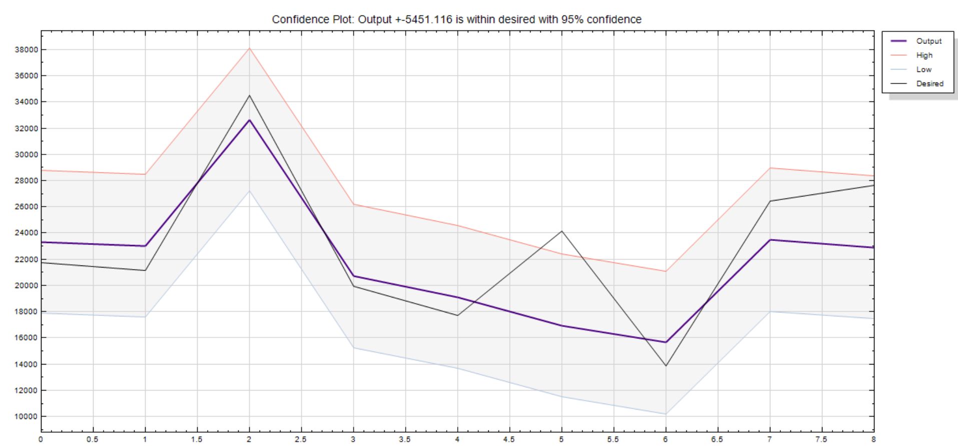
a) Network structure and training performances on training and validation data. The two blocks on the left indicate input and output data, the meshes represent weights and the two numbers superimposed on the meshes indicate the number of inputs and neurons, respectively. For example, this model has 6 inputs, 4 hidden neurons in the first layer, 6 hidden neurons in the second layer and one output neuron.



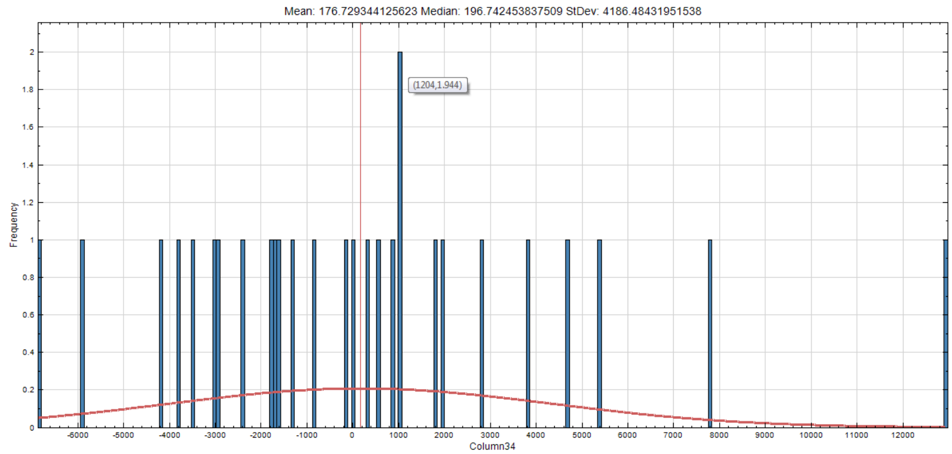
b) Actual and predicted energy consumption with 95% confidence bands (training data)



c) Actual and predicted energy consumption with 95% confidence bands (validation data)

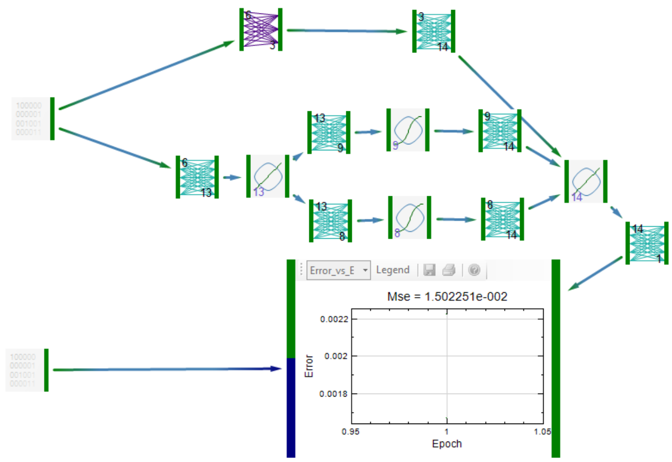


d) Prediction error distribution (validation data)

