# ENERGY AND ECONOMIC ANALYSES OF PEPPER PRODUCTION UNDER PLASTICULTURE AND CONVENTIONAL SYSTEMS

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**To my mother, and in the memory of my father**

# ABSTRACT

Energy availability and natural resource base protection are issues of crucial importance. Efforts have been made intensively at all levels, nationally and globally, to secure energy supplies while at the same time ensuring the protection of the environment. The interaction between these issues and agriculture is intimate. Agriculture is highly sensitive to interruption in energy availability, although it is gradually becoming more energy intensive. With respect to the environmental aspects of agricultural production, agriculture has recently been a target of criticism for being responsible for a number of environmental problems. Most of these problems, if not all, are associated with the use of fossil fuel-based inputs, such as chemicals and machinery.

Faced with the twin challenges of food security and environmental protection, given the energy resource scarcity, agriculture needs to develop production systems that are highly productive, economically viable and environmentally sound. In this regard, several production systems have been recently developed. All of them share the general objective of using less energy per unit of output.

The focus of this study for red pepper, is to examine the environmental performance of a plasticulture system compared to a conventional system in terms of

1. energy inputs per unit of output; and
2. cost per unit of output.

Energy analysis was performed to account for the total energy consumed in red pepper production under silver mulch and no-mulch. The method of process analysis was employed to account for total energy requirements for different inputs. Partial budgets for both type of production systems were constructed to estimate the costs of production. The analysis boundary was set at the farm gate. Production costs are derived from secondary data. Data on mulch yield were based on the results of an experimental trail conducted on the farm of Macdonald Campus of McGill University in the West Island of Montreal (Fava, 1996).

Costs per hectare were estimated at $9,898 and $6,725 for plasticulture and conventional systems respectively. Revenues were estimated at $49,704 and $22,640 for the plasticulture and conventional systems respectively. On a per hectare basis, net margins for both types of production were calculated at $39,488 and $15,592. Financial productivity was measured in terms of revenues relative to costs. Financial productivities were found to be 4.9 and 3.2 for the plasticulture and conventional systems respectively.

Total energy consumption in plasticulture and conventional systems were found to be 206,992 MJ/ha and 137,403 MJ/ha respectively. The efficiencies of energy use expressed as energy input per unit of output were found to be 0.13 kg/MJ and 0.09 kg/MJ for the plasticulture and conventional systems respectively.

Results indicate that plasticulture, while being more energy and capital intensive, is more efficient. Thus, this study recommends the adoption of plasticulture.

# RÉSUMÉ

La disponibilité d'énergie et la protection des ressources naturelles de base sont des problèmes d'importance critique. Des efforts se sont faits intensivement à tous les niveaux: national et globale, pour assurer les réserves d'énergie tout en assurant la protection de l'environnement. Les interactions entre ces problèmes et l'agriculture sont intimes. L'agriculture est extrêmement sensible aux interruptions de disponibilité d'énergie, malgré qú elle change graduellement en s'orientant vers l'utilisation intensive d'énergie. Quant aux aspects environnementaux de la production agricole, l'agriculture fut récemment portée responsable pour certains problèmes environnementaux. La majorité de ces problèmes, sinon la totalité, sont associés avec l'utilisation d'intrants à base de combustible fossile, tels les produits chimiques et les machineries.

Confrontée par le double défi de la sécurité des aliments et la protection environnementale, étant donné la rareté des ressources d'énergies, l'agriculture a besoin de développer des systèmes de production qui sont hautement productifs, viable économiquement et qui ne nuisent pas à l'environnement. À cet égard, plusieurs systèmes de production ont été récemment développés. Tous partagent l'objectif général d'utiliser moins d'énergie par unité de production.

Le but de cette étude de piment rouge, est d'examiner la performance environnementale d' un systéme plasticulture, en comparaison avec un systéme conventionnelle par rapport à:

1. Les intrants d'énergie par unité de production; et
2. Les coûts unitaires de production.

Une analyse d'énergie a été exécutée dans le but de justifier la totalité d'énergie consommée lors de la production de piments sous plasticulture et conventionnelle. La méthode d'analyse procédée a été employée dans le but de justifier les exigences totales en énergie pour différents intrants. Des budgets partiaux pour les deux types de a systémes production ont été construits dans le but de déterminer les coûts de production. Les limites de l'analyse se sont situées au niveau de la production sur la ferme seulement. Les coûts de production sont dérivés à l'aide de données secondaires. Les données pour le rendement sous paillis ont été basé sur les résultats d'une expérience menée sur la ferme du Campus Macdonald de l'Université McGill dans l'Ouest de l'île de Montréal (Fava, 1996).

Les coûts par hectares ont été estimé à $9898 et $6725 pour les systèmes sous paillis et sans paillis respectivement. Les revenus ont été estimés à $49,704 et $22,640 pour les systèmes plasticulture et conventionnelle respectivement. Sur une base par hectare, les marges nettes pour les deux types de production ont été calculée à $39488 et $15592. La productivité a été mesurée en terme des revenus relatives aux coûts. Les productivités financières ont été évaluée à 4.9 et 3.2 pour les systèmes plasticulture et conventionnellle respectivement.

Les consommations totales d'énergie dans les systèmes plasticulture et conventionnelle ont été évaluée à 206992 MJ/ha et 137403 MJ/ha respectivement. Les

efficacités d'utilisation d'énergie par unité de production ont été évaluée à 0.13 kg/MJ et 0.09 kg/MJ pour les systèmes plasticulture et conventionnelle respectivement.

Les résultats indiquent que la plasticulture est non-seulement intensive en energie et capitaux, mais est aussi plus efficace. Donc, cet étude recommande l'adoption de la pratique de la plasticulture.

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# CHAPTER ONE

# PROBLEM STATEMENT

## 1.1 - -INTRODUCTION :

Agricultural production is an energy conversion process, where plants, through photosynthesis, transform solar energy into food, feed, fuel, and fiber suitable for human and animal consumption. Primitive agriculture, powered by human and animal energy, involved not much more than scattering seeds over a parcel of land and waiting for the rain. Yields were only enough to feed farmers and their families. In contrast, modern agriculture has combined fuel energy for operating machinery and fossil fuel-based inputs in the form of fertilizers and pesticides in the attempt to keep up with the nutritional needs of the steadily growing world population.

The energy used in modern agricultural production can be divided into two categories: direct and indirect. Direct energy refers to any fuel used to power various on-farm operations, from field preparation to drying. Indirect energy is the energy expended to make inputs available to agricultural production. Such inputs include pesticides, fertilizers, machinery, and other supplies. The energy embodied in these inputs is defined as the energy expended to supply raw materials, for manufacturing and processing raw materials into final products, manufacturing spare parts, and for maintenance.

Increased dependence upon fossil fuel inputs has changed agriculture from a state where it was an energy producer to a state were it has become an energy-intensive sector.

Energy use in modern agriculture has increased several fold since 1960. As shown in figures 1.1, 1.2, and 1.3, this increase is reflected in the pattern of use of various energy inputs in agricultural production in Canada. Pesticides sales have increased almost nine fold, while, fertilizer consumption and number of tractors used have increased by almost four and two times, respectively, over the period 1960-1990.

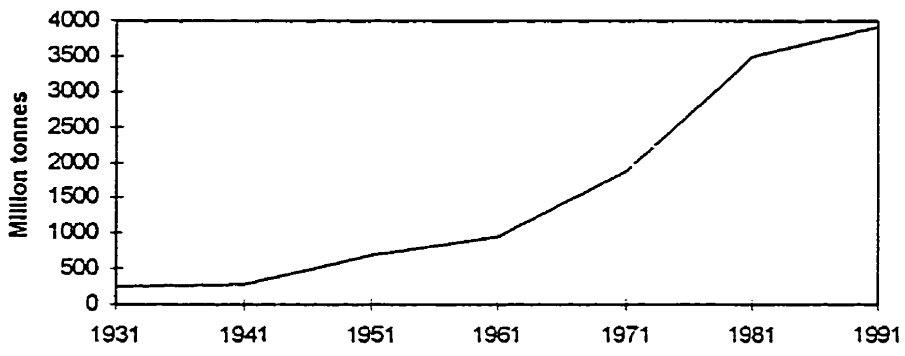
Continuing dependence on fossil fuel energy for modern agricultural has raised concerns over the ability of modern agriculture to sustain an increasing world population with the continuing depletion of fossil fuel reserves (IFPRI, 1996). The energy situation does not look promising with the expectation that recoverable crude petroleum reserves will be depleted over the next century (Cramer and Jensen, 1994). There is also concern over the environmental costs of modern agricultural applications. Such issues include the problem of ground and surface water degradation, impacts on wildlife, chemical residuals in food, and the continuing release of greenhouses gases, GHG.

In response to these concerns, attempts have been made to reduce the use of energy in modern agriculture. However, such attempts seem to be difficult to achieve because current agricultural systems are characterized by a great reliance on fossil fuel inputs. Such attempts may result in a reduction in food production necessary for supplying a growing population. There is nonetheless a need to give this high priority. Thus, different systems of production should be evaluated based on their potential to decrease environmental costs.

It has been recognized that an appropriate understanding of the environmental performance of agricultural systems requires accounting for energy inputs, used directly and indirectly. Energy analysis, as a measurement tool of energy flows on a farm, can be used to compare alternative production systems (Fluck and Baird, 1980). It has proved to be a useful tool to evaluate alternative production systems on the basis of their efficiency of energy use (Stanhill, 1984; Fluck, 1992).

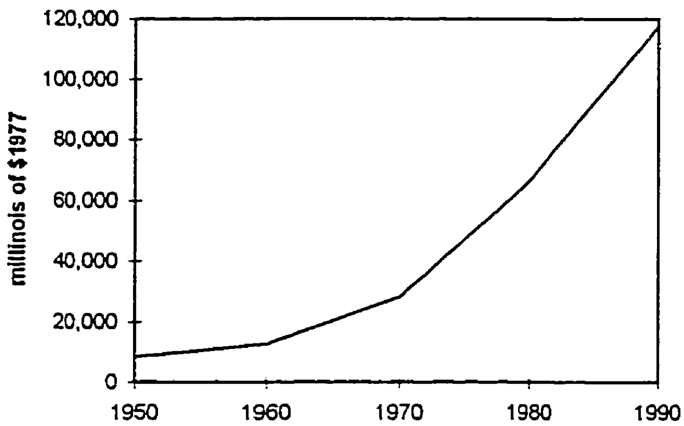
Several agricultural systems have been developed recently. One of these systems is plasticulture. It involves the use of plastic material as mulch, tunnels, and thermo -tubes. It has been used to produce vegetables in various parts of the world. The main advantage of this system is its capability to provide plants with favorable growing conditions.

**Figure 1.1: Quantities of Fertilzers Sold, 1931-1991, in Canada**



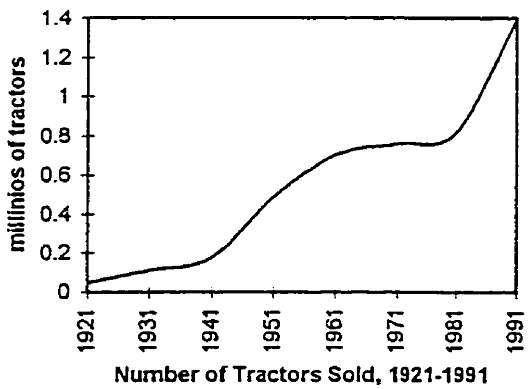

Source: Statistics Canada, Cat. 11-509, 1978.
Statistics Canada, Cat.11-528 E, 1996

**Figure 1.2: Sales of Pesticides for Agricultural Use, 1950-1990, in Canada**




Source: Statistics Canada, Cat. 11-509, 1978.
Statistics Canada, Cat.11-528 E, 1996

**Figure 1.3: Tractors Sold, 1921-1991, in Canada**




Source: Statistics Canada, Cat.11-509, 1986
FAO (Production year book).

In Quebec, plasticulture is applied mainly to the production of tomatoes, and pepper. Pepper is not a major crop, as it presents only 2.1% of total vegetable cultivated land. Its share of the total value of vegetable production in Quebec in 1994 was 2.5% (Bureau de la Statistisique du Quebec, 1995). The low pepper area can be attributed mainly to the fact that pepper's requirements for heat are difficult to meet under the climatic conditions of Quebec. This has been reflected in low yields, and thus unfavorable returns that discourages farmers from growing pepper. It has been suggested that adopting plasticulture would allow farmers to overcome this climatic obstacle and achieve higher yields.

It is the objective of this thesis to compare the energy efficiency of a plasticulture system, to a conventional (no-mulch) system. Energy budgets are constructed to account for the total energy requirements for both systems. The financial performance will be also be evaluated.

## 1.2 - ENERGY NEEDS AND SCARCITY:

### 1.2.1 - Population Growth:

World population has now reached almost 6 billion people, with an average annual rate of increase of 1.84 % (FAO, Production year book). Each person, on average, needs 14 MJ of daily food energy, which means that 84 PJ of food energy are required daily to sustain the global population (Cramer and Jensen, 1994).

It was suggested by Malthus (1778) that there was no way to meet global food needs where the human population increases geometrically, while food production increases arithmetically. This suggestion seems to be still valid. While world food production has increased by 21% over the period 1980-1991, world population has increased by 30% over the same period (FAO, Production year book). In addition, estimates show that there are over 500 million undernourished people in the world (Cramer and Jensen, 1994). Moreover, world population is expected to increase greatly in the next fifty years. Different rates of growth are projected for different regions of the world. These rates range from 51% in Asia, to 200% in Africa (Cramer and Jensen, 1994). Therefore, some institutions have advocated that enormous efforts and emphasis must be placed on increasing yields, if the food supply is to keep pace with the steady growth in world population.

### 1.2. 2- Industrial Agriculture:

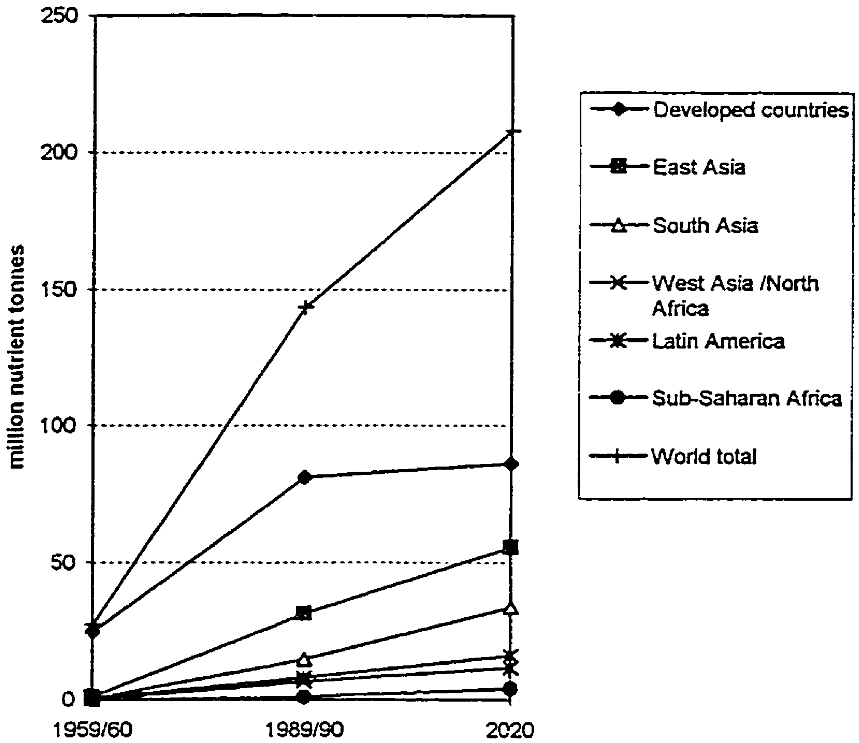
Over several thousand years humans have managed to overcome environmental limitations and fluctuations by focusing the energy flow toward species that are useful as food, and at the same time increasing the efficiency of sunlight conversion by using other forms of energy. Humans managed to do so by amplifying their physical power with non-human energy resources such as domesticated animals and water power. With the advance of technology, humans were able to use more concentrated forms of energy presented in the energy of fossil fuels, thus increasing the energy invested in agriculture. This in turn has been reflected in the dramatic increase in land productivity and total production since the beginning of the 1950s (Cramer and Jensen, 1994).

Fossil fuel energy invested in agriculture includes direct and indirect energy inputs. Direct energy is energy in the form of electricity, diesel, and gasoline. Indirect energy refers to energy used to manufacture and transport energy based inputs, such as fertilizers, pesticides, and machinery.

World energy consumption in agriculture has increased several fold, in particular with the advent of the green revolution in the 1970s. Fertilizer consumption is a marked example. It has increased almost 5 times during the period 1960-1990, and it is expected to increase by 45% by the year 2020 (IFPRI, 1996) (Figure1.4).

In Canada, energy use in agriculture accounted for only 1.6% of nation's energy in 1995, down from 1.8% in 1983, 206 Terajoule and 246 Terajoule in absolute values respectively (Statistics Canada, 1996). Refined petroleum products, including for example gasoline and diesel are the major type of fossil fuels used in agricultural production. However, their share of total direct energy used in agriculture has declined. from 81% in 1983 to 62% in 1993 (CAEEDAC, 1996). On the other hand, the shares of natural gas and electricity, have increased from 8% and 11% in 1983 to 16% and 21% in 1993, respectively (CAEEDAC, 1996). This change in the pattern of fuels use is due to the growing adoption of energy conservation practices and to changes in farming practices (CAEEDAC, 1996).

