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A field study of energy consumption in wheat production in Canterbury, New Zealand

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ABSTRACT

This paper examines the energy consumption of wheat production in Canterbury province, New Zealand. This study was conducted within a 35,300 ha of irrigated and dry land wheat fields in Canterbury in the 2007–2008 harvest year.

Total energy consumption for wheat production was estimated at 25,600 MJ/ha. On average, fertilizer and electricity were used more than other energy sources, at around 10,654 (47%) and 4870 (22%) MJ/ha, respectively. The energy consumption for wheat in irrigated farming systems and dry land farming systems was estimated at 25,600 and 17,458 MJ/ha, respectively. The main source of energy in both systems is fertilizer and it consumed around 10,188 and 11,429 MJ/ha for irrigated farming and dry land farming, respectively.

The average operational energy consumption was 7997 MJ/ha. In irrigated farming system, operational energy was approximately three times more than that in dry land farming. The maximum energy consumed in operational wheat production was about 7762 (71%) MJ/ha for irrigated farming systems, including irrigation, and it was 1451 (46%) MJ/ha for dry land farming including tillage. The average values of estimated output to input energy ratio for wheat in irrigated and dry land farming systems were 11.5 and 15.1, respectively.

1. Introduction

Wheat is one of the eight food sources (wheat, rice, corn, sugar, cattle, sorghum, millet and cassava) which provide 70–90% of all calories and 66–90% of the protein consumed in developing countries. Globally, wheat provides nearly 55% of the carbohydrate and 20% of the calories consumed [1]. Also, more than 40% of world grain is being fed to livestock [2]. The wheat is cultivated under a wide range of climatic conditions. Most people consume wheat more than any other cereal grain. Global production of bread wheat in 2003 was 557 million tons (Mt), with an average yield of 2.68 t/ha [3]. The world's major bread wheat producing areas are in northern China, northern India, northern USA and adjoining areas in Canada, Europe, Russia, Latin America and Africa [4]. It covers around 25% of the total global area devoted to cereal crops. It is the staple food of nearly 35% of the world population. Recent statistics show the demand for wheat grows faster than that for any other major crop. In the last few decades, developed seed varieties have increased the yield; however, in many areas, due to the use of old growing systems, yields have stayed at less than desired levels. The forecasted global demand for wheat in 2020 varies between 840 and 1050 Mt [5,6]. To reach this target, global production will need to increase by 1.6–2.6% 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 [7] 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 [8]. For wheat, the global average grain yield must increase from the current 2.7 t/ha to 3.8 t/ha [4]. This means that the average yield of wheat should increase by about 40% in the short term.

Due to rising fuel prices in recent years, the price of production of crops that are dependent more on fuel has increased faster than that of other crops. However, farmers still select agricultural production with minimum fuel share. Moreover, in recent years, the production of ethanol from wheat has increased. The ethanol production from wheat is highly competitive [9] and this new demand has raised the wheat price in the global market.

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 methods and techniques used [10]. There should be a plan for energy consumption; otherwise, with current population growth, the present life style will be unsustainable. In last years of the twentieth century, energy consumption has been reduced by 1.3–4.9% in developed industrial countries [11]. Use of diesel in tractors and diesel engines for various operations contributed 27.2% to the total

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energy input under irrigated conditions; and electricity which was used in irrigation only supplied 12.7% energy [11]. Therefore, it is important to recognize the input elements and recommend methods to control them. Since, there are different methods to estimate the energy consumption, comparison and evaluation of results from past studies are difficult. For example, some researchers consider human labor as an energy input in their calculation; however, many others do not [12–15]. Furthermore, a general international agreement on how to estimate input energy is difficult to achieve. The lack of reliable data for each country and region often forces researchers to take values from other countries without making adjustment for different circumstances in those countries [16].

Agricultural energy use can be classified as either direct or indirect [17]. The primary means of direct energy (operational energy) use on-farm involves the consumption of fuels such as diesel, furnace oil, gasoline, other petroleum products, electricity and wood. 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 farms and about 50% on arable farms [18,19]. In other words, direct energy is that energy used directly by the operation and is most easily recognized as fuel, electricity and human sources. Most indirect energy resources include fertilizer, biochemical products and crop propagation. The energy includes not only the 'useable' energy but also the energy expended or lost during processes such as extraction, conversion, refining and transportation [10,17,20,21].