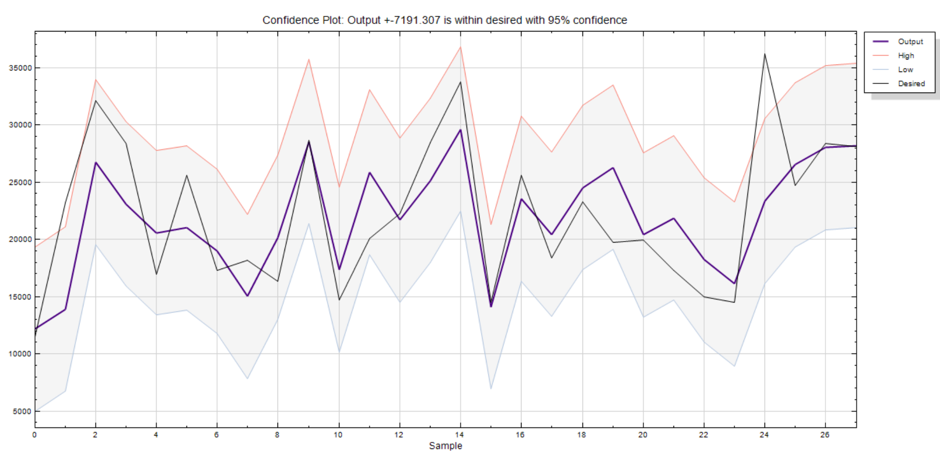


2- A Modular network with a Hebbian layer

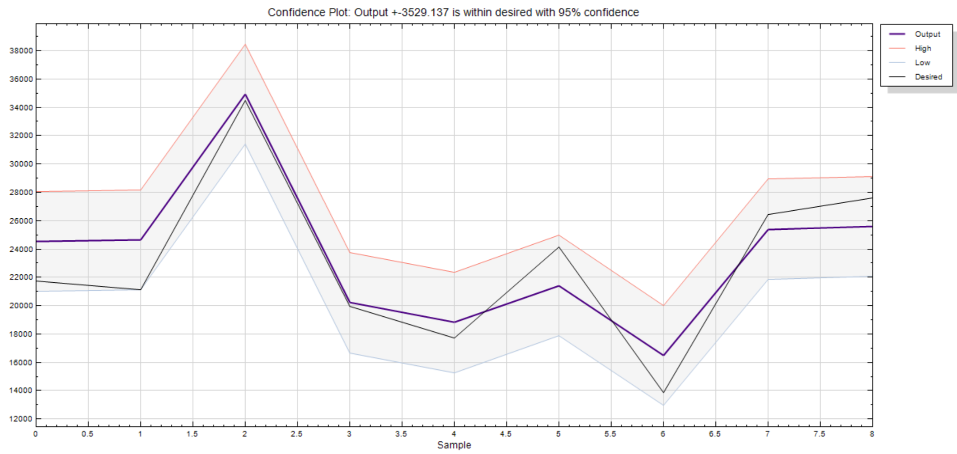
a) Network structure and training performances



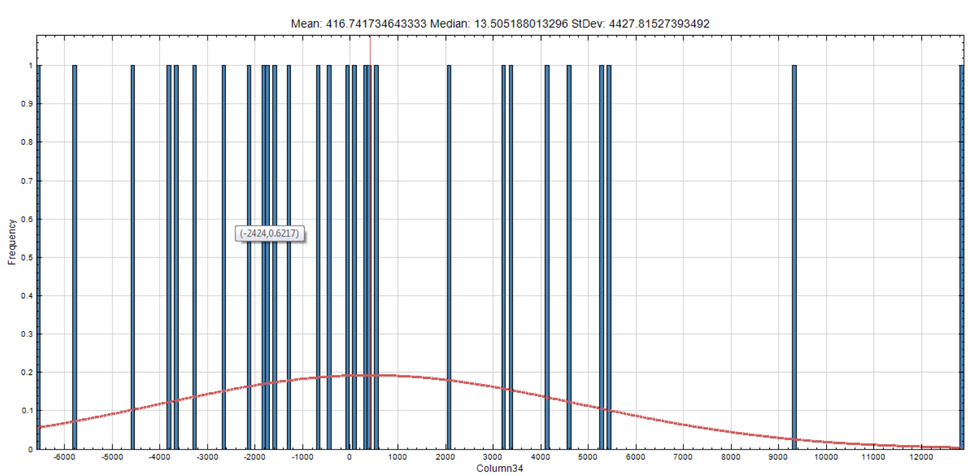
b) Actual and predicted energy consumption (training data)



c) Actual and predicted energy consumption (validation data)



d) Error distribution (validation data)



Appendix C

- **Cover letter and questionnaire used in the survey**
- **Two filled in questionnaires**

Dear farmer
This survey is related to my thesis (PhD) study at Lincoln University.