**Figure 1.4: Fertilzer Use, 1959/60, 1980/90, and 2020**




Source: IFPRI, (1996)

The continuous application of fuel energy inputs has resulted in the degradation of high quality soils. As a result, farmers have been forced to invest further energy inputs into agricultural production to obtain the same level of yields.

The need for more food, the advancement in agricultural technologies and the degradation of high quality land mitigated by an intensive use of energy inputs has encouraged humans to expand cultivated areas to include lower quality soils. This expansion involves massive use of fossil fuel inputs.

## 1.3 - GREENHOUSE EFFECT:

The twentieth century has witnessed the shift of industrial economies towards highly energy and capital intensive economies. Energy consumption has increased several-fold in the industrialized nations. This increase was based primarily on advanced mechanized technology and cheaper fuel prices. This shift has not been free of consequences. One of these consequences is the greenhouse effect. This phenomenon has resulted as a direct effect of the steadily increasing release of carbon dioxide, which results from burning fossil fuels to produce energy.

Carbon dioxide, nitrous oxide, ozone, and methane, constitute what are known as greenhouse gases. Increasing concentration of these gases is believed to be having a dramatic influence on global climate. The increase in the earth's surface temperature is expected to have profound impacts not only on socio-economic activities but also on the world environment. For the agricultural sector in Canada, the primary concern of this study, such an increase is anticipated to have various implications. These include:

*1*- An increase in length and warmth of the growing season;

*2*- 15% increase in yields, as a direct effect of increasing carbon dioxide as well as improving plant water use efficiency (Environment Canada, 1985).

*3*- Reduced water supply, in the form of less precipitation, and frequent and more severe drought.

As a net result, the expected increase in moisture stress may negate the positive effects of increased carbon dioxide concentration and longer growing seasons causing a net decrease in the productivity of the major crops growing in Canada (Environment Canada, 1985).

Carbon dioxide, from a physical point of view, is not the most powerful of the greenhouse gases. However, it is considered to be the most important. This is due to its greater abundance and its high rate of increase. It was reported by the International Energy Agency that carbon dioxide will be responsible for almost 61% of the greenhouse effect expected to occur in the upcoming 100 years (Smith, 1995). The atmospheric concentration of carbon dioxide has increased during the last two centuries by 36% to a level of 375 ppmv (Smith, 1995). This increase is unprecedented in human history.

Combustion of fossil fuel is the major source of human-made carbon dioxide. Other sources of carbon dioxide include biomass utilization in the production and consumption of wood, paper, and agricultural products, as well as the production of cement, ammonia, and natural gas. The total release of carbon dioxide resulting from global fossil fuel combustion and cement production for the period over 1860-1987 is estimated at 732 Gt. ±10. On an annual basis, the release of carbon dioxide has increased from 0.37 Gt to 118 Gt between 1860 and 1987 (Smith, 1995).

Most of the carbon dioxide generated from fossil fuel combustion has originated in industrialized countries, approximately, 95%. (Smith, 1995). It was documented by Smith (1995) that the per capita emission rate has been increasing annually at a rate of almost 6% in developing nations, while this rate is estimated in the range of 1-3% in developed countries. This can be attributed to the increasing rate of energy production in these countries to achieve economic growth.

Canada contributes 2% of current world emissions of carbon dioxide (excluding carbon dioxide emissions from biomass, which are difficult to estimate) (Jacques, 1992). Fossil fuel production and combustion are responsible for approximately 97% of these emissions, while cement, lime, ammonia, natural gas manufacturing, and utilization of lubricants and petroleum feedstocks account for the rest. The agricultural sector's share of total emissions of carbon dioxide in Canada has declined from 4.7 million tonnes of carbon equivalent to 3.5 million tonnes between 1983 and 1993 (CAEEDAC, 1996).

However, it is still necessary to investigate measures to reduce carbon dioxide produced by agriculture. Achieving Canada's pledge to the international community to stabilize its greenhouses gases at the 1990 level by the year 2000 is not easy, and requires all the economy's sectors to put all their efforts towards fulfilling this goal. This necessitates investigating every possible measure to reduce carbon dioxide. One way to reduce carbon dioxide emissions from agriculture is by reducing fossil fuel use, either in the form of direct inputs or indirect inputs. This reduction can be achieved by adopting various means of energy conservation. Energy conservation is based mainly either on direct reduction in energy use, or the efficient use of energy inputs. In either case, energy performance should be examined.

## 1.4 - - ENERGY ANALYSIS:

The basic theme of modern agriculture is the intensive use of more concentrated forms of energy. These forms of energy constitute various fossil fuel-based inputs, such as machinery, fertilizers, and pesticides. Using these inputs is aimed at improving the capability of plants to capture solar energy. Studying such energy flows lies within the realm of energy analysis. Energy analysis is defined as the "computation and the measurement of energy flows in a society, and in particular the quantification of the volume of energy resources embodied, directly and indirectly, in various commodities" (Alessio, 1981, P.62). The term "embodied" refers to the total quantity of energy required to produce goods or services, whether directly or indirectly (Bullard and Herendeen, 1975). Indirect energy is the energy used by suppliers of goods and services to an industry and by suppliers of these suppliers, etc. (Hannon, 1973). The sum of all this energy traced back to their primary source is termed Gross Energy Requirement, GER.

The justification of energy analysis is based upon the recognition that energy is required for producing goods and services and that these goods and services are essential for life. Hall et al. (1986) suggested that energy is the most important production factor as no economic activity could exist without energy, and vigorous economic growth can be only achieved with abundant energy resources.

An appreciation for the importance of energy analysis can be inferred from its increasing and varied applications. Energy analysis has been applied in various fields: studying the effects of price changes of various fuels on the price of goods and services; estimating the energy requirements of an economy given expected demand for various goods; estimating the depletion rates of non-renewable energy resources given anticipated levels of exploration and extracting technologies and the requirements for energy by the economy. Yet the major contribution of energy analysis resides in its capability of tracing energy flows with the objective of evaluating production systems on the basis of energy use efficiency.

With regard to agriculture, energy analysis has proved to be a useful tool in providing necessary and important information (Pimentel et al., 1973; Steinhart and Steinhart, 1974; Leach, 1976; Smil et al., 1983; and Fluck, 1992). Such information includes: identifying the energy inputs used at all steps of the production system. Also by conducting standard budgeting, in terms of energy units, it is possible to estimate the difference in energy costs for producing different products in different ways or identical products with different ways. Moreover, energy analysis can point out steps of production that could be a source of energy inefficiency, offering the potential for a possible reduction in total energy requirements.

## 1.5 - THE RESEARCH PROBLEM:

Based on the previous discussion, one can readily observe an emerging problem. The world faces a severe problem not only regarding its supply of energy but also in terms of how to deal with the negative impacts on the environment of producing and consuming energy. Therefore, prudent and efficient use of the limited energy is crucial.

In the field of agriculture, a number of new methods have been developed to obtain higher productivities in order to satisfy the increasing nutritional needs of the steadily growing world population. Plasticulture is one of these methods. The basic idea of this method is to provide plants with more favorable growing conditions, and thereby increase output.

Plasticulture has been criticized on the basis that : (1). It is more costly; and (2). It could lead to more environmental degradation as it involves using more energy inputs per hectare, which implies, more pollution in terms of released GHG.

As a result, it is the main objective of this study to shed light on the production of agricultural crops using mulches. Using red pepper production as the unit of analysis, this study will provide information concerning the feasibility of plasticulture regarding its requirements of energy and investment. To be more specific, this study attempts to answer the following questions with regard to plasticulture compared to conventional methods:

1) Is crop production using plasticulture more expensive in terms of cost per unit of output?

2) Does plasticulture involve more intensive use of energy inputs per unit of production ?

Needless to say, a method may incur higher monetary cost, but still be applicable if its profit exceeds that of the other methods. This will be examined in this study. In the same manner, the second question to be asked is whether a system is energetically more efficient. If a system is energetically more efficient, the system achieves two goals simultaneously: (l). Less GHG, as a result of less environmental degradation is expected; and (2). An effective way for using the limited available energy.

### 1.5.1 - Objectives:

The objectives of this study are to:

1). determine the total energy consumed in both systems, plasticulture and conventional;

2). determine the profitability of producing pepper using both systems; and

3). relate both costs, energy and monetary, with the production of each system to evaluate their efficiency.

### 1.5.2 - Methods:

1). perform an energy accounting for each system to estimate total energy consumed.

2). construct partial budgets to determine the monetary cost of both systems..

3). estimate the energy efficiency of each system.

4). estimate the profitability of each system.

5). compare the energy productivity and profitability of plasticulture versus the conventional method.

## 1.6 - THESIS ORGANIZATION AND SCOPE :

This study is restricted to the farm conditions in Quebec. The study depends on both primary and secondary data. Primary data on yields and production operations were collected from an experiment conducted at the Macdonald Campus of McGill University on the West Island of Montreal, Canada. Secondary data were gathered from relevant resources to determine operations and input costs in monetary and energy units.

This study is organized as follows: the second chapter of this thesis discusses major issues in energy analysis, and reviews the literature in this field.

Chapter 3 explains the methodology used to deal with the economic and energy aspects of growing pepper using different practices of production. A detailed outline of the production operations of pepper is also presented in this chapter.

Chapter 4 presents and discusses the results of the analyses.

Finally, chapter 5, summarizes the results and suggests a number of measures to encourage the adoption of plasticulture. The limitations of this study are also discussed as well as recommendations for future research.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 - - INTRODUCTION:

Energy analysis is an old concept that began to attract the attention of researchers and policy makers as well as ordinary people with the oil embargo of OPEC in 1973. Its general objective is to measure the efficiency with which energy resources are used in conveying products to their final use.

Alessio (1981) justified the adoption of energy analysis based on the following three assumptions:

1) Energy is considered to be the limiting factor. This assumption is based on the observation that: energy is a crucial factor in the production process, and energy resources are scarce.

2) Energy scarcity increases with the passage of time and the economic development of nations.

3) Energy measurements are more efficient, compared to economic analysis, to assist in the identification of actions and decisions that lead to energy scarcity, and anticipating and consequently dealing efficiently with scarcity consequences.

The discipline of energy analysis is characterized by an array of various ideologies and concepts which are reflected by divergent procedures and methodologies. Slesser (1977) pointed that most of these ideologies can be classified under two distinct schools of thought: the Eco-Energetic school and the IFIAS school, International Federation of Institutes for

Advanced Study. Differences between these schools stem mainly from the way they view the role of energy in natural systems, and consequently the scope for energy analysis in the support of decision-making.

The Eco-Energetic school argues that energy analysis is capable of reflecting the true environmental and social value of goods and services, thus capable of guiding decision-making independently of any supplemental information. The ultimate objective of this school is stated as analyzing linkages between fuel systems and natural ecosystems. Practitioners of this school apply energy analysis through holistic modeling systems that encompass all inputs including solar radiation and human labour. The methodology of the Eco-Energetic school is based upon the following assumptions:

1). most of the valuable work upon which the biosphere depends is done by atmospheric and ecological systems and these systems in turn depend on energy. i.e., energy exists in all processes, and

2). energy is the ultimate, unique, all-pervasive resource, thus all commodities can be valued in terms of their embodied energy.

On the contrary, the second school, IFIAS points out that energy analysis should complement economic analysis in order to encompass all aspects of any production process, physical as well as social and economic constraints. It is assumed by IFIAS that energy is but one of several other essential resources. The ultimate objective of energy analysis, according to the IFIAS school, is estimating the potential for energy savings. Energy analysis is constructed to forecast demand, predict effects of energy shortages, and estimate impacts of energy shortages (Fluck and Baird, 1980).

Though it was expected by Slesser (1977), and Fluck and Baird (1980) that differences between schools would disappear as the discipline of energy analysis matured, differences between schools still exist. In fact, not much evolution in the discipline of energy analysis can be recognized more than 20 years since the first meeting of IFIAS (1974), which was held basically to agree upon conventions, terms, and methodologies related to energy analysis.

The following sections, review the history of energy analysis, outline methods used to account for energy requirements, describe recommended methodology, and current controversial issues.

## 2.2 - HISTORY OF ENERGY ANALYSIS:

The rapid rise in oil price in 1973 prompted physicists and engineers to focus their attention and efforts on analyzing the role of energy in productive processes, developing empirical approaches that answer economic questions of energy use and conversion based on thermodynamic laws (Bruggink, 1985). These approaches are grouped under the title of energy analysis.

The major objective of energy analysis is mapping the direct and indirect energy used in producing goods and services in an economy. Though energy analysis began to attract public attention starting with the early seventies, one can trace back its roots over one hundred years (Cleveland, 1987; Martinez-Alier, 1987).

Podolinski's work (1880) on the energy return from cultivation by human and animal effort is considered to be a forerunner of energy analysis. Around a half century later, Lotka (1924) attempted to measure energy flow in ecosystems using energy units and applying thermodynamic concepts. Following Lotka, Transeau (1926) published an analysis of the energy cost of cultivating maize, the first analysis of its kind. Though accounting only for the flow of solar energy, Transeau's study had great influence on subsequent ecological energy studies (Stanhill, 1984). Soddy (1926) outlined in his famous book "Wealth, Virtual wealth and Debt" that energy should be accounted for by taking into account both direct and indirect energy. However, it was only 1967 when the first comprehensive and detailed energy analysis of the energetics of different agricultural systems was published. Odum (1967) conducted an energy analysis for six agricultural systems ranging from primitive agricultural, to corn production in industrialized systems, and microbial conversion of fossil fuel into a high value protein under industrial conditions. To understand the impacts of energy intensiveness on agriculture production, Odum plotted outputs of these systems against fossil fuel-based energy inputs, measuring both in the same units of energy intensities and on logarithmic scales. The result was a linear relationship with a slope of unity. This suggests that a 1% increase in the use of fossil fuel based-inputs increased the productivity of agriculture by 1% (Stanhill, 1984).

Pimentel et al.'s (1973) energy analysis of corn production in the U.S over the period 1945-1970 is considered to be a landmark study in the history of energy analysis applied in agriculture. In this study, energy production and consumption were analyzed on the basis of the energy ratio (energy harvested in grain over gross energy requirements for corn production). It was found that energy harvested in grain had increased over the years, however, this increase was associated with a greater than proportional increase in energy consumption causing the energy ratio to decrease by 24% over the 25 years under study.

The energetics of corn production in the U.S over the same period (1945-1970) has been subject to reexamination by other energy analysts ( Leach, 1975 and Smil et al., 1983). These analyses reached different results, though using the same data used by Pimentel et al. (1973). The difference can be attributed to advancements in the discipline of energy analysis in methodologies and conventions. The Pimentel et al. (1973) study led to a wave of energy analysis studies that examined agricultural production. One of the most influential of these studies was Leach's (1975) study on the energetics of the United Kingdom food production, processing and distribution sectors in his famous book, Energy and Food Production. Leach`s book included detailed energy balances of over 50 production systems in the UK and 85 worldwide food production systems. The energy embodied in urban service and manufactured inputs to agricultural production were taken into account.

In an attempt to unify conventions and procedures used in energy analysis, consecutive meetings of the IFIAS were held in 1974 and 1975. Slesser (1975) reported the summary of recommendations reached by the 1974 meeting. It is worth noting that these meetings did not make much progress. Disputes over some of the critical issues of energy analysis were not resolved. These disputes concerned the purpose of energy analysis, its procedures, its conventions, as well as other questions including whether human energetics should be considered, what should be the extent of an ideal boundary of systems analyzed, and the necessity for considering natural inputs such as solar radiation and soil fertility, as well several other questions. Some of these questions shall be addressed in detail in section 2.5.

## 2.3 - METHODS TO ESTIMATE ENERGY REQUIREMENTS:

The gross energy requirement for a good or service is the energy that has been embodied in it during the process of its production. Several methods have been employed to determine the energy embodied in goods and services. However, before approaching these methods, it is important to define some energy concepts (Fluck and Baird, 1980, P.183-185) :

### 2.3.1- Definition of Terms:

1). Cultural energy: Embodied energy for agricultural production, excluding solar radiation (Heichel, 1973).

2). Energy efficiency: Quotient of the energy embodied in an output to the energy embodied in all direct and indirect inputs (Pimentel et al., 1974).

3). Energy Intensity: Embodied energy per unit of output, i.e., MJ/$ or MJ/MJ in the case where energy is the output (IFIAS, 1974).

4). Energy productivity: Quotient of the quantity of a product produced to the energy embodied in its production. (Fluck and Baird, 1980). It is the inverse of energy intensity.

5). Enthalpy: Gross heat of combustion of a fuel (Fluck and Baird, 1980).

6). Primary energy: Fossil fuel energy extracted from the earth, expressed as total enthalpy (Bullard and Herendeen, 1975).

7). Direct energy: Enthalpy of fuels plus the electrical energy used directly in a process under study (Hannon, 1973, IFIAS, 1974).

8). Indirect energy: Energy used by suppliers of goods and services to an industry and by suppliers of these suppliers, etc. (Hannon, 1973).

9). Gross energy requirement (GER): Amount of energy sources embodied by the process of making a good or a service; includes feedback energy to obtain energy output. (IFIAS, 1974).