In 2007, Canterbury, with an average precipitation between 500 and 750 mm [22], contained a total of 77,600 ha of arable land; it is approximately 66% of New Zealand arable land. From 2006 to 2007, the wheat area harvested increased by 7% to 40,500 ha and the tonnage harvested increased by 32% to 344,400 tons in New Zealand. Canterbury reported 87% of the national wheat area harvested [23].

The objective of this study was to determine the energy consumption in wheat production based on field operations and energy sources in dry land farming and irrigated farming.

2. Methodology

Energy consumption is defined as the energy used for the production of wheat until it leaves the farm. The data was collected from three different sources: questionnaire, literature review, and field measurements. The questionnaire was improved by interviews with farmers step by step. The methodology of this study is a cradle-to gate analysis, meaning that transport and waste disposal components of the product's life cycle are not considered after they leave 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.).

A survey was conducted to identify farmers' attitudes and opinions towards energy consumption. In this study 40 arable farms were selected randomly. These farms comprise approximately 2390 (7%) ha of wheat lands in Canterbury. The number and duration of operations, the rate of seed, pesticide and fertilizer applications, and amount of human labor were investigated using a questionnaire and personal interviews with farmers. Randomly selected farm owners completed the questionnaire. From the literature review and ASAE standards, equivalent energy inputs were determined for all input and output parameters for wheat production. From the initial analysis, it was found that 30 farms were irrigated and rest were dry land farms. In irrigated farming, farms are irrigated between 1 and 10 times depending on the annual rainfall. Some irrigated farms are converted to dry land farms, or vice versa, in different years. For this reason, it should be noticeable that in Canterbury region, it is difficult to find boundaries between dry land farming and irrigated farming.

To have a better view of energy consumption in wheat production, operational (direct) energy including human energy, fuel, and electricity and each farm operation are first investigated. Then, the whole energy inputs (direct and indirect) are considered. The inputs for energy analysis in wheat production in this study thus include direct energy: labor, electricity and fuel, and also indirect energy: fertilizer, pesticides, machinery (production and repair), and seed. Therefore, this study examines the two major parts of, energy use: operations and energy sources.

2.1. Operations

Energy consumption in wheat production operation, such as tillage, planting, fertilizer distributing, spraying, irrigation, transportation and harvesting, were determined in the Canterbury region. Operational (direct) energy includes human energy, fuel and electricity. Human labor energy is quite low and electricity is used mainly in irrigation. In other operations, fuel is the most important operational energy. The energy component in irrigation mainly includes the energy use for constructing the water supply source, providing the conveyance works, maintaining, and operating the system.

2.2. Energy sources

2.2.1. Human

Introducing new machines reduced human labor in industry, but in field activities still human labor plays a key role [24]. Even now, human power is the main source (73%) of energy in agricultural operation in many of the developing countries [25]. Human labor is used for almost every task on the farm, from driving machinery, maintenance, repair, irrigation, spraying, and fertilizer to management. Many of the labor activities can be substituted for by machinery in agricultural production. However, sometimes this change has little or no effect on crop yields. If all agricultural operations are run by human power, at least 1200 h/ha is required. It means each person can mange just 1 ha during a growing season [2]. New machines and tractors allow farmers to raise their crops only with spending 11 h per hectare [26]. In future, human labor could be reduced on fully mechanized (mechatronic) farms to almost nil. Nevertheless, some scientists believe that the modern and organic agriculture need more manual work for harvesting and weeding and in some crops it could be up to 35% [27–29]. Energy output of humans depends on gender, weight, body size, age, activity and climate. Therefore, there are different estimations of energy output in human labor. Most of physical activities on farms are driving and adjusting and servicing the tractors and machinery. In this study, labor work was calculated by using survey and estimating how much work was done in each operation. It is clear that farmers use different amount of energy per hour for each operation. In the research area, most farmers and workers are male but some females are rarely seen as well. Currently, the energy output for a male worker is about 1.96 MJ/h and 0.8 MJ/h for a female [11]. One must recognize that human energy is the most expensive form of energy in field operations.

The technique used in these studies to estimate the labor energy use has been to estimate the hours of the activities which need the labor. Energy consumption has been determined by multiplying the energy coefficient of workers by total hours of human activities.