The research will estimate the energy consumption, fuel consumption, and CO_2 emissions in wheat production, and will develop a model to forecast and classify energy consumption on Canterbury farms in 2007/2008.

This model will help compare different agricultural systems and find the best methods for saving energy with minimum income reduction.
If you don’t know the exact data values, give good estimates (but the exact data will be much better if possible).

This research is done in complete confidence, and I do not require your name, but it might be useful if I need to recheck your information.

Please if you have any queries, do not hesitate to contact me.

Thank you

Majeed Safa
PhD Student, Lincoln University
Email: safam2@lincoln.ac.nz
Address: PO Box 84, Natural Resources engineering Group, Lincoln University, Lincoln 7647, Canterbury, NZ

QUESTIONNAIRE

Farmer Information

Name	District	Distance from Nearest Town for Shopping(km)

Total Farm Area (ha)	Crop Area (ha)	Wheat Area (ha)	Number of Paddocks	Number of Paddocks for Wheat

Number of Cows/Beef	Number of Sheep

Age (year)	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79

Education	Primary school	High school	Diploma	Under Graduate	Post graduate
	☐	☐	☐	☐	☐

Relevant Experience (year)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64

Soil structure (soil type)	Sandy	Light to Medium	Loam(Medium)	Med to Heavy	Clay
	☐	☐	☐	☐	☐

Type of Farm Ownership	Owner	Rent	Share

Annual Rain (mm)	400	500	600	700

Yield of Wheat(tonnes/ha)	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15

Tractor Information

Brand and Model	Age of Tractor	hp	Ownership			Operations Used for			
			Owner	Rent	Share				
			☐	☐	☐				
			☐	☐	☐				
			☐	☐	☐				
			☐	☐	☐				

Annual Inputs Used on Wheat crops

	Fertilizer(kg) / Herbicide / Fungicide / Insecticide (l)								
Input Name									
Amount (kg or l)									

Source of Seed	My Own Seed	Seed Company
	☐	☐

Product Target	Milling	Feeding
	☐	☐

	Cultivar Name	Amount (kg/ha)
Spring Sowing		
Autumn Sowing		

Irrigation per Hectare on Wheat Crops

Irrigation System	Irrigation Frequency	Irrigation Duration (hrs)	Electricity Consumption (kW/h)	Fuel Consumption (l/h)

Operation	Brand of Machine	Number of Passes	Total Hours of Operation(h/ha)	Width of Machinery (m)	Ground Speed (km/h)	Fuel Consumption (l/ha)	Age of Machine	Ownership
Mouldboard Plough								
Chisel Plough								
Heavy-duty Disc								
Field Cultivator								
Spring tine Harrow								
Rotary Cultivator								
Air Seeder								
Grain Drill								
Fertilizer Spreader								
Boom-type Sprayer								

Harvester								

Other Energy Consuming Activities			**- Physical Energy** **-Power** **-Fuel**
Name of Operation	**Duration of Operation (hour)**	**Operation Frequency**	

What is your suggestion to reduce energy (especially fuel and electricity) consumption on farms?

Thank you for your time in filling this out

1-

QUESTIONNAIRE

Farmer Information

Name	District	Distance from Nearest Town for Shopping(km)
[redacted]	ASHBURTON	10

Total Farm Area (ha)	Crop Area (ha)	Wheat Area (ha)	Number of Paddocks	Number of Paddocks for Wheat
880	850	260	23	7

Number of Cows/Beef	Number of Sheep
N/A	N/A

Age (year)	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79
				✓									

Education	Primary school	High school	Diploma	Under Graduate	Post graduate
	✓	✓	✓	☐	☐

Relevant Experience (year)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64
			✓										

Soil structure (soil type)	Sandy	Light to Medium	Loam(Medium)	Med to Heavy	Clay
	☐	☐	☑	☐	☐

Type of Farm Ownership	PARTNER Owner	Rent	Share
	✓		

Annual Rain (mm)	400	500	600	700
	830			

Yield of Wheat(tonnes/ha)	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15
					✓	✓						

Tractor Information

Brand and Model	Age of Tractor	hp	Ownership: Owner	Ownership: Rent	Ownership: Share	Operations Used for			
John Deere 8320	5	300	☑	☐	☐	Cultivations Planting			
Challenger MT765 B	1	320	☑	☐	☐	" "			
JCB loadall 536-60	2	150	☑	☐	☐	Grain handling in/out store			
			☐	☐	☐				

Annual Inputs Used on Wheat crops /Ha.