**2.3.2 - Statistical Analysis**

The average energy intensity of all goods and services included in the GNP is determined by using the quotient of the total primary energy consumption to the gross national product (GNP) (Fluck and Baird, 1980). The quotient was estimated to be 17.87 MJ/US$ for the United States in 1989 (Fluck, 1992). This value may under or overestimate the real value of the energy intensity for any particular good or service. Fluck (1992) has recommended that statistical analysis should be used as an estimate, only in cases where there is no other method available.

**2.3.3- Input-Output Analysis**

Bullard and Herendeen (1975) were the first to employ I/O analysis to determine energy requirements. They managed to estimate the energy requirement for each output in 357 sectors in the U.S economy, for the base year 1967. The authors showed procedures to update their requirements and to account for transportation and distribution energy at the point of purchase (Bullard et al., 1976). Input-output analysis suffers from several inadequacies (Bullard and Herendeen, 1975) such as data accuracy limitations due to incomplete coverage of a sector; limitation of accuracy due to the linearity assumptions; underestimation of coefficients induced by considering capital goods as a final demand rather than as an input; unstable coefficients; and demand being measured in producers' rather than consumers' prices. However, it is expected to yield better results compared to statistical analysis.

**2.3.4- Process Analysis**

Process analysis is a measurement of the energy consumed in a specific process or product in terms of the gross energy requirements for inputs. The processes required to make a final product are identified. Each process is examined to determine its inputs and their gross energy requirement hence the gross energy requirements. (Fluck and Baird, 1980). This method is considered to be the best because all the indirect energy inputs that have been used in producing the product, are traced.

Perhaps the most useful general approach to determining gross energy requirements may be to combine process analysis and input-output analysis, i.e., to utilize process analysis for the immediate past energy inputs and employ input output analysis to evaluate energy inputs from earlier production stages (Bullard et al., 1976).

Regardless of its superiority compared to the other methods of accounting, its application may involve several problems. Leach (1976) stated that results may be biased by incomplete analysis, or measuring energy coefficients based on a limited number of firms that may not be representative of the industry. Also, as pointed by Bullard et al. (1976) process analysis may involve double-counting.

**2.3.5 - Input-output/ Statistical Method**

Observing the shortcomings of applying either economic or energy accounting for the use of energy in agriculture, Cleveland (1995) developed a new method of accounting for the energy requirements for agricultural production. Cleveland's method is based on two premises:

1. different types of energy should be distinguished, hence accounted for separately; and
2. quantities of energy used should be accounted for in physical units.

Cleveland separated energy inputs into two types, direct and indirect. For the direct energy inputs, Cleveland used the following formula to calculate the expenditure on direct energy on farms:

$TE_f = \sum P_i X_i$

where $TE_f$ is the total cost of direct energy ($), $P_i$ is the nominal price of fuel type i (cents per MJ), and $X_i$ is the quantity of fuel type of i used directly (MJ). This equation is solved for X given known prices, shares, and monetary expenditure of different types of fuels used on farms (reported by the Economic Research Services of the USA Department of Agriculture).

For the indirect energy inputs, Cleveland used the following formula:

$I_t = \sum(C_{k,t} * \varepsilon_{k,t} + (E_t (\eta_t))$

where $I_t$ is the total quantity of indirect inputs (MJ), $C_{k,t}$ is the monetary value of the kth input ($), $\varepsilon_{k,t}$ is the energy intensity of the kth input (MJ/$), $E_t$ is the quantity of electricity farmers purchased (MJ), $\eta$ is the thermal efficiency of power plants in the USA (MJ of fuel input /MJ of electricity generated), and t refers to time (year).

Cleveland used energy intensities that are generated from input-output tables constructed by the Energy Research Group at the University of Illinois (Herendeen and Bullard, 1974; Hannon et al., 1985). These tables have been constructed to represent 393 sectors of the U.S. economy. Table 2.1 reports data for 5 energy sectors and a number of the 393 other sectors of the U.S. economy (Adopted from Spreng, 1988).

**Table 2.1: Energy Intensities of Selected Sectors of the US Economy (1977)**

| Energy intensity | | | | | | |
|---|---|---|---|---|---|---|
| Commodity | Coal | Crude Oil | Refined Oil Prod. | Electric Utilities | Gas Utilities | Primary |
| Energy sectors (MJ/MJ of commodity output) | | | | | | |
| Coal mining | 1.014 | 0.021 | 0.014 | 0.004 | 0.007 | 1.04 |
| Crude oil, gas | 0.005 | 1.065 | 0.007 | 0.002 | 0.009 | 1.070 |
| Refined oil Prod. | 0.017 | 1.113 | 1.086 | 0.009 | 0.055 | 1.196 |
| Electric utilities | 1.592 | 1.206 | 0.692 | 1.118 | 0.577 | 3.662 |
| Gas utilities | 0.006 | 0.981 | 0.030 | 0.003 | 1.057 | 1.122 |
| Non-energy sectors (MJ/$ value of commodity output | | | | | | |
| Vegetable | 5.04 | 24.40 | 16.05 | 2.92 | 8.18 | 31.44 |
| Tobacco | 3.34 | 28.22 | 20.77 | 1.63 | 7.69 | 34.51 |
| Feed grains | 7.39 | 39.53 | 23.80 | 4.22 | 16.49 | 52.75 |
| Poultry, eggs | 7.37 | 34.03 | 24.01 | 3.85 | 13.84 | 49.87 |
| Dairy | 7.78 | 34.33 | 21.87 | 4.43 | 13.05 | 47.64 |

Adopted from Spreng (1988).

In this table, each commodity has five energy intensities. Each indicates the quantity of each energy sector (coal; crude oil; refined oil products; electric utility; and utility gas) used in producing a dollar value of this commodity either directly or indirectly. Energy intensities are measured in MJ/dollar. The sixth column in this table represents the total primary energy required to produce one dollar value of each commodity. In other words, this column accounts for only the primary energy that enters an energy sector and is then passed on to produce one dollar value of a commodity. Using figures of the primary column prevents the double counting that would occur if the energy intensities of the five columns were simply added. To understand this point, consider the case of accounting for the energy intensity of vegetable production: simple calculation of the energy intensity of vegetables would involve the summation of the energy intensity of different energy sectors that provide necessary power to produce vegetables. In this case, the energy intensity of vegetables would be 56.59 MJ/$. However, it is known that some of the crude oil accounted for is used as an input to generate electricity, and some other amount is refined to produce petro-chemicals. The same can be also applied on coal, as most of it is used to produce electricity. Thus, adding up all quantities of fossil fuel expended to make vegetables available would be a clear example of double counting. Hence, any attempt to solve this problem should consider primary energy used as an input in the other energy sectors. Figures in the sixth column are calculated on this basis. In the vegetable case, 31.44 MJ/$ was found to be the actual energy intensity of vegetable production.

Using table 2.1 is straightforward and practical. However it is not free of shortcomings. The numbers used in this table are for 1977. So, using these numbers for determining energy values for years other than 1977 would assume that sector requirements have remained constant, i.e., technology has not changed over time. In addition, as the numbers are measured in MJ/$, relying on them to calculate more recent energy requirements would ignore inflation. Cleveland suggested that energy intensities can be extrapolated by applying the annual change in the ratio of U.S total energy use to the Gross National product.

On the other side, Cleveland's method has the advantage that it incorporates quantities used of different types of energy in physical units. Therefore, the technical and physical aspects of production processes or commodities can be assessed.

## 2.4 - METHODOLOGY:

A general methodology for performing an energy analysis has been outlined by Fluck (1992) :

1- Draw a boundary around the process, operation, system, enterprise, etc. to be analyzed. Various boundaries may be chosen for agricultural production systems, such boundaries may include the firm, the 'farm gate', the enterprise, field and building.

2- Identify and quantify all inputs crossing the boundary, with respect to a time interval and units of output. All energy inputs should be included, both direct energy inputs as well as all non-energy inputs in which indirect energy is embodied.

3- Assign gross energy requirements to all inputs.

4- Identify and quantify all outputs. Most agricultural production practices result in more than one product, either in the form of main products or by-products.

5- Relate gross energy requirements to the outputs. Many parameters have been used. Energy ratio (energy content of output to gross energy requirements) has been used for quite a long time. However, Fluck and Baird (1980) proposed a new measure, energy productivity, the ratio of output, measured in physical quantities, to gross energy requirements for production. This parameter is suitable for agricultural outputs that do not involve energy production.

6- Apply the results of energy analysis.

## 2.5 - PROBLEMS AND ISSUES:

The application of energy analysis is not as straightforward as the above methodology might suggest. Moreover, each case is unique, and there are no uniformly accepted methods for conducting the analysis. In each case, the analyst's assumptions play a significant role in forming the boundaries and hence the results of energy analysis will differ from one analysis to the another. Therefore, caution is required in interpreting the results. Also various conventions for different concepts may be used so that different results will be obtained. A number of problems have been identified, and these are discussed in detail below.

### 2.5.1 - Energy theory of value

Valuation is a weighting method for determining the relative importance of each individual commodity in relation to the importance of all other commodities. Hence, a value is the base of comparison between goods, services, or processes to determine which is more important. An entity, defined as a material, good or an energy flow, has value if it is recognized to be useful by its owner and if it could be exchanged for another good. For an entity, being useful or exchangeable indicates that this entity is capable of producing utility. Value can be explained according to different perspectives :

For economists, the word "value" has two meanings :

> The word VALUE, it is to be observed, has two different meanings, and sometimes expresses the utility of some particular object, and sometimes the power of purchasing other goods which the possession of that object conveys. The one may be called value in use; the other value in exchange. (Smith, 1776, p.131)

This difference in the way value is viewed was explained in different ways by the two predominant economic schools: Classical, and Neoclassical schools. The Classical school of economics emphasizes the exchange meaning of value. Classical economists consider the quantity of labour that is required to produce a certain good to be the determining factor in exchanging it with another good. While for the Neoclassical school, value is determined according to the utility the good provides to its possessor.

Value can be also viewed from another perspective other than the economic perspective. The physicistic paradigm suggests that values should reflect only the energy embodied in object, other factors necessary to make this commodity available, and that the value placed on it by the buyer is not of any relevance (Odum, 1977).

The next sections describe in more detail the basic concepts of the economic schools and the physicistic paradigm. This description draws upon the seminal work of Hall et al. (1986)

**2.5.1.1 - Classical Economics School**

The fundamental basis of the Classical school was first stated by Adam Smith in his "Wealth of Nations": "The value of any commodity... is equal to the quantity of labour which it enables him to purchase or command. Labour, therefore, is the real measure of exchangeable value of all commodities." (Hall et al., 1986, p.71). That is, the exchange value is determined by the embodied labour, labour hours that were required to make the good available. Adam Smith noted also that the exchange rate does not only depend on the quantity of labour work but also in the quality of this work, i.e., the value of labour is not the same.

> ...the amount of another labour that an object could command also depended on the quality of the work involved. If the one species of labour should be more severe than the other, some allowance will naturally be made of one hour's labour may frequently exchange for that of two hour's labour in the other. (Smith, 1776, p. 150)

Thus, a commodity that requires work that involves risk and exertion is higher in value compared with another commodity that does not involve the same difficulties, regardless of the amounts of labour hours that were required to produce both goods.

Following the same path as of Smith's labour theory of value, David Ricardo stated that:

> It is the comparative quantity of commodities which labour will produce that determines their present or past relative value. (Ricardo, 1817, p. 9.)

Ricardo went on to explain economic rent in terms of the labour theory of value. In his explanation, Ricardo pointed out that the commodity's price is determined by the amounts of labour used by the least efficient producer of that good :

> The exchangeable value of all commodities ..is always regulated...by those who continue to produce them under the most unfavourable circumstances. (Ricardo, 1817. p. 37)

According to Ricardo's explanation, farmers who produce crops with the greatest amount of labour are those who set crop prices. In the same manner, owners of fertile farm lands can charge rent because there is always demand for renting this land, as farmers with less fertile land have the willingness to pay rent for more fertile land to be able to produce more yields with less amounts of labour input. Rents charged for different lands depend on their fertility relative to the least fertile land under cultivation.

Ricardo went one further step than Smith, as he recognized that goods values rely also on indirect labour costs, labour hours required to produce capital used by the labourer. Ricardo expanded Smith's example of the hunter's catch value, based on the time spent in catching it, by emphasizing the concept of the indirect labour costs saying:

> The value of these animals would be regulated, not solely by the time necessary for their destructor, but also by the time and labour necessary for providing the hunter's capital. (Ricardo, 1817, p. 13.)

Karl Marx, following Adam Smith and David Ricardo recognized labour as the source of all value:

> Commodities...in which equal quantities of labour are embodied, or which have been produced in the same time, have the same value. (Marx, 1867, p. 34)

While Ricardo's greatest contribution was the explanation of the economic rent in terms of the labour theory of value, Marx's most significant contribution was his explanation of the origin of profit based on the labour embodied in capital. Marx stated that labour value should be set using the same method of setting values for all other commodities, i.e., value of labour determined according to the amount of labour needed to produce labour. This amount of labour refers to the work time a labourer has to spend to earn wages needed to purchase necessary goods and needs for him and his family. Marx defined the minimal wage, subsistence wages in his terms, as the wage that just enables labour to purchase commodities that are indispensable to provide labour with the energy required to sustain physical effort. These wages, according to Marx, determine the lower bound of wages. Marx also stated that labour always has to work extra hours to get the subsistence wage. This situation occurred due to the superior bargaining position of the capitalists as there is always excess supply of labour.

**2.5.1.2 - Neoclassical Economics**

Neoclassical economists have never accepted the valuation of goods and services on the basis of the quantity of labour that is required to make these goods and services available. For them it is subjective human wants which are the most important factor. In other words, they believe that the value of a good resides in its desirability to people, and its ability to be exchanged in markets through which this value is discovered. Therefore, goods should be exchanged in the market in order to have their values set. In these markets, values are determined according to the supply of goods, which in turn depends on people's willingness to work, and to the demand on these goods which indicates people's willingness to purchase these goods in order to get a certain level of utility. However, to establish their theory of value, early Neoclassical economists had to overcome a theoretical paradox proposed by Adam Smith :

> Things which have the greatest value in use have frequently little or no value in exchange, and on the other contrary, those which have the greatest value in exchange frequently have little or no

value in use. (Smith, 1776, p. 131).

Smith gave an actual example emphasizing his idea through recognizing the fact that a diamond is more valuable than water despite the fact that water is more important :

> Nothing is more useful than water; but it will purchase scarce anything; scarce anything can be had in exchange for it. A diamond, on the contrary, has scarce any value in use, but very great quantity of other goods may frequently be had in exchange for it.
> (Smith, 1776, p. 132)

The water-diamond paradox was not solved until the 1870's when Jevons; and Walras independently formulated the concept of marginal utility, which is the basis of the Neoclassical theory of value. According to the utility theory of value, consumers' willingness to pay for obtaining goods or services can be explained through recognizing the following two concepts : utility, the benefits obtained by consuming a good or a service, and marginal utility, the utility derived from the last unit consumed. Whereas humans conceive the value of any good or service based on the benefit obtained from it, it is only the amount of the utility that obtained from the last unit consumed of a good or a service which determines the value of this good or service in exchange. Consumers' willingness to pay declines for each purchased unit as utility obtained diminishes with each additional unit consumed. Using the concept of marginal utility, Neoclassical economists managed to solve the diamond-water paradox. Though the utility obtained from the first unit consumed of water is great, as water is plentiful, additional units of water add little if any utility. On the contrary, the additional unit of diamonds while it has less usefulness compared to that of water, has great value as people do not have enough of it.

Neoclassical economists believe that the value and the price of all traded goods and services are determined when the amount produced of these goods and services equals the amount of productive services offered. In other words, the amount of money consumers are willing to pay for an additional unit of a good or a service is equal to the amount of money consumers are willing to work for it in extra hours. For Neoclassical economists, the individual is the unit of analysis, as it assumed that each individual has unique tastes and preferences and that the individual is making rational decisions concerning the amount of labour and capital he is willing to offer in the market to exchange them with purchased goods and services. The cornerstone of the Marginal Utility valuing theory is the market or more specifically, the efficiency of market operations. If the market is operating efficiently, individual supply and demand can be integrated setting the value of goods and services. Although achieving such ideal values seems to be impossible due to market failure (externalities, subsidies, and other market failure factors), Neoclassical economists claim that by identifying these disruptions, evaluating their magnitude, and suggesting and implementing correcting polices, ideal values can be reached.

**2.5.1.3 - Energy Theory of Value**

Since the middle of the 19th century when the laws of thermodynamics were formalized, concepts and principles derived from these laws have been employed in many sciences such as biological, physical, and social sciences. However, economics has made little use of these laws in economic theory, despite the critical role of fuel and natural resources in the production process (Hall et al., 1986). Daly (1977) and Georgescu-Roegen (1971) are exceptions. They recognized the need to incorporate thermodynamic principles into economic theory.

Georgescu-Roegen in his revolutionary book "The Entropy Law and the Economic Process" (1971) described the flows of conserved energy and the irreversibility of entropy. In other words, Georgescu-Roegen analyzed the economic process thermodynamically. However much of the work done to examine and interpret the role of energy in the economic system has been conducted by physicists and ecologists, notably Howard Odum and Robert Costanza. Those two scholars along with several other biologists, ecologists and physicists with a biophysical perspective of economics have developed the energy theory of value based on the idea initiated eighty years ago by Frederick Soddy in 1926 (Hall et al., 1986) :

> If we have available energy, we may maintain life and produce every material requisite necessary. That is why the flow of energy should be the primary concern of economics. ( Hall et al., 1986, p.74)

These words of Soddy served as a basis for a new paradigm that attempts to explain the economic system in terms of energy flows, making energy and other resources' availability and quality the main focus of analysis (Hall et al., 1986).

The main assumption of the energy theory of value is that environmental factors, including natural resource quality and availability, influence individual and societal tastes, preferences and economic decisions. Therefore, according to Hall et al (1986), energy can be conceived as the organizing factor that determines all values either economic, social or political. Based on Lotka's (1924) hypothesis that natural selection is influenced by efficiencies of energy use and differential rates relative to competitors, Odum's energy theory of value (1977) proposes "surviving patterns" as the ultimate values that determine moral, ethical and all psychological phenomena. He justified his proposition on the basis that different patterns would vanish. Odum defined "surviving patterns" as the required patterns for any an organism, system, or culture to convert energy into beneficial power in an efficient way and proper rate in order to overcome rivals. Odum also proposed that human behaviour is greatly influenced by energy availability, and the rate and the efficiency of energy transformations. Based on his two propositions, Odum supposed that changes in energy availability, and rate and efficiency of energy transformation are the major factors in natural and cultural selection and economic development (Hall et al., 1986).

Costanza (1980) empirically examined Odum's energy theory of value by plotting GNP against the energy embodied in goods and services. Costanza showed that there is a significant correlation between the monetary value of goods and the embodied energy of goods and services. Thus, Costanza argued, embodied energy is a capable indicator of the monetary value of goods and services and consequently the relative embodied energy of goods and services can be used to determine their relative prices. However, Costanza pointed out that such a conclusion could not be verified unless a comprehensive analysis is conducted.

The energy theory of value has been used to explain the origin of economic profits on the basis that these profits are the unpaid effort of nature in dollar terms (Hall et al., 1986). Billions of years of solar energy and radioactive decay energy of the Earth's interior have created natural resources which are found in an unconcentrated form. Humans have to invest industrial energy (fossil fuel, electricity, etc.) to upgrade these natural resources to a state that allows them to be used in the economic process to eventually produce commodities. Hence, humans are making use of nature's work without compensating it for its services.

One of the advantages of energy analysis resides in its capability to describe and value transactions and services that are not coupled to the monetary valuation of the economic system. As a result, it is possible to describe non-marketed and unpaid goods, such as environmental services and pollution, and to evaluate nonmarket decisions (Hertzmark, 1981; Kaberger, 1992). Energy analysis, in addition to material balance analysis, can provide useful information on a number of environmental issues, such as the greenhouse effect and chemical pollutants. It is worth noting that there is little economic data on such issues. Also, energy analysis can be useful to monitor the relative efficiencies of using unpriced intermediate inputs in alternative operations.

Within the energy theory of value, environmental and social impacts as well as economic factors, including labour, are accounted for as "embodied energy". According to Gilliland (1975), energy analysis is capable of producing a single measure that can reflect all the environmental, social, and economic costs that are incurred as a result of economic decisions. Energy analysis is comprehensive enough to be employed alone. Moreover, Gilliland argued that energy analysis yields more accurate and reliable results than that of economic analysis to the extent that these results remain constant over time. Although, conversion efficiency may change because of technological advances, these results are not influenced by changing preferences or market conditions. It was not surprising that when taking into consideration all of these features of energy analysis, many energy analysts have suggested using energy content as a standard of value rather than relying on the market :

> In the long -run, we must adopt energy as a standard of value and perhaps even afford it legal right. (Hannon, 1975, p. 101)

Also the idea was pointed out by Hatfield, a U.S. Senator, :

> Pragmatically, a way to begin would be to budget according to flows of energy rather than money. (Hatfield, 1974, p. 6053)

As pointed out by Alessio (1981), the energy theory of value, like other single-factor theories suffers from several weaknesses. A theory of value is a method of determining the relative value of each good and service involved in the production process or consumed by the society in relation to the values of all other goods and services (Alessio, 1981). Single theories of value have been built around one resource, such as land, labour, or energy. Relative values of goods and services are based on the relative value of the single resource. For example, the relative value of any commodity is based on the relative value of, exclusively, energy inputs used in the production process, while resources, such as labour, water, capital, and other natural resources are ignored. Moreover, value of goods and services to consumers is assumed away. Relative values are determined only on supply side information.

According to Hertzmark (1981) and Alessio (1981), there are two principle reasons to refute an energy theory of value. First, the energy theory of value fails to determine the relative values of commodities (as demand information is ignored as well as complete supply information, due to the fact that factors other than energy are ignored). It is worth noting that supply and demand information are a must to make proper production and consumption decisions. Second, failing to determine the relative value of resource inputs used in the production process other than energy would result in a misallocation of these resources followed by a reduction in overall economic efficiency.

Moreover, even assuming away the deficiency of not recognizing other resources and human preferences, this system is still incapable of dealing with several production process-related issues. For instance, how can an energy-based system deal with the issue of the time lag involved in production processes? The production process takes some time between manufacturing inputs and getting the final goods into the market. Undoubtedly, the investor should be rewarded for this waiting time. This reward is represented as an interest rate included in the relative value of the final good. Hence, the final value of goods and services can be conceived as the total value of production factors in addition to the interest rate paid to the producer to compensate for the waiting time. The critical question now is can an energy-based valuation system express the reward that capital should be accrued due to the time lag between the process of inputs manufacturing and the appearance of the final products in energy terms?

Berry et al.(1978), Hertzmark (1981), and Huettner (1976) made it clear that an energy theory of value can not deal with some aspects of daily life activity such as: fixed capital, subjective utility, and a variety of imposed constraints on economic choice.

**Summary of energy theory of value** :

A theory of value is just an accounting method to determine the relative price of any good. Theories that attempt to explain the origin of values can be classified under two categories. The first explains the origin of value as an interaction between both supply and demand sides of the system. An example is the Neoclassical theory. The second, is the single-factor theory of value, in which values are determined according to only the supply side. In other words, relative prices are determined based on the relative value of a single resource in the production process (Alessio, 1981). Individual's preferences and other resource values are ignored. Inputs other than the single factor (either labour or energy) are expressed in terms of quantities of that single factor which is used to produce them. Regardless of the accuracy of expressing different inputs and factors in terms of these single factors, critics argue that such a method would fail to account properly for relative prices. As a result, failing to signal proper relative prices will prevent making proper production and consumption decisions (Alessio, 1981). To sum up, single-factor theories of value are not accepted because they ignore not only the demand side of the economic system, but also some aspects of the supply side.

### 2.5.2 - Human Energetics :

Perhaps the major unresolved issue in applying energy analysis is whether and how to account for the energy value of human labour. Energy analysts separate into three camps.

Some energy analysts, like Norman (1978) and Wells (1984), would just account for the metabolic energy, (food heat energy), as a basis for evaluating human labour. Other analysts, such as Hall et al. (1986) and Smil et al. (1983) would ignore accounting for human labour in energy terms. These analysts justify their view by appealing to the fact that there is no general agreement on the accounting method. Also they claim that the human contribution, in terms of applied power, to agricultural production is not significant, thus evaluating human labour is not worth doing. In the middle stand energy analysts, including Fluck and Baird (1980), and Giampietro and Pimentel (1991), who account for the energetic value of human labour in terms of gross energy requirement (GER), i.e., the energy embodied in labour.

The claims of these camps will be discussed in detail in the next two sections.

**Justification of accounting for human energetics:**

There are some cases where accounting for human energetics is important. Such cases include: studying the consequences and the energy cost of the substitution of energy-based inputs for human labour (Stanhill, 1984). These kinds of studies would include analysis of agricultural development, either at the level of individual cropping systems, or at the national and international levels. These studies include estimating trends in the substitution ratio of fossil fuel for human labour and labour productivity. Results of these studies should reveal the relationships among labour use, fossil fuel-based inputs, and food production indicating the feasibility of substitution of fossil fuel energy for labour. One other case where the energy content for human labour should be accounted for is when analyzing the performance of primitive agricultural systems. Human labour in these systems can be an essential energy input, in some cases the sole energy input. In most cases, monetary evaluation methods are not available with these systems, hence, energy accounting seems to be an attractive method of evaluation.

**Difficulties of accounting for human labour energetics**

The debate among energy analysts on the issue of evaluating human energetics is due mainly to two reasons. The first is related to the wide range of functions that human labour can play in food production. Human labour can provide two forms of flows. One is the flow of applied power, in the form of muscle power, which is physically measurable. The other is the flow of information, decision making, planning, and management roles. Theory provides little guidance to the measurement of this flow.

A second source of the debate is a philosophical difference in interpreting the role of humans in food production systems. The human role can be viewed to be just like any other input, the ecological point of view. Or, it can be regarded to be superior relative to other inputs, an anthropocentric point of view (Stanhill, 1984).

The ecological group of energy analysts, led by Odum, considers the role allocated to human labour to be equivalent to any other input such as tractors, or horses. Therefore, human energetics is accounted for in terms of its gross energy requirement, the energy embodied in human labour in the form of consumed goods and services. However, the extent to which goods and services should be accounted for is another source of debate among followers of this school. While Williams et al. (1975) account only for the direct energy consumed by workers, Twidell and Kumar (1979); Lewis and Tatchell (1979); Odum (1983); Costanza (1980) account for the total energy embodied in products and services consumed by agricultural labour. In a latter modification, Fluck and Baird (1980) account only for that portion of the energy embodied in the GNP which is required as a feedback to support labour enabling them to undertake their usual work.

The anthropocentric view of agriculture is led by Leach (1975), and considers only the energy content of food as the value of human energetics. However, followers of this method separate into three groups based on three different types of food energy.

To understand differences between these energies, it is worth imagining an agricultural labourer that works for a certain number of hours a day and consumes a particular amount of food to sustain his physical effort. One group of analysts would account for the metabolized energy of the food consumed by the labourer over a 24 hour day (Deckkers et al., 1974 and Hudson, 1975). The other group led by Deleage et al. (1979b) recommends that only the energy metabolized during work should alone be considered as the energy value of human labour (Stanhill, 1984). The last group would consider only the net metabolic energy, energy metabolized necessary to support the physical work. Net metabolic energy can be accounted for by subtracting basal metabolic energy expenditure from the gross energy expenditure (Norman, 1978).

Attempting to resolve this philosophical debate of whether to adopt the ecological or the anthropocentric points of view, Fluck (1992) suggested using the metabolized energy to estimate the energy value of human labour engaged in subsistence agricultural systems, where human energy is the major source of energy, and consumption of fossil fuel energy is very low. Meanwhile, for industrialized agricultural systems, he suggested using an estimate of the energy sequestered in products and services. Using this approach with industrialized agricultural systems is justified since these agricultural systems consume significant amounts of fossil fuel. Hence, a method that accounts for energy either embodied in labour or substitutes for labour is preferable (Fluck, 1992).

Two approaches for accounting for labour energetics are discussed in detail in the following section. One of them, Hall et al. (1986), represents, with justification, the group of energy analysts who reluctantly include human labour input into the analysis of agricultural systems. While they recognize that energy expenditure is associated with labour, they would argue that a proper accounting is difficult, and may involve double counting. The other, Fluck

(1992), accounts for human labour in the same way as any other input.

**2.5.2.1 - Hall et al.'s Approach:**

Hall et al. (1986) considered human labour as an input that is produced by the household sector, and requires the investment of energy along with other resources to sustain it. They identified three types of energy associated with human labour:

(1) The heat value of food consumed by the workers; (2) The gross energy requirements for producing that food; and (3) The embodied energy of workers' incomes.

Following is a brief description of the three types of energy costs associated with human work :

(1) . Biological Energy Equivalent of labour :

The work done by labour depends on an amount of food, which is burned to produce energy for work. Hall et al. (1986) suggest using a respiratory instrument to indicate the amount of energy released by burning the food that is required by workers to do their jobs. This amount of energy was estimated to be 0.3 MJ/h for desk type work, and twice this quantity for manual work.

(2). Energy Embodied in Food

The gross energy requirement for producing the food metabolized by labour could be accounted for. Obviously, this energy requirement is different from one country to another depending on agricultural system. In developed countries, where agricultural systems are characterized by heavy reliance on fossil fuel-energy based inputs, gross energy requirements for food are high. For example, 1 joule of edible energy has a gross energy requirement of 9.5 joule (Hall et al., 1986). Taking into account that an American person consumes on average a diet of 14.2 MJ/day or 5.7 MJ/h, Hall et al. (1986) estimated the gross energy requirements of human labour at 54.15 MJ/h.

(3). Embodied energy of Income

The energy requirements for producing all goods and services that are purchased by the worker should be accounted for, since these goods and services are necessary to sustain labour in its work. Hall et al. (1986) noted that accounting for this type of cost involves several problems. First, if the energy cost of all goods and services is accounted for, then the method generates an overestimate, as not all goods and services purchased by labour are essential to production. In other words, a portion of these goods and services could be taken away without affecting the worker's level of performance. This extra income above the necessary income may reflect the competition between companies to secure skilled labour. Second, Hall et al. (1986) also noted that people tend to consume equal amounts of some goods and services regardless of whether they are employed or not. Therefore, total energy consumed by workers should not be considered as the actual energy cost of labour. It was estimated (Landsberg and Dukert, 1981) that employed people use 51% more services and goods than unemployed people. Based on this estimate, Hall et al. (1986) suggested that accounting for labour energy cost should be corrected according to the above estimate and according to the employment category. Also the authors noted that the energy consumed in U.S society has not changed markedly during the period 1972-1982, which means that energy requirements of workers were diminishing despite that fact that living standard was increasing. Moreover, double counting seems to be inevitable when accounting for the energy embodied in consumed food and the embodied energy of income.

**2.5.2.2 - Fluck and Baird's Approach : Net energy analysis of the energy value of labour**

Fluck and Baird (1980) proposed "net energy analysis" as a new method of accounting for the energy sequestered in human labour. This method is based on net energy analysis used to estimate the efficiency of energy-producing industries (Odum and Odum, 1976, Bullard, 1976). For these industries, their efficiencies were evaluated by taking into account that portion of the energy produced that is required as a feedback in order to sustain the extraction and conservation activities of these industries. Fluck and Baird (1980) suggested that only a portion of the energy consumed by human labour should be accounted for in determining the energy value of labour. This portion is that amount of energy consumed in the form of goods and services which is required as a feedback to enable labour to maintain its activities. The remainder of the sequestered energy is to support leisure, family, and luxury activities, etc.

Fluck and Baird (1980) justified his method on the premise that humans pursue productive employment in order to provide a livelihood, not because employment activity is desirable by itself. Therefore, a similarity could be established between energy-producing activities and humans in the sense that both of them are productive activities with a main output that is used to pursue other activities, various production activities in case of energy-producing systems, or leisure and family activities in case of human labour. Meanwhile some of this output is used as feedback to support these productive activities.

The methodology of net energy analysis involves the disaggregation of the GNP into its components (personal consumption, governmental purchases of goods and services, gross private domestic investments and net exports) and identifying the energy portion of each component that is required as feedback, to sustain labour. Dividing this feedback energy by the number of persons in the labour force and by an assumed number of days worked, the outcome would be the energy sequestered in the average employee per day.

Clearly, the energy value of human labour assigned using this method represents the portion of energy resources, in the form of goods and services, consumed by workers, necessary to pursue their activities. Hence, using this value is suitable most with energy analyses aimed at evaluating primary energy consumption. Difficulties stem mainly from the number of variables required to assign an energy value. These include: GNP; total energy consumption; energy consumed by different categories with the GNP; the labour force size; ratio of energy expenditure in rural farm household to non farm rural household; and the ratio of the earnings of employees in the agricultural sector to those employees in sectors other than agriculture. Fluck and Baird (1980) estimated the energy value of human labour to be 594MJ/d.

Theoretically there is no difference between Fluck's "Net Energy Analysis" and Hall et al.'s (1986) "Embodied Energy of Income" approaches of estimating human energetics. However in practice, they differ in the portion of an individual's consumption of goods and services that is required to support labour activities. Fluck and Baird (1980) assumed the feedback energy to be 22% of the total production of energy in the economy. Hall et al. (1986) based their estimate on the assumption that an employed person uses 51% more fuel and buys 51% more goods and services compared to unemployed person. Thus almost 30% of all individual purchases is the societal energy cost of having a new employed person.

### 2.5.3 - Energy Quality:

Energy quality refers to variations in the amount of useful work that can be generated by a unit of heat energy (Kaufmann, 1992). These variations stem from different combinations of physical, engineering, and economic characteristics of different types of energy. These characteristics include : weight, heat content, cleanliness, cost of conversion, ability to do work, safety, energy density, amenability to storage, entropy, ease of usage, volatility, economic value, etc. Therefore, measuring energy by its heat content, which is the standard way of measuring energy, cannot determine the quality of different types of energy. More specifically, measuring energy in terms of its heat content results in missing important information that is related to the ability of different types of energy to do work. Masking this information renders the energy analysis an incomplete tool to analyze the performance of using individual energy sources. Several methods have been proposed to assess energy quality. These methods can be grouped under two classifications : physical approaches, and economic approaches. Physical approaches refer to methods that use thermodynamic laws to assess energy quality. These approaches notably include emergy analysis and exergy analysis. While exergy analysis is based mainly on the conversion law, which explains changes in the characteristics of energy when converting energy from one type to another, emergy analysis is based on the first law of thermodynamics.

Physical approaches aimed at assessing energy quality are subdivided into two techniques : production side techniques and end-use techniques. On the other hand, economic approaches include methods that use economic indicators, such as relative prices and; marginal product to assess quality of different types of energy at the point of end use.

**2.5.3.1 - Production Side Techniques-Emergy Analysis**

A production side technique, so-called emergy analysis, has been developed by Odum and his colleagues (Odum and Odum, 1983; Odum et al., 1987; Odum, 1988). Emergy analysis determines the quality of a particular type of energy by measuring the transformity, the amount of energy required to generate a one unit of heat equivalent of another type of available energy (Cleveland, 1992). To overcome the problem of assessing the quality of heat equivalents of different types of energy characterized by various attributes, solar emjoules (SEJ) have been suggested by Odum as a unit of measurement. SEJ refers to the amount of solar energy used to produce another type of energy. According to Odum, the higher transformity of a particular type of energy, the greater the amount of solar energy that was required to produce it, the more useful it is, and the higher quality it is. Electricity which is the most valuable type of energy has the highest rate of transformity among all types of primary energy. Transformity rates, quality factors, for different types of energies are shown in table 2.2.

Odum illustrated his method of calculating transformity using an example of the production of electricity in a wood-fired power plant in Brazil (Odum and Odum, 1983). In his method, two components are essential in the sequence of energy conversions : the principal environmental conversions, and the industrial energy conversions. The environmental conversion refers to the amount of sunlight required to produce one joule of standing wood of the forest. This amount was estimated to be $3.23 * 10^4$ SEJ. Industrial energy conversion refers to the amount of energy that is required to convert solar energy embodied in wood to energy in the form of electricity. This energy is expanded through a series of energy conversions in the economy (harvest, transport, combustion, etc.), and amounts to $1.59 * 10^5$ SEJ per each joule of electricity.

Odum's method of accounting for differences in energy quality is not free of shortcomings. While Odum assumes the constancy of transformities, his method of calculating them indicates explicitly that transformities are dynamic (Cleveland, 1992). This dynamism stems from the observation that transformities depend on the efficiency of conversion technologies such as power plants, coal liquification, and oil refineries, and such technologies are subject to modifications through time and space (Smil, 1991). Though transformity as a concept for measuring energy quality may be accepted, the way Odum calculates these transformities makes it hard to accept them in practice. While the determination of the quality of different types of energy, based on scientific methods, should yield constant quality rates, (quality of gasoline calculated today should be the same tomorrow), Odum's calculation method of transformity would result in changeable relative energy qualities. This is explained by the fact that his method of calculation is based on a set of temporal, spatial, and technologically sensitive assumptions. Another shortcoming of Odum's method of accounting for differences in energy quality stems from the observation that Odum did not explain the relationship between the embodied solar energy in a fuel and the economic usefulness of this fuel. In other words, the relationship between solar energy embodied and the differences in the combination of characteristics of different types of energy has been proved neither theoretically nor empirically (Hall et al., 1986, Cleveland, 1992). For all of the above stated reasons, emergy can not be used as a measure of energy quality.

**Table 2.2: Quality Factors for Various Energy Types**

| Energy Type | Transformity (SEJ/ joule) | Market price (cents /$10^3$ MJ) |
|---|---|---|
| Coal | $3.98 * 10^4$ | |
| Bituminous | | 110 |
| - mine-mouth | | |
| - delivered cost | | |
| Anthracite | | |
| - mine-mouth | | 199 |
| Oil | | |
| - well head | $5.3 * 10^4$ | 279 |
| - No. 2 fuel oil | | 647 |
| - gasoline | $6.6 * 10^4$ | 757 |
| Natural gas | | |
| - well head | $4.8 * 10^4$ | 158 |
| - Delivered cost | | 300 |
| Electricity | | |
| - leaving power plant | $1.59 * 10^5$ | |
| - delivered cost | | 1474 |

Adopted form From Cleveland (1992).

**2.5.3.2 - End Use Technologies- Exergy Analysis**

Exergy is the maximum amount of physical work that can be obtained by a given flow of energy measured in joules (Cleveland, 1992). Exergy analysis accounts for quantity taking into consideration energy degradation and loss (Larson and Cortez, 1995).

Exergy analysis is considered to be more powerful than typical energy analysis in assessing quality, as it is based on both the first and second laws of thermodynamics. Thus, it considers the change in energy quality, the potential to do mechanical work, associated with its conversion from one type to another (Cleveland, 1992). Exergy flow is calculated by multiplying the enthalpy of a fuel by the appropriate Carnot factor $\{1-(T_a/T_b)\}$ where $T_a$ and $T_b$ are the ambient temperature and output temperature of the conversion process, respectively, measured in degrees Kelvin (Cleveland, 1992). Energies with an exergy flow close to their enthalpy are of high quality. The major objective of exergy analysis is the identification and measurement of usable energy, exergy, and non usable energy, irreversibility (Van Wylen and Sonntag, 1978). As exergy analysis measures mainly the capability of doing a useful work, electricity is considered to have the highest exergy because the efficiency of transforming it into useful work is almost 100%. Exergy analysis can provide beneficial insights to energy conversion processes through its capability of identifying the reductions in the ability to do work associated with energy conversions (Cleveland and Herendeen, 1989; Larson and Cortez, 1995). Thus, exergy analysis can be used to evaluate the efficiency of energy use in the most complex processes that involve large amounts of energy, such as evaporation, refrigeration, and milk processing. In the literature, no reference has been found that exergy analysis is used to measure the quality of different types of energy, it has been found to be used only in measuring the efficiency of different types of energy in specific operations or processes.

### 2.5.3.3 - Economic Perspective of Energy Quality

For economists, assessing energy quality is more than just measuring the heat equivalent of various types of energy, determining the solar energy required to produce these energies, or even accounting for fuels' ability to do useful work. From an economic perspective, the best method to evaluate energy quality is one that takes into account the economic factors present in demand which determines the usefulness of a fuel (Mitchel, 1974; Webb and Pearce, 1975). Therefore, economists develop alternative methods to assess energy quality.

**The relative price approach**

Economic theory suggests that prices may be the best expression of energy quality. The justification is based on the notion that qualitative differences between various types of energy are expressed by their marginal product, the increase in the output generated by the use of one additional thermal unit of energy (Cleveland, 1992). The marginal product is not only due to the heat content of energy, but also to the other characteristics of energy such as volatility, weight, ease to storage, availability, cleanliness, etc. According to the Neoclassical theory, in a competitive market, price per heat equivalent should equal the value of the marginal product, assuming that this price represents the marginal factor cost. Market price is supposed to reflect the combination of attributes that determines the usefulness of a fuel from an end-user point of view along with the supply side of the market. Different prices per heat equivalent for types of energy indicate that consumers give more weight to attributes other than its heat equivalent (table 2.2).

Attempting to relate the heat equivalent of different types of energy with prices, Cleveland (1992) suggested a modification of the above method. He used the ratio $P_{it}/P_{1t}$ where $P_{it}$ is the price per unit heat content of the ith type of fuel, while $P_{1t}$ is the price of fuel type 1 (numeraire). Cleveland noted that, from economic point of view, the validity of this factor requires that perfect substitution between different fuels exists. Perfect substitution is required if a suggestion is to be made to use a fuel with a higher quality ratio rather than ones with lower ratios. Clearly, perfect substitution is not available.

The use of an economic perspective to assess energy quality involves holding on to the assumption the fuel markets are perfect, thus prices are accurate indicators of marginal product. Yet, it seems that the fuel market is far from being a perfect indicator of marginal product. Fuel markets are characterized by governmental regulations, monopoly, and many other aspects of market failure. Some economists claim that the interaction of different sources of market failure make the deviations of market prices from the theoretical ideal not that serious, and this deviation can be estimated (Mitchel, 1974). However, detecting these deviations and quantifying them is difficult due to the complexity of world energy markets.

**Summary**

The standard method of measuring energy inputs and outputs in terms of their heat contents masks some of the most important information related to the physical and economic characteristics of energies. Several physical and economic approaches have been proposed to assess energy quality. However, none has been found to handle this problem adequately. This issue needs considerable research however, " a starting point is the recognition that the physical and technical aspects of energy quality must be considered in the boarder arena of the market where end-users select the fuels that are best suited for the particular task at hand" (Cleveland, 1992, p. 150).

# CHAPTER THREE

# METHODOLOGY

## 3.1– INTRODUCTION

This chapter consists of two sections. The first considers the economic aspects of growing red peppers with conventional and plasticulture methods, and the methodology used to estimate the production costs and revenue.

The second deals with the energy aspects of pepper production under both production methods. This section explains the methodology used to estimate the energy requirements for pepper production.

## 3.2—ECONOMIC CONSIDERATIONS

### 3.2.1- Assumptions :

1) This study is based on a representative pepper farm in Southern Quebec in terms of the scale of operation. It is assumed that a typical pepper farm is 20-25 ha.
2) Machinery complements used in the model are assumed to be five years old. Machinery data are gathered from various dealers, provincial agencies, or the literature.
3) It is assumed that farmers following both systems of production are using a drip irrigation system as a means for supplying water and nutrients.
4) Yields for the plasticulture production systems come from an experiment conducted by Fava (1996) at the Macdonald farm of McGill University. Data on yields of

conventional production are based on personal communication (Yelle, 1996 and Bleho, 1996). Yield considered is in terms of red fruits only.

5) It is assumed that soil used for growing pepper is sandy loam, well drained, with an average pH of 7.

6) The study does not extend beyond the farm gate.

### 3.2.2- Accounting Model:

Budgeting is an organised means for presenting data related to enterprise cost and return projections. Budgeting is essential in making accurate management decisions. These decisions might concern the choice between different options, selecting an appropriate investment, evaluating various production and marketing plans, choosing a long-run farm plan, or comparing different production systems, which is the case in this study.

Comparing budgets of both plasticulture and conventional practices of pepper production should reflect differences in field operations, chemicals, harvesting, expenses, machinery, labour and capital requirements, irrigation cost and yield. Accounting for all of these items would point out differences in returns and costs, and as a result, an appropriate decision can be made on whether to grow pepper following conventional practice or plasticulture.

In order to determine the profitability of both production systems, an accounting model is established. The accounting model used in this study is an enterprise budget, defined as an estimate of the average annual costs and returns for the enterprise ( Boehlje and Eidman, 1984). The focus in this model will emphasise differences resulting from changes in the farm plan rather than conducting a complete budget. As a result, not all cost items are considered, only those items that change with a change in the production plan.

The accounting model is based on two types of data: experimental and secondary. Experimental data are based on field experiments on the Macdonald farm. These data are used throughout this study when referring to yields of plasticulture. Secondary data gathered from available literature are used to estimate operations and fixed costs.

The model accounts for variable and some of the fixed costs. These costs are summed to derive the total cost of production on a per hectare basis. Variable costs refer to those costs which vary directly according to the level of the production of the grown crop. These costs include seedlings, hired labour, fertilisers, pesticides, machinery operating costs, and interest on operating capital. Fixed costs are defined as costs that do not change with the level of production (Boehlje and Eidman, 1984). These costs include depreciation and interest on machinery, landownership, and insurance. The model will account for machinery depreciation and interest on investment, and insurance and shelter. Taxes and other overhead, such as landownership, are not accounted for, as these costs are common to both systems.

Depreciation is the loss in the asset value due to wear, or age (Boehlje and Eidman, 1984). To estimate depreciation, two factors have to be determined: salvage value and life time. Salvage value is the expected remaining value of an asset at the end of its useful life. It is estimated as a percentage of the current list price of the machine. In this study, field machinery fall into four categories. Estimates of salvage values and useful life for these categories of farm machinery are reported in Appendixes 1 and 3.

Machinery have been evaluated based on their current 1996 prices, adjusted to $1995, and have been gathered from machinery dealers in southern Quebec. Prices gathered are list prices. 14% (applicable Federal and Provincial taxes) have been applied to these prices to derive the current prices.

The model accounts for the interest on operating capital. Therefore, an interest rate, which represents the cost of using the capital, should be assigned. The real rate is calculated by subtracting inflation from the nominal interest rate. A real rate of 5 percent is found to be commonly used in the literature (Boehlje and Eidman, 1984 and Tayara, 1996), and is used in this study.

The capital recovery method will be used to estimate the annual cost of depreciation and interest on farm machinery. This method has the advantage over other traditional methods of calculating depreciation and interest in that it yields enough money to pay for both depreciation of the capital and to cover the interest on the unrecovered amount of capital at the designated real interest rate over a certain period of time.

The annual cost for depreciation and interest is calculated using the capital recovery method as given in equation (3.1)

$$AC = [(P-SV) * CRF] + (SV * R) \qquad 3.1$$

where AC is the Annual Capital Recovery Factor, P is the purchase price, SV is the Salvage value, CRF is the Capital Recovery Factor, and R is the real interest value.

The Capital Recovery Factor is defined as "the amount of money required at the end of each year to pay interest on the unrecovered capital at the designated rate and recover the investment within the specified number of years" (Boehlje and Eidman, 1984, P.142). The Capital Recovery Factor used varies according to the specified life time and real interest rate.

Repairs and maintenance : Machinery repair expenses vary mainly according to machine type, soil type, geographic and climatic conditions, and operator conduct. Recording repair expenses is no doubt the most accurate way to account for repair costs. In cases of missing data, estimates of repairs and maintenance are made based on recorded repair expenses (Boehlje and Eidman, 1984). These estimates are calculated as a percentage of the list price. These estimates are reported in Appendix 2..

Fuel consumption for various field operations is estimated based on the following formula (John Deere, 1996):

Fuel consumption (L/ha) = The tractor horse power (Hp) * 0.2 * time. 3.2

It was assumed in this study that farmers use a 76.5 Hp John Deere tractor (Yelle, 1996). Fuel consumed in various operations is estimated based on the time required to conduct these operations, which is in turn based on OMAF (1992) and on personal communication (Bleho, 1996).

Boehlje and Eidman (1984) used an average of 15% of fuel cost for lubrication. The same figure will be used here. The price used to estimate the fuel cost is $0.50/L (Yelle, 1996 and Bleho, 1996)

Labour wage per hour used in the model is determined according to labour wages dominant in the rural area of southern Quebec. The following wages were found: $8.50 for machinery labour, and $6.5 for hired labour. (Yelle, 1996 and Bleho, 1996).

### 3.2.3 - Data Sources and Methodology:

All data used to establish the accounting model, except those related to the yield of plasticulture, are gathered from the literature and personal communication. Prices and returns are estimated and expressed in $1995. Plasticulture yields are based on research experiments conducted on the Macdonald farm of McGill University located in the West Island of Montreal, Quebec (Fava, 1996). The objectives of this experiment were to examine the efficiency of nitrogen application through fertigation (applying fertilizers through irrigation systems), evaluate the use of the SPAD meter, and evaluate the impacts of plastic mulch on the incidence of insects and diseases. Two types of mulch were considered in this experiment, silver and black.

The experiment consisted of eight treatments. All the treatments received a preplant fertilizer application of 60 kg/ha of nitrogen. Two different methods of fertilizer application were examined. One involved applying 40 kg/ha of nitrogen on a weekly basis over a period of ten weeks through fertigation. The other involved the utilization of a SPAD chlorophyll meter. This meter measures the level of nitrogen in the plant, which reflects the need for nitrogen application. Nitrogen was applied as needed, as indicated by the meter readings. In order to evaluate water efficiency, three different treatments of irrigation were applied: drip, sprinkler, and no applied irrigation. As it is the main purpose of this thesis to evaluate the feasibility of plasticulture and fertilizing using the SPAD meter, only one treatment (number four) has been chosen to be the alternative plan, the plasticulture system. This treatment consists of using silver mulch, applying nitrogen on the basis of the SPAD readings and using a drip irrigation system as a source of water. The conventional plan is considered to be growing pepper in a bare soil with drip irrigation system, and applying nitrogen on a weekly basis in quantities recommended by MAPAQ. Recommended quantities of fertilizers assumed in this study are listed in Appendixes 4 and 5. The experiment was conducted on a sandy loam soil which is similar to the type of soil used in growing pepper commercially in Quebec. For both systems, irrigation was supplied according to the readings of tensiometers placed at depths of, 30 cm and 60 cm. This method of irrigation is recommended by the Provincial extension service and is widely used by pepper producers.

### 3.2.4 - Production Operation:

The production of pepper as any other crop involves a series of operations in order to give a desirable yield. These operations include field preparation, transplanting, irrigation, fertilizing, chemicals, harvesting, and grading. The production plan followed in this study represents typical commercial operations in the area of Southern Quebec. Appendixes 6 and 7 report operating costs for plasticulture and conventional systems respectively.

- Field preparation :

Preparing the land for planting is necessary with either plasticulture or conventional practices. Conventional tillage systems, such as plowing, and discing are used. Field preparation starts in the spring with plowing, followed by discing. The time and labour required for conducting these operations are estimated in accordance with OMAF (1992). Applying preplant herbicides is common as are preplant fertilizers. Half of the required nitrogen is added, while all the required amounts of potassium and phosphorus are applied in this process. Data on time required for spraying and spreading various agro-chemicals and on prices of these agro-chemicals are obtained from OMAF studies and dealers.

Field preparation also includes laying out the drip irrigation system. In the case of plasticulture, drip lines are installed simultaneously with laying the mulch using a mulch layer machine. 215kg of standard mulch (36" width, 1.1Mil thickness) are needed for one hectare. The price of this machine, mulch layer PlastiTech model 2500 (towed by a tractor), and labour requirements for this operation were obtained from Caron (1996). Installing drip lines is done manually with the conventional system.

-Transplanting :

Transplants are planted in early May, almost one week after installing the irrigation system. A hectare requires 22000 plants. Farmers with both systems plant transplants mechanically. Costs of labour and time required for transplanting are estimated based on personal communication (Caron, 1996).

- Irrigation :

It was found that the plasticulture producers and the majority of traditional pepper producers are using a drip irrigation system to provide their plants with water and fertilizers. A normal drip irrigation system consists mainly of pump, filter, fertilizer injector, main and sub-main valves, main and sub-main lines. There is no difference in the irrigation treatment between plasticulture and conventional systems. As a result, accounting for irrigation costs with either systems will not be included in this study.

- Fertilization :

The quantities of applied fertilizers differ from one field to another and are determined by soil tests. Assuming that pepper is grown in average soil conditions, sandy loam soil with a pH of 7, the requirements for nutrients are 130 kg of nitrogen, 90-120 kg of potassium, and 120-140 kg of phosphorus per hectare in accordance with MAPAQ recommendation. The potassium, phosphorus and half of the nitrogen are applied after plowing. The rest of the nitrogen is applied during the growth period, through the irrigation system. There is no difference in the recommended requirements of nutrients between the two systems. However, by using the SPAD meter, quantities of applied nitrogen were found to be reduced by almost the half. Only 72kg of nitrogen were added in the experimental treatment (Fava, 1996). Quantities of fertilizers used with both systems are listed in Appendixes 4 and 5.

- Weed Control

Weeds such as purselance, lamb's quarters, and different types of grasses are common in pepper fields. Herbicides are used to control these weeds in order to achieve potential yields. However, if farmers use mulch and pre-plant herbicides (Treflan at 0.7 kg/ha) there is no need for herbicides on plant rows during the growth period (Yelle, 1996, Bleho, 1996). This is assumed for the plasticulture system. Yet, a herbicide application is still needed in between plant rows to control weed growth (one treatment of 1kg/ha of Treflan is commonly applied among mulch growers). For the conventional system, weed control is carried out by spraying with relevant herbicides (Treflan at 1kg/ha or Gramaxone at 4l/ha, twice) during plant development, or cultivation (which is commonly followed by farmers at the commercial level). Normally, three cultivations are required.

- Disease and Insect Control

Pepper is susceptible to a number of insect pests and diseases. However with alert observation and applying regular chemical control, problems of diseases and pests can be minimized. One of the most serious disease problems in peppers is Bacterial Spot. This disease can reduce yields significantly. A treatment of two applications of Kocide 101 (2.25 kg/ha ) is considered to be the best protection against this disease.

White Mold is another disease that attacks pepper causing significant losses. This disease is best treated by applying Zineb 80W at 2.2 kg/ha four times on average.

European Corn Borer is the major insect problem in peppers. It is best controlled with two applications of Ambush (140ml /ha ) .

Aphids are considered to be a dangerous insect pest. Its impacts are due mainly to its role in infecting plants with viruses, for which there is no cure. Aphids are controlled using Pirimor 50 DF and Malathion (500g/ha each). Tarnished Plant Bugs, another severe insect pest, can be controlled simultaneously with Aphids.

Silver mulch has demonstrated to have a great effect on the spread of aphids. As a result, there is a lower requirement for treatments against Aphids. Only two treatments were required with the plasticulture system against four with the conventional system (Fava, 1996). Prices of pesticides are collected from Plant-Prod. Quebec (1996). Time required for spraying treatments is estimated using OMAF (1992).

- Harvest :

Fruits are ready for harvest after almost 70 days for the bell cultivar, and are harvested by hand. Picking fruits begins by the middle of July and is repeated every 7 days until the end of September for green pepper. For red pepper, the harvesting season begins by late August and ends by late September. Data on harvesting cost, including times of harvesting, and labour and machinery requirements, are based on personal communications (Janik, 1996 and Bleho, 1996). Harvest operations accounted for include three separate suboperations: harvesting (gathering fruits manually), loading the harvest (loading the gathered fruits into the truck), and hauling to market (grading the harvest and loading it on pickups going to the market).

- Grading :

There are two grades for marketable pepper fruits. A first grade fruit should be mature, firm, well defined and shaped, has 3 to 4 lobes, and weigh more than 100g. Second grade fruit is less than 100g, and has only 3 lobes.

- Storage

Fresh fruits can be kept in coolers for 3-8 weeks in a temperature range of 4 to 7 C and a humidity coefficient of 95. In commercial scale, farmers sell their fruits immediately after harvest. Therefore, this study will not account for storage expenses.

- Marketing

Peppers are shipped in various types of rigid walled cartons that minimise damage. Fruits are packed in size 36 boxes. Each box contains 90 fruits and weighs 29lb on average. Cartons cost will be accounted for.

-Mulch Removal:

Mulch can not be used for more than one season. It is removed at the end of the season either mechanically, using a mulch retriever machine, or manually, which is commonly followed in Quebec. It was assumed in this model that eight labour hours are required to remove one hectare of mulch by hand. Commonly, farmers dump used mulch around their farms (Janik, 1996 and Fava, 1996). Though there is certainly an environmental cost associated with this practice, it is beyond the scope of this thesis to estimate this cost.

## 3.3 -- ENERGY ANALYSIS :

### 3.3.1 - Assumptions :

The energy analysis conducted in this study is aimed at estimating the difference in total energy requirements due to using mulch to grow peppers, compared to conventional methods. The term "total energy requirements" refers to the energy expended in producing all inputs, direct and indirect, into pepper production. In this study, total energy requirements are estimated in terms of GER.

Obviously, total energy requirements for peppers grown using mulch involves using energy in different ways. The following applications are identified to be expected sources of additional energy use in growing pepper using mulch :

1. manufacturing mulch;

2. installing mulches;
3. spraying herbicides between plant rows;
4. picking additional yield; and
5. removing and disposal of mulch.

On the other hand, growing peppers using mulches can reduce total energy consumption. This reduction results from:

1. no cultivation;
2. reduced insecticides treatments.

Each production practice will be analysed in terms of GER. Results obtained will be related to yields in order to estimate energy productivity (energy per unit of output). The method of process analysis is used to estimate GER for different inputs. In cases that process analysis is not practical, the statistical analysis method will be applied. Inputs accounted for include machinery, fuel, transplants, fertilisers, pesticides, labour and mulch.

The boundary of the energy analysis is the field gate, i.e. marketing, including shipping, is not included in the analysis. An assumption is made that farmers sell their yields immediately, therefore, storage will not be considered in the analysis.

- Machinery :

It is assumed in this study that 20-25 hectare is the commercial scale of producing peppers in Southern Quebec. Based on this assumption, the machinery requirements are determined. Appendix 10 lists the required machinery for a typical pepper farm in Southern Quebec. Also shown in the same Appendix, are the mass and the useful life of each machine.

Different estimates of machinery gross energy requirements have been found in the literature. For example, Deleage et al. (1979a) calculated the machinery energy requirements at 75GJ per tonne a year. Bridges and Smith (1979) considered energy embodied in machinery as only the energy expended in manufacturing both equipment and spare parts. They used 91.9 MJ/kg as an estimate for the energy embodied in machinery. Based on estimates of Doering et al. (1977) and Fluck (1985), Bowers (1992) has come up with a new method of accounting for energy embodied in machinery. He classified energy embodied in machinery into three different kinds of energy: manufacturing energy, energy used for producing raw material, such as iron, lead; transport energy, energy required in the manufacturing process; as well as energy embodied in repair parts.

A value of 86.66 MJ/kg is used to estimate manufacturing energy (Bowers, 1992 modified from Doering et al., 1977), while a value of 8.8 MJ/kg is used to account for transportation energy (Bowers, 1992, modified from Doering et al., 1977). Energy embodied in repair parts is calculated as a proportion of the manufacturing energy. This proportion depends on the specific machine and its expected total life, and was developed based on actual records of reported sales of manufactured machines and their repair parts, and service at both dealer and farmer levels (Fluck, 1985). Bowers' method to account for embodied energy in machinery has been found to be the most comprehensive, and recent. Thus, it is has been adopted in this study. In cases where the repair proportion of a specific machine is not reported by Fluck (1985), an average of the total reported proportions, 0.55 %, will be used to account for the repair and maintenance energy requirements of that specific machine (adopted from Bowers, 1992). Appendix 10 shows the energy embodied in machinery used in growing pepper.

- Fuel :

Fuel consumption is estimated based on the following formula (John Deere, 1996):

Fuel consumption (L/ha) = The tractor horse power (Hp) * 0.2 * time (h/ha).

47.78 MJ/L (Cervinka, 1980) has been found to be the only estimate for the gross energy requirement for diesel fuel cited in the literature. Appendixes 11 and 12 list quantities of fuel consumed in different field operations with both systems.

- Fertilizers :

Different energy requirements for fertilizers were found in the literature. Blouin and Davis (1975) calculated the energy estimates for nitrogen, phosphate and potash fertilizers to be: 57 MJ/kg, 12.5 MJ/kg, and 6.6 MJ/kg respectively. While Mudahar and Hignett (1987) estimated them at 78 MJ/kg, 17.4 MJ/kg and 13.7 MJ/kg. for nitrogen, phosphate and potash respectively. Both estimates account for energy requirements in terms of GER, i.e., production energy, energy for transportation, and energy for storage and transfer are all accounted for. Also, each of the two methods is based on US technology. Mudahar and Hignett's (1987) estimates are applied in this study, as these are more recent.

- Herbicides and Pesticides:

Green's (1987) estimates have been found to be the only estimates for energy requirements for various pesticides and applied in this study. Green's method accounts for direct energy inputs, such as electricity, gas, stirring, distilling, fettering and drying, and indirect energy inputs, which are the sum of all inherent energies of all the material derived from fossil fuels used in the manufacturing process. Total energy requirements for pesticides also include energy required for formulation, packaging, distribution and transport. The energy required for formulating depends on the product categories. 20 GJ/t, 30 GJ/t, and 15 GJ/t are added for formulating pesticides into miscible oils, wettable powder, and granulates, respectively. Green assumed 2 GJ/t additional energy for packaging and distribution, and 1 GJ/t for transport.

- Irrigation

Energy for irrigation is consumed in constructing the water supply source, installing the field irrigation system, operating and maintaining the system. In general, energy requirements consist of direct energy, which is required for operating the pumps, and indirect energy, the energy required for producing and repairing the irrigation equipment. Batty and Keller (1980) assumed the gross energy requirements for a drip irrigation system to be 4215 MJ/ha per year. This figure is used in this study, as no other estimates were found in the literature.

- Labour :

The literature on the energetics of human labour is rich with different methods to estimate the energy equivalents of labour. These methods, based on different concepts, measure various forms of energy. For example, energy value of human energy can refer to: (1) the metabolic energy of the labour during work (Revelle, 1976); (2) the total metabolic energy of the labour (Dekkers et al., 1974; Hudson, 1975); (3) the energy embodied in food (Wells, 1984); (4) or the energy embodied in goods and services consumed by labour (Williams et al., 1975; De Wit, 1975; Leach, 1977; Lewis and Tatchell, 1979; Odum, 1983, Stanhill, 1984; Fluck, 1992). Energy equivalents derived from these methods are found to be in the range of 8 MJ/day to 1448 MJ/day. Fluck (1992) recommended applying methods that measure energy consumed by labour in services and goods when analyzing the energetics of industrialized production systems. He justified his recommendation upon the fact that energy in industrialized economies is essential for operating all activities including those of labour. Labour wage pursuing activities, for instance, are dependent on the consumption of goods and services that would not to be available unless enormous amounts of fossil energy were expended. Accordingly, and as the systems analyzed in this study are industrialized, Fluck's (1992) estimate, 594 MJ/day, is used in this study.

Further details on Fluck's method can be found in the Chapter 2. Labour requirements for both systems are found in Appendixes 11 and 12.

- Transplants :

The statistical analysis method is used to account for the energy requirements for transplants. The energy intensity of transplants is based on a unit price of 10c/transplant (Yelle, 1996) and an average energy intensity of the Canadian economy (in $1986) of 16.1 MJ/$ (Statistics Canada, 1996). Energy intensity of the economy is estimated by dividing the Gross Domestic Product (GDP) by the total production of commercial energy.

- Plastic mulch :

158 MJ/kg (Fluck et al., 1978) is used in the literature as an estimate of the GER of mulch. This figure is used in this study.

- Packages :

Data on the gross energy requirements for packages are not readily available. Therefore, the statistical analysis method has been used to estimate energy requirements for packaging. The energy requirement for packages is based on a price per unit of 1.3c/carton (Yelle, 1996) and an energy intensity of the paper products of 26.23 MJ/$ (Smith, 1995). Energy intensity of paper product is estimated by dividing total energy consumption over total output of this sector.

# CHAPTER FOUR

# RESULTS

## 4.1 – INTRODUCTION:

Results obtained from economic and energy analyses of alternative pepper production systems are reported and interpreted in this chapter. This chapter is divided into two sections. The first reports the results on the cost and profitability of growing pepper under each production system. The second section presents the results of the energy analysis of both systems.

## 4.2 – ECONOMIC RESULTS :

Economic data are compiled in three main sections: 1) variable cost; 2) fixed cost; and 3) net returns. Detailed budget information can be found in the Appendices, while summary results are presented in table 4.1.

### 4.2.1 - Variable Costs :

Variable costs include: fuel, lubricants, labour, machinery repairs and maintenance, seedlings, mulch, cartons, fertilizers and pesticides. Variable costs have been accounted for each field operation in terms of repairs and maintenance, fuel and lubricants, and labour. Variable costs have been evaluated on a per hectare basis.

Table 4.1 SUMMARY OF RESULTS: COSTS AND RETURNS

| | **COST ($/ha) Plasticulture** | **COST ($/ha) Conventional** | **Plasticulture relative to Conventional (%)** |
|---|---|---|---|
| VARIABLE COSTS | | | |
| Labour: | | | |
| Hired | 1874.52 | 1583.36 | 18.38 |
| Machine Operator | 156.50 | 154.51 | 1.28 |
| Total labour | 2031.02 | 1737.87 | 16.86 |
| Transplants (22250/ha) | 2031.94 | 2031.94 | 0.0 |
| Fertilizers | 448.35 | 565.64 | -20.74 |
| Pesticides | 482.00 | 439.93 | 9.56 |
| Tractor & machinery cost | | | |
| Repair & Maintenance | 20.61 | 21.86 | -5.72 |
| Fuel & lubricants | 175.29 | 173.49 | 1.04 |
| Mulch | 1506.25 | | |
| Cartons | 3202.66 | 1754.51 | 82.53 |
| **TOTAL VARIABLE COSTS** | **9898.12** | **6725.24** | **47.18** |
| | | | |
| FIXED COSTS | | | |
| Tractor & machine costs: | | | |
| Depreciation & interest | 277.44 | 284.91 | -2.62 |
| Insurance & shelter | 37.48 | 38.42 | -2.44 |
| SPAD | 2.51 | | |
| **TOTAL FIXED COSTS** | **317.73** | **323.33** | **-1.73** |
| *TOTAL COSTS* | *10215.85* | *7048.57* | *44.94* |
| | | | |
| REVENUE | | | |
| **Yield (kg/ha)** | **25,600** | **11,700** | **118.80** |
| **Gross income** | **49704.20** | **22640.76** | **119.53** |
| Total Variable Costs | 9898.12 | 6725.24 | 47.18 |
| Gross Margin | 39806.08 | 15915.52 | 150.11 |
| ***Net Margin*** | 39488.35 | 15592.19 | ***153.26*** |

4.2.1.1- Repair Costs :

Repair and maintenance for both tractor and the attached implement have been accounted for (Appendix 2). Total repair costs have been estimated at $21 and $22/ha accounting for less than 0.01% of total variable costs for both methods of production (Appendix 6 and 7). The difference in costs between both systems, though insignificant, $1, can be attributed to the lower level of annual use of machinery with the plasticulture system.

4.2.1.2 - Fuel Consumption :

Data on fuel consumption for various operations and using 50c/L of diesel (Bleho, 1996 and Yelle, 1996) as a fuel cost have been compiled to derive the hourly cost per operation, (Appendixes 6 and 7) for plasticulture and conventional systems.

With the assumption that lubricants cost 15% of fuel costs (Boehlje and Eidman, 1984), the lubricants cost has been calculated on an hourly basis for each field operation. Fuel and lubricant costs combined amount to nearly 1.8% and 2.6% of total variable costs for plasticulture and conventional systems respectively. However, fuel cost for the plasticulture system is 1% higher than the conventional system. This increase is due mainly to the additional use of the tractor in loading the harvest, which in turn is due to the higher level of yields obtained with the plasticulture.

4.2.1.3- Labour Cost :

Labour charges have been calculated for each operation based on two hourly rates: $8.5 for machinery operator and $6.5 for hired labor (Bleho, 1996 and Yelle 1996). Total labour costs have been found to be 21% and 26% of the total variable costs for plasticulture and conventional systems respectively. Differences in labour requirements between production systems have been found to be significant. These differences come mainly from different labour requirements for the harvesting operation. Labour hours for harvesting with the plasticulture system have been found to be 50% higher than those with the conventional system. This significant difference is due to the dramatic increase in yield obtained with the plasticulture system.

Other sources of difference in labour requirements between the two systems are laying and removing plastic mulch, and weed control operations. While laying mulch needs only 4 hours of labour, removing it requires 8 hours, all amounting to 20% of total labour hours needed with the conventional system (excluding labour for harvesting). On the other hand, with the conventional system, hand hoeing is necessary to control weed growth in plant rows. Hand hoeing requires 52.5 h/ha accounting for 69% of total labour hours (excluding labour requirements for harvesting). Another source of additional use of labour, 4 hours, with the conventional system is laying out the drip lines (which is done simultaneously with laying the mulch in the plasticulture system). Weed control within rows with the plasticulture system is obtained as mulch prevents weed growth.

In general, the plasticulture system has been realized to be more labour intensive, 17% higher over the conventional system, causing an additional expense of almost $294/ha. Labor requirements for different field operations with both systems are illustrated in Appendixes 6 and 7 for plasticulture and conventional systems respectively.

4.2.1.4 - Agro-chemicals Cost :

Fertilizers, pesticides, and herbicides are a major expense as they account for 9.4% and 15% of total variable cost for plasticulture and conventional systems respectively. Major differences in total requirements of fertilizers and pesticides have been noted. Lower quantities of fertilizers were applied with the plasticulture system due to the use of the SPAD fertilizing method. This difference amounts to 58kg of nitrogen per hectare or almost 43% less than the conventional system, and a saving of $117 per hectare.

Also, with silver mulch a reduction of two sprays against aphids are obtained resulting in a saving of $52. On the other hand, an additional treatment of herbicides is required with the plasticulture system to control weeds between rows, incurring an additional cost of $94. In total, the cost of agro-chemicals in the conventional mulch system has been found to be $75 or 8% higher compared with that of the plasticulture system. These costs are illustrated in Appendixes 4 and 5 for plasticulture and conventional respectively.

4.2.1.5 - Transplants Cost :

The total cost of transplants is calculated using a unit price of 10c/transplant (Yelle, 1996). Transplants account for 21% and 30% of total variable costs for plasticulture and conventional systems respectively, although the absolute cost for both systems are identical, $2032.

4.2.1.6 - Plastic mulch Cost :

Plastic mulch amounts to 15% of total variable costs for the plasticulture system. Cost is based on a price of $120.5/roll (36" * 4000') for silver mulch (PlastiTech, 1996) and a requirement of 12.5 roles (Yelle, 1996). It is worth stating that the price of silver mulch is higher than the average price of different types of mulches. For instance, the average price for black mulch, commonly used, is $101/roles (PlastiTech, 1996).

4.2.1.7 - Cartons Cost:

Cartons account for 32% and 26% of total variable costs for plasticulture and conventional systems respectively. The plasticulture system incurs an additional cost of cartons of $3202/ha, that is 83%, higher than the conventional system. This difference can be attributed to the significant increase of the yield obtained with plasticulture system.

4.2.1.8 - Total Variable Costs

Total variable costs are $9898.12 and $6725.24 per hectare for plasticulture and conventional systems respectively. Total variable costs account for almost 97 and 95% of the total cost in plasticulture and conventional systems respectively.

Among the various variable costs, surprisingly, the container cost is the most expensive input accounting for 32% and 26% of the total variable cost for plasticulture and conventional systems respectively.

4.2.2 - Fixed Costs:

Fixed costs include machinery depreciation and interest, and insurance and shelter. Fixed costs have been calculated on an hourly basis and for each field operation. Detailed calculations are illustrated in Appendix 3.

4.2.2.1 - Depreciation and Interest Costs :

The difference in machinery depreciation and interest costs between both systems, ($7.47 higher with the conventional system), though insignificant, is due mainly to the use of the mulch layer machine with plasticulture system and the use of a cultivator in the conventional system. Total investment cost of machinery is illustrated in Appendix 1, while depreciation and interest costs on hourly basis are reported in Appendix 3. Depreciation and interest costs per operation are shown in Appendixes 6 and 7.

4.2.2.2 - Insurance and Shelter Costs:

These are assumed to be 1.5% of the current value of machinery (Tayara, 1996). Insurance and shelter costs per hourly and per hectare are reported in Appendixes 3, and 6 and 7.

Insurance and shelter costs account for nearly 12% of total fixed cost for both systems, and are virtually identical in absolute terms.

4.2.2.3 - SPAD Meter Cost:

Depreciation and interest on the SPAD meter used with the plasticulture system are included in the total fixed costs. The purchase price is $1400. The salvage value has been determined at $0, and lifetime at 10 years. It was assumed that one SPAD meter can be used for 100 hectares throughout the year, two seasons, with pepper or any other crops (Janik, 1996). The net present value method has been applied to estimate the total fixed cost for SPAD, which has been estimated at $251 a year, amounting to $2.51/ha.

4.2.2.4 - Summary of Fixed Costs :

Total fixed costs are $317.73 and $323.33 per hectare for plasticulture and conventional systems respectively, almost 3% and 5% of the total cost for plasticulture and conventional systems respectively. As noted, the difference in total fixed cost between the two systems is not significant and could be attributed to the similarity of field operations applied in both systems. Among fixed costs, depreciation and interest have been found to be the most costly, accounting for 87% and 88% of total fixed costs for plasticulture and conventional systems respectively. Appendixes 8 and 9 show total fixed costs for each operation.

4.2.3 - Yield Returns :

Yield obtained under mulch is based on experimental results (Fava, 1996). Data on yields obtained under silver mulch applied commercially are not available. The experimental yield was almost 26 tonne of red pepper per hectare for the year 1995. On the other hand, the average yield of pepper grown with drip irrigation and on bare soil has been determined at 11.7t/ha (Bleho, 1996 and Yelle, 1996). The difference in yields is nearly 119%. This difference can be expected to have more than a proportional effect on total revenue, as it is believed that mulch improves early yield which can be sold at, relatively, higher prices.

In order to account for this effect, a more detailed analysis has been conducted. The harvesting period has been divided into three periods: early (August 23- 30); mid (September 2- 9); and late (September 13- 23) sessions. Yield for each period has been multiplied by the average of the weekly reported prices for the same period to derive the return of the specific session. The distribution of yield through time for pepper under mulch or on bare soil have been developed based on Fava's (1996) results. Prices used are average prices for each session for the Montreal market for the period of August-September, as reported by the Ontario Vegetable Producers Marketing Board (1996). Average prices were computed on the basis of daily price quotations for No 1 grade red peppers.

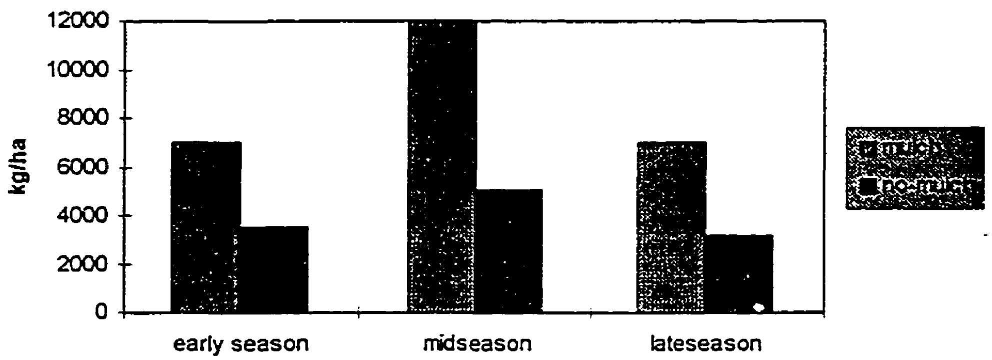
Figure 4.1 shows the yield distribution for both systems. It is shown clearly in this figure that:

1- the quantity of pepper for the plasticulture system is greater in each session compared to the conventional system, at least twice as great as, in all sessions;

2. the largest absolute yield increase is in the mid-season; and

3. yield distribution is virtually identical for the two systems.

Figure 4.1 Yield Distributions Throughout the Harvesting Season




A revenue analysis for both systems is illustrated in table 4.2. Higher gross revenues have been achieved, (+120%), with the plasticulture system due to the greater yield obtained, (+ 119%). As indicated in table 4.1 gross and net returns are both substantially higher for the plasticulture system, which has a net return of $39,488/ha compared to $15,592 /ha for the conventional system.

4.2.4 - Summary: Pepper Enterprise Budget:

Economic data presented and discussed in the previous sections are compiled to project the final enterprise budget of pepper. The enterprise budget consists of three major sections: variable costs; fixed costs; and returns. Table 4.1 represents the final budget of each of the two production systems.

**TABLE 4.2 : GROSS REVENUE ANALYSIS FOR PLASTICULTURE AND CONVENTIONAL SYSTEMS**

| | SHARE OF TOTAL HARVEST | | QUANTITY (KG/HA) | | PRICE ($/KG) | GROSS REVENUE ($/HA) | |
|---|---|---|---|---|---|---|---|
| | Mulch | Conve-ntional | Mulch | Conve-ntional | | Mulch | Conve-ntional |
| Early Har. | 0.27 | 0.30 | 7020 | 3510 | 2.5 | 17550 | 8775 |
| Mid. Har. | 0.46 | 0.43 | 11960 | 5031 | 1.72 | 20571 | 8653 |
| Late Har. | 0.27 | 0.27 | 7020 | 3159 | 1.65 | 11583 | 5212 |
| Total | | | 26,000 | 11.700 | | 49704 | 22640 |

4.2.5 - Financial Productivity :

Financial productivity is estimated as the ratio of total revenue to total costs, fixed and variable. Financial productivities are estimated at 4.87 and 3.21 for plasticulture and conventional systems, respectively. The productivity of the plasticulture system is significantly greater (+119%), and is due mainly to the variations in yields as illustrated earlier. While one dollar invested in growing pepper using silver mulch earns almost $4.9 he conventional system earns only about $3.2.

It is worth noting that although the plasticulture system is associated with, relatively, greater costs, its productivity is more than enough to compensate the higher costs. As noted, analyzing financial productivity of the plasticulture system reveals highly efficient performance compared with that of the conventional system.

## 4.3 – ENERGY ANALYSIS RESULTS:

Data on the energetics of growing pepper with alternative systems have been compiled to design the energy budget for pepper production under each system. The results are summarized in table 4.3.

### 4.3.1 - - Machinery Energy:

The gross energy requirements for machinery are the total energy consumed in manufacturing raw material, processing, and lifetime maintenance and repair, that is the energy that has been used to make the machine available for use. The results of machinery energy calculation are outlined in Appendix 10. Gross energy requirements for each operation have been accounted for, based on estimating the energy depreciated over the

TABLE 4.3: TOTAL ENERGY REQUIREMENTS (TER) FOR PLASTICULTURE AND CONVENTIONAL SYSTEMS

| **Item** | **Plasticulture (MJ/ha)** | **% of the TER** | **Conventional (MJ/ha)** | **% of the TER** | **Difference (%)** |
|---|---|---|---|---|---|
| Machinery | 1,126 | 0.01 | 1,290 | 0.94 | -12.71 |
| Labour | 23,932 | 11.56 | 20,426 | 14.87 | 17.16 |
| Fuel | 15,582 | 7.53 | 15,381 | 11.19 | 1.31 |
| Fertilizers | 9323 | 4.50 | 13,853 | 10.08 | -32.70 |
| Pesticides | 2,062 | 1.00 | 2,088 | 1.52 | -1.25 |
| Irrigation | 4,215 | 2.04 | 4,215 | 3.07 | 0.00 |
| Plastic mulch | 34,013 | 16.43 | - | | |
| Transplants | 35,822 | 17.31 | 35,822 | 26.07 | 0.00 |
| Packages | 80,916 | 39.09 | 44,328 | 32.26 | 82.54 |
| *TER. Excl. Labour* | *183,060* | | *116.977* | | *56,49* |
| **TER** | **206,992** | | **137,403** | | **50.65** |
| *Productivity (kg/MJ)* | *0.13* | | *0.09* | | *44.44* |

lifetimes for both tractor and implements used in performing the operation and then adjusted to MJ/h. Multiplying the estimated hourly energy consumed by the productivity of this operation yields the gross energy requirements for each operation (Appendix 11 and 12).

The transport operation has the largest gross energy requirements in terms of machinery energy requirements at 470 MJ/ha and 381MJ/ha for plasticulture and conventional systems. High energy requirements for harvesting can be attributed to the relatively low productivity of this operation.

Despite the observation that the plasticulture system involves the use of additional field machinery, (mulch layer, and additional use of the tractor for the harvesting operation), machinery energy requirements for this system have been found to be lower than those for the conventional system. This can be explained based on the fact that the conventional system involves the use of cultivators, which are not used with the plasticulture system, as well as additional pesticides treatments. As a result, the energy requirements for machinery with the conventional system have been found to be 14.6% higher, or 164 MJ/ha, compared with those of the plasticulture system.

4.3.2 - - Fuel Energy:

Fuel consumption in various field operations along with their energy equivalent in MJ/ha are shown in Appendixes 11 and 12.

As noted from these Appendixes, loading the harvest consumes the largest amount of fuel, at 187 L/ha and 151 L/ha for plasticulture and conventional systems respectively.

The plasticulture system has been found to be 1.3% higher in terms of total fuel consumption per hectare. This can be attributed mainly to the additional use of the tractor in loading the harvest. Energy requirements for fuel contribute 7.53% and 11.19% of total energy requirements for pepper production with plasticulture and conventional systems respectively.

4.3.3 - Energy Requirements for Field Operations:

The total energy requirements for field operations are derived as the sum of the energy value of fuel and the total energy requirements for machinery (Appendixes 13 and 14). Results indicate that the plasticulture system expends slightly more energy for field operations (37 MJ/ha or 0.22%).

4.3.4 - Energy Requirements for Labour:

Gross energy requirements for labour have been accounted for each operation (Appendixes 13 and14). The energy value of human labour has been determined at 594 MJ/d, assuming 8 working hours a day (Fluck, 1992). Labour energy requirements for each operation have been calculated by multiplying the amount of labour required on an hourly basis times the energy value of human labour. The results show that the plasticulture system is more energy intensive in terms of human labour; 17% higher (3,506 MJ/ha), than the conventional system. This increase is due to the higher requirements of labour associated with harvest operations. Mulch planting and removing were another source of utilizing more labour. Energy requirements for labour used in these operations have been found to be higher than for those operations that are unique to the conventional system: cultivating, hand hoeing, and laying drip lines.

4.3.5 - Energy Requirements for Fertilizers :

Quantities of applied phosphorous and potassium fertilizers for both systems are identical and determined according to MAPAQ recommendations. Requirements of phosphate, and potash are 130 kg/ha and 105 kg/ha respectively. Applied quantities of nitrogen differ between the two systems. In the experimental trial of Fava (1996) plants were fertilized according to the readings of the SPAD meter. Pepper grown under silver mulch received only 72 kg of nitrogen, while 130 kg of nitrogen were applied with the conventional system following MAPAQ recommendation.

Gross energy requirements for fertilizers amount to 9323 and 13854 MJ/ha for plasticulture and conventional systems respectively. The difference is due to the lower level of nitrogen fertilizer applied with the plasticulture system. In total, fertilizers represent 4.5% and 10% of gross energy requirements for plasticulture and conventional systems respectively. Energy requirements for fertilizers applied for both systems are illustrated in Appendixes 15 and 16.

4.3.6 - Energy Requirements for Pesticides:

It was assumed that pepper growers follow the recommendation of MAPAQ for pesticides. Energy values are based on Green's estimates (1987), which account for all energy consumed in the production, formulation, packaging, and transport of various pesticides. Total energy requirements are shown in Appendixes 15 and 16 along with their applied quantities.

Gross energy requirements for insecticides have been estimated at 1807.3 and 1998.3 MJ/ha for plasticulture and conventional systems respectively. This difference is due to the reduction in treatments applied against aphids with silver mulch. During 1995, when climatic conditions where suitable for aphid growth, farmers had to spray their fields six times, while with silver mulch, only three sprays were applied. It has been assumed that silver mulch can save half of the required treatments against aphids, and that 4 treatments are needed under normal conditions.

In terms of energy requirements for herbicides, it has been noted that plasticulture involves a higher requirement, on the order of 165 MJ/ha. The reason is that additional treatment with herbicides is required to limit weed growth between plant rows.

In total, the results show that the plasticulture system consumes slightly less energy in the form of pesticides with a saving of 1.2% of total energy required for the same inputs with the conventional system.

It is worth noting that pesticides are the most energy intensive of all agricultural inputs. Though pesticides and herbicides are applied in relatively small amounts, 18.48 and 18.38 kg/ha against 307 and 365 kg/ha of fertilizers for plasticulture and conventional systems respectively, their total energy requirements account for 1% and 1.5% of total energy consumed in pepper production, with plasticulture and conventional systems respectively.

4.3.7 - Irrigation Energy:

The gross energy requirements for the drip irrigation systems used with both systems are estimated at 4215 MJ/ha (Batty and Keller, 1980) accounting for 2% and 3% of the gross energy requirements for plasticulture and conventional systems respectively.

4.3.8 - Transplants Energy:

Gross energy requirements for transplants should account for direct and indirect fossil energy inputs used in the production, processing and distribution. Because of the lack of data needed to estimate the energy costs of transplants, the statistical analysis method has been used to estimate energy requirements. Energy requirements obtained by this method are computed by multiplying the monetary value of the input, $2225/ha or 10c/transplant (Yelle, 1996), by the dollar to energy transformation, 16.1 MJ/$ (Statistics Canada, 1996). The result is 35,823 MJ/ha. There is no difference in energy requirements for transplants with both systems, as the quantities planted with each system are identical.

It is also interesting to note that the energy requirement for transplants is one of the largest for pepper production. Transplants account for 17% and 26% of gross energy requirements for plasticulture and conventional systems respectively.

4.3.9 - Energy Requirements for Plastic Mulch:

Gross energy requirements for plastic mulch has been determined at 158.2 MJ/kg (Fluck et al., 1978). 215kg of mulch is used for one hectare. Total energy requirements for plastic mulch are 34013 MJ/ha. Energy expended in plastic mulch accounts for 16.4% of total energy consumed with the plasticulture system.

4.3.10 - Energy Requirements for Packages :

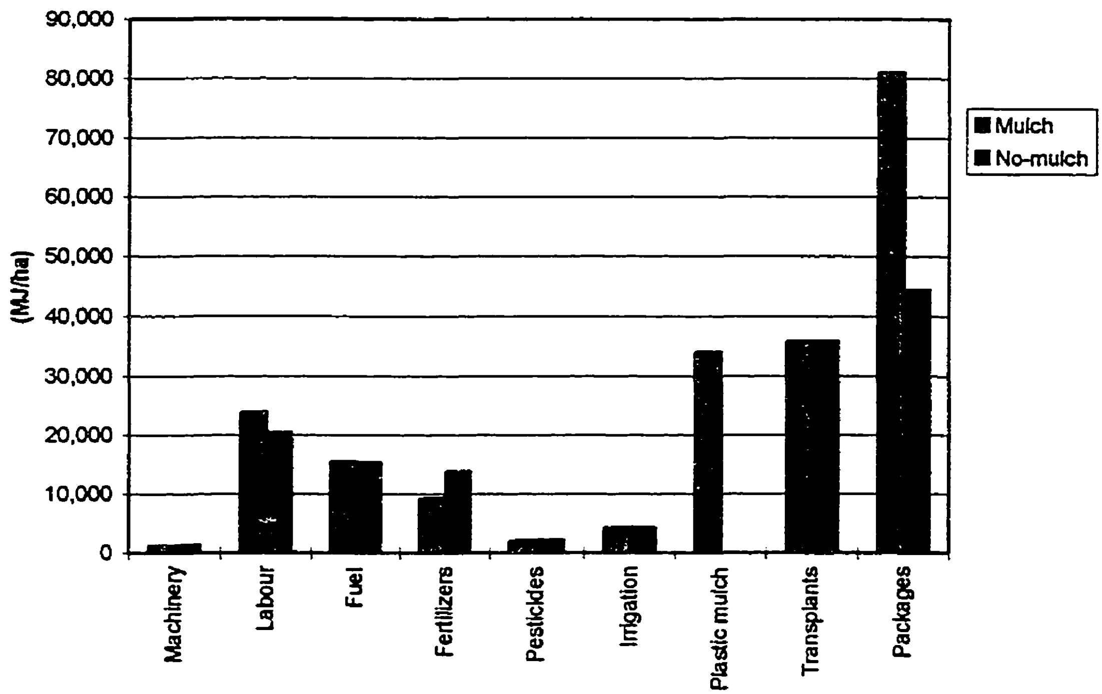
Data on energy requirements for packages are not readily available. Therefore, the statistical analysis method has been used to estimate energy requirements for packages. With a price of $1.3 per carton (Yelle, 1996), requirements of 2373 cartons and 1300 cartons with plasticulture and conventional, respectively, and an energy intensity of paper products of 26.23 MJ/$ (Smith, 1995), the energy requirements for packages has been estimated at 80,916 and 44,328 MJ/ha for plasticulture and conventional, respectively. Energy expended for packages account for 39% and 32% of total energy requirements for plasticulture and conventional systems respectively. Packages represent the largest requirements of energy in total.

## 4.4.- ENERGY PRODUCTIVITY:

It has been found that the plasticulture system has a higher total energy requirement at 206,992 MJ/ha compared to the conventional system at 137,403 MJ/ha. However, in terms of energy productivity per unit of output, the plasticulture system is superior. Although the plasticulture system consumes about 51% more energy per hectare, energy productivity for the plasticulture system is 0.13 kg/MJ, whereas energy productivity for the conventional system is 0.09 kg/MJ. The plasticulture system is 44%

more efficient in terms of energy use, with labour included. Energy requirements for different inputs used with both systems under study are shown in figure 4.2.

Figure 4.2 Energy Requirements for Plasticulture and Conventional Systems



# CHAPTER FIVE

# SUMMARY

## 5.1 – INTRODUCTION:

This chapter summarizes the results of the study. Policy issues related to the adoption of plasticulture at the commercial level are presented. Limitations of this research and recommendations for further research are also discussed.

## 5.2 – RESEARCH CONCLUSION:

This research applied energy and economic analyses to determine the efficiency of plasticulture applied to the production of red pepper. An accounting model was constructed based on a typical pepper farm in Southern Quebec. Energy analysis was performed using the method of process analysis to account for the energy consumed in pepper production under mulch and no-mulch. Total energy requirements for production with each system were related to yields obtained. Data on mulch yield were based on an experimental trial conducted at the farm of Macdonald Campus, McGill University. No-mulch yield was estimated from secondary data. Analyzed also, was the efficiency of using the SPAD meter as a tool to make fertilization decisions. Enterprise budgets were constructed to determine the profitability of each system. Costs were related to returns to derive financial productivity in order to determine the efficiency of each system.

5.2.1 - Energy Results:

In total, the plasticulture system was found to be 51% more energy intensive in terms of GER per hectare. Mulch and packages are the major energy inputs accounting for 49% and 53% of the net difference respectively. The potential reduction in the energy requirements for these inputs, which is expected with the advancement in technology, would result in a reduction in the total energy requirements for pepper production under mulch. This in turn will raise the energy productivity, given that the yield does not decrease.

The energy requirements for the following inputs were accounted for: machinery, fuel, labour, fertilizers, pesticides and herbicides, mulch, cartons, and transplants. Total energy requirements for each system were calculated as the sum of the energy expended on inputs.

Energy productivities were estimated for each system, by dividing pepper output by the total energy requirements. While 0.13 kg of red pepper can be produced with an investment of one MJ energy, only 0.09 kg of pepper can be obtained with the conventional system. The difference, 44%, is significant and indicates clearly the superiority of the plasticulture system in using energy resources efficiently.

Energy savings obtained with the plasticulture system were due to lower applications of pesticides and no herbicides treatments within plant rows. These savings were found to be higher than the energy expended to lay mulch and spray herbicides in between plant rows. The difference in total energy requirements between the plasticulture system and the conventional system only amounts to 37 MJ/ha, or less than 1% of the total energy requirements for operation in the conventional system.

Due to the use of the SPAD meter, less nitrogen fertilizer was used leading to a saving of 4530 MJ/ha or 49% of total energy requirements for fertilizers in the plasticulture system when compared to the conventional system. Also, lower treatments against Aphids, two treatments with the plasticulture system against four treatments with the conventional system, results in savings of 191 MJ/ha or 10% of total energy requirements for pesticides applied with the plasticulture system when compared to the conventional system. On the other side, applying herbicides in between plant rows in the plasticulture system results in additional energy requirements of 165 MJ/ha or 83% more than for the conventional system. Energy requirements for all chemicals used with the plasticulture system were found to be lower by 29%.

The higher yield obtained from the plasticulture system results in higher energy requirements for packages, almost 83%. There was no difference in the energy requirements for transplants as both system used the same amount of transplants.

Labour requirements were estimated at 23,932 MJ and 20,426 MJ per hectare for plasticulture and conventional systems respectively. Labour energy requirements constituted 12% and 15% of total energy consumed with the mulch and plasticulture and conventional systems respectively.

5.2.2 - Financial Results:

Financial productivity was calculated to determine the economic efficiency of each system. The financial productivities, gross return divided by total cost, were found to be 4.9 and 3.2 on a per hectare basis for plasticulture and conventional systems respectively. While $4.9 were obtained as a gross return from each dollar invested in the plasticulture system, only 3.2 were obtained from the same dollar if invested with the conventional system.

Enterprise budgets were constructed to determine the profitability of each system in $1995. Total cost for operations in the plasticulture system was found to be 13% higher, ($285), compared to the conventional system. The difference is due mainly to the higher requirements of labour, in addition to the difference in operations followed in each system.

Variable costs accounted for in this study include machinery repair and maintenance, labour, fuel, transplants, fertilizers, pesticides, herbicides, packages, and mulch. Due to the use of the SPAD meter, a saving of $117/ha was obtained with the plasticulture system. Cost of pesticides was decreased by $52 or 10% due the capability of silver mulch to limit the spread of Aphids. Mulch and cartons account for 47% and 46% of the net difference in variable costs between the two systems.

In total, although no labour was used in weeding, and the use of chemicals was lower, variable costs were found to be higher, $3173 or 47%, for the plasticulture system.

Fixed costs accounted for included machinery depreciation and interest rate, and insurance and shelter. No significant difference was found between the two systems, almost $6 or 1.7% more with the plasticulture system.

While incurring an additional $1400, as the cost of the SPAD meter, fertilization decisions based on this meter seem to be economically accepted. Nitrogen fertilizers were reduced by almost 43% leading to a saving of $117/ha. The present value of potential savings over ten years of expected time life of the SPAD meter has been estimated at $80,845, assuming that the SPAD meter can work to monitor the nitrogen level in plants over an area of 100 hectares and that it can save the same amount of nitrogen with other crops.

To estimate returns, the harvesting season was divided into early season, midseason, and late season. The yield of each season was multiplied by the average Montreal price for the specific season. The return analysis demonstrated that the plasticulture system achieved a superior gross return with a difference of $ 27,064 or almost 120%. This difference is explained by the greater yield obtained. Compared with other types of mulch, silver mulch was found to have no effects on the distribution of yield throughout the harvesting season.

Results, from both the energy analysis or economic analysis, showed that the plasticulture mulch system is more efficient compared with the conventional system, even though it involves more capital and energy requirements.

5.3 – POLICY ISSUES:

Plasticulture has been criticized by environmentalists for introducing high levels of energy use in the form of plastic mulch, fertilizers and pesticides. The results of this research show that while plasticulture involves more energy use per hectare, it uses this energy more efficiently, i.e. less energy inputs are required to produce one unit of output. Applying this method of production on a large scale would reduce energy expended in producing a constant quantity of peppers. Based on the results of this research, plasticulture should be promoted as a recommended method for vegetable production.

One of the barriers that may impede the adoption of plasticulture is that it is 47% or $3173/ha more intensive in terms of operating capital. Mulch and cartons were found to have the largest contribution in the net difference, 47 and 46 % respectively. This barrier can easily be overcome as long as financial institutions are willing to provide the necessary operating credit. Though, mulch system involves the use of an additional piece of machinery, mulch layer, it saves the use of other machinery, the cultivator. The costs of both pieces of machinery are virtually identical.

The safe disposal of used mulch is a yet unresolved problem. Farmers have been known to dump used mulch on their farms. Attempts to safely dispose of used mulch are yet in early stages, and may lead to an additional expense. However, growers can easily afford the cost of dealing safely with this problem, due to the profitability of the system. For example, charging farmers $150/tonne for this purpose would only reduce profit by about 10% ($3840/ha).

## 5.4 -- LIMITATIONS OF THIS STUDY:

This study has several limitations:

1). This analysis has not accounted for the production of green pepper. Data on yields of green pepper under plasticulture were not available. Having data on green pepper should give a complete picture of the performance of pepper production under plasticulture. However, it is not unreasonable to expect very similar results.

2). Several dated energy coefficients have been used. Energy coefficients are subject to change with the advance in technology. The total amount of energy expended to produce a tractor is lower compared with that of ten years ago. Hence, energy coefficients should be reviewed and updated.

3). Energy requirements for a number of the inputs accounted for in this study have been estimated using the statistical analysis method, which gives less accurate results compared with that of the process analysis method.

4). Data on yield obtained commercially under sliver mulch were not available rendering the comparison between both systems less accurate.

5). Results of this research is limited to southern Quebec, i.e. results cannot be compared to that of other areas.

## 5.5 – SUGGESTIONS FOR FURTHER RESEARCH:

It would be interesting to conduct a comparison analysis for other crops that may grow with the plasticulture system. Such crops include tomatoes, lettuce, and also green pepper. It would be valuable to extend this analysis to account for the performance of other types of plastic mulch, such as black, and perforated mulches. Another interesting suggestion would be to extend the analysis over more than one year.

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# APPENDIXES

## APPENDIX 1

## MACHINERY INVESTMENT AND TECHNICAL COEFFICIENTS

| Machinery | List price ($) | Purchase Price ($) | Useful Life (h) | Annual Use (h) | Accumulated Hours Use (h) | Fuel Consumption (L/ha) |
|---|---|---|---|---|---|---|
| Tractor: John Deere 6300, 76hp, cabin | 34823.53 | 39698.82 | 4000 | 400 | 2000 | |
| Plow: John Deere 3-16 furrow plow | 4177.20 | 4762.01 | 1250 | 125 | 625 | 16.83 |
| Harrower: John Deere 12" | 6497.87 | 7407.57 | 1250 | 125 | 625 | 4.67 |
| Fertilizer: MS R1915 Spreader | 9126.44 | 10404.14 | 600 | 60 | 300 | 1.68 |
| Sprayer: John Deere 50" | 7685.42 | 8761.38 | 600 | 60 | 300 | 1.68 |
| Mulch Layer Model 2500 | 3837.91 | 4375.22 | 1250 | 125 | 625 | 33.66 |
| Planter Model 1400 | 2723.52 | 3104.82 | 600 | 60 | 300 | 58.91 |
| Cultivator | 4377.62 | 4990.49 | 1250 | 125 | 625 | 21.03 |
| Farm Truck | 480.94 | 548.27 | 1250 | 125 | 625 | |
| *TOTAL INVESTMENT ($)* | | *84052.72* | | | | |

Notes:
1) Prices are listed in $1995.
2) Machinery prices have been collected from different dealers.
3) Purchase Prices are calculated as List Price plus applicable taxes.
Applicable taxes are: 6.5% (PST) and 7% (GST), a total of 14%.
4) Annual use hours, and useful life are estimated based on manufacturer's data.
5) Accumulated hours use are estimated based on the assumption that all field machinery are five years age.
6) Fuel consumption is estimated based on manufacturer's data. Fuel consumption for each operation represents fuel used to drive the tractor through the field, and is estimated based on the following function (John Deere, 1996):
Fuel consumption (L/ha) = The tractor horse power (Hp) * 0.2 * time
Fuel consumption related to farm truck is varied based on harvest volume.
7) Farm truck is a used one. Its price is based on personal communication (Janik, 1996).

## APPENDIX 2

## REPAIRS AND MAINTENANCE COSTS

| Machinery | List Price ($) | Estimated Annual Use (hr) | Accumulated hours of Use | Useful life (hr) | Percent of Acc.hours (useful life) | Total R & M (% list price) | Total R & M ($/hr) |
|---|---|---|---|---|---|---|---|
| Tractor | 34823.53 | 400 | 2000 | 4000 | 16.67 | 8.16 | 0.71 |
| Plow | 4177.20 | 125 | 625 | 1250 | 25.00 | 19.76 | 0.66 |
| Harrower | 6497.87 | 125 | 625 | 1250 | 25.00 | 19.76 | 1.03 |
| Fertilizer | 9126.44 | 60 | 300 | 600 | 25.00 | 14.40 | 2.19 |
| Sprayer | 7685.42 | 60 | 300 | 600 | 15.00 | 7.98 | 1.02 |
| Mulch layer | 3837.91 | 125 | 625 | 1250 | 25.00 | 19.76 | 0.61 |
| Planter | 2723.52 | 60 | 300 | 600 | 25.00 | 16.31 | 0.74 |
| Cultivator | 4377.62 | 125 | 625 | 1250 | 25.00 | 19.76 | 0.69 |
| Farm truck | 480.94 | 125 | 625 | 1250 | 25.00 | 11.51 | 0.04 |

NOTES:
1) Accumulated hours of use are calculated by multiplying estimated annual use hours by the number of years the machine has been used.
2) Total R&M costs are calculated using the equation:

$$\text{Repair cost per hour} = \frac{\text{List price * total accumulated repairs percentage}}{\text{Accumulated machine's hours use}}$$

Percentages of total accumulated repairs for different machinery are estimated using the following equations (Boehlje and Eidman, 1984):

For tractor: 0.12(100*Accumulated hours/ useful life)exp 1.5

For Plow, Harrower, cultivator and mulch layer: 0.301(100*Accumulated hours/ useful life)exp 1.3

For planter: 0.180(100*Accumulated hours/ useful life)exp 1.4

For fertilizer: 0.159(100*Accumulated hours/ useful life)exp 1.4

For sprayer: 0.180(100*Accumulated hours/ useful life)exp 1.4

## APPENDIX 3

## FIXED COSTS

| Machinery | Insur.& Shelter ($/y) | Purchase Price ($) | Salvage Ratio (%) | Salvage Value ($) | Deprecation & Interest ($/y) | Insurance & Shelter ($/h) | Depreciation & Interest ($/h) | Total Fixed Cost ($/h) |
|---|---|---|---|---|---|---|---|---|
| Tractor | 595.48 | 39698.82 | 29.5 | 10272.79 | 4324.31 | 1.49 | 10.81 | 12.30 |
| Plow | 71.43 | 4762.01 | 17.7 | 739.36 | 557.90 | 0.57 | 4.46 | 5.03 |
| Harrower | 111.11 | 7407.57 | 17.7 | 1150.12 | 867.85 | 0