	Fertilizer(kg) / Herbicide / Fungicide / Insecticide (L)								
Input Name	P. K.	N	Gardoprim Herb.	Karate Fung.	Cougar Glean Herb	Maestro Herb	others as needed		
Amount (kg or L)	as needed about 250 kg	as needed av. 400 kg	1 L	70 ml	.5 L 15 gm.	1 L			

Source of Seed	My Own Seed	Seed Company
	✓	✓ only if needed

Product Target	Milling	Feeding
	✓	✓

	Cultivar Name	Amount (kg/ha)
Spring Sowing		
Autumn Sowing	Torlesse	50-60
	Solstice	50 - 60

Dryland.
~~**Irrigation per Hectare on Wheat Crops**~~

Irrigation System	Irrigation Frequency	Irrigation Duration (hrs)	Electricity Consumption (kW/h)	Fuel Consumption (L/h)

Operation	Brand of Machine	Number of Passes	Total Hours of Operation(h/ ha)	Width of Machinery (m)	Ground Speed (km/h)	Fuel Consumption (L/h)	Age of Machine	Ownership
Moldboard Plough								
Chisel Plough	Plucks	1	6mins /Ha.	8	14	4	6	own.
Heavy-duty Disc								
Field Cultivator								
Spring tine Harrow								
Rotary Cultivator								
Air Seeder	Simba-Horsch CO8	1	6mins / Ha.	8m	14	4	6	own.
Grain Drill								
Fertilizer Spreader	Amazone	3-4		24 m		.5	4.	Contractor
Boom-type Sprayer	Bateman	5-6		24m		1	3	Contractor
Harvester	LEXION 600	1	[illegible] 75-80 T/h	9	7	1.2 L/Tonne.	3	own

2-

QUESTIONNAIRE

Farmer Information

Name	District	Distance from Nearest Town for Shopping(km)
[redacted]	North Canterbury	22km

Total Farm Area (ha)	Crop Area (ha)	Wheat Area (ha)	Number of Paddocks	Number of Paddocks for Wheat
126	120	50	20	5

Number of Cows/Beef	Number of Sheep
	300

Age (year)	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79
									✓				

Education	Primary school	High school	Diploma	Under Graduate	Post graduate
	☐	☑	☐	☐	☐

Relevant Experience (year)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64
									✓				

Soil structure (soil type)	Sandy	Light to Medium	Loam(Medium)	Med to Heavy	Clay
	☐	☐	☐	☑	☐

Type of Farm Ownership	Owner	Rent	Share
	✓		

Annual Rain (mm)	400	500	600	700
			✓	

Yield of Wheat(tonnes/ha)	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15
							✓					

Tractor Information

Brand and Model	Age of Tractor	hp	Ownership: Owner	Ownership: Rent	Ownership: Share	Operations Used for			
6610 John Deere	7	100	☑	☐	☐	Drilling (Seeding)	General Farm Use	Has front end loader	for bales etc
John Deere 6620?	4	125	☑	☐	☐	Ploughing	Power Harrowing	Topdressing	
			☐	☐	☐				
			☐	☐	☐				

Annual Inputs Used on Wheat crops

	Fertilizer(kg) / Herbicide / Fungicide / Insecticide (L)								
Input Name	Sulphur Super	Urea		Gleon	Cougar	Starane	Proline	Granstar	Karate Zeon
Amount (kg or L)	500 kg/ha	300kg/ha		20gms/ha	300mls/ha	400ml/ha	300mls /ha	20gms/ha	40mls /ha

Source of Seed	My Own Seed	Seed Company
	☐	☑

Product Target	Milling	Feeding
	☑	☑

	Cultivar Name	Amount (kg/ha)
Spring Sowing		
Autumn Sowing	Conquest	120kg/ha
	Gladiator	100kg/ha
	Phoenix	100k/ha

Irrigation per Hectare on Wheat Crops

Irrigation System	Irrigation Frequency	Irrigation Duration (hrs)	Electricity Consumption (kW/h)	Fuel Consumption (L/h)
Hand Hose Guns	Three times	11 hrs	Approx $2.00 per hour	

Operation	Kind of Tractor	Number of Passes	Total Hours of Operation(h/ha)	Width of Machinery (m)	Ground Speed (km/h)	Fuel Consumption (L/h)	Age of Machine	Ownership
Moldboard Plough	John Deere	1	.75	2	10		7	
Chisel Plough								
Heavy-duty Disc								
Field Cultivator	John Deere	1	.25	3	12		15	
Spring tine Harrow	John Deere	1	.25	3	14		12	
Rotary Cultivator	John Deere	1	.75	3	5		8	
Air Seeder								
Grain Drill	John Deere	1	.5	3	6		15	
Fertilizer Spreader	John Deere	2	.25	24	14		2	
Boom-type Sprayer								
Harvester	New Holland ########	1	.5	5	4		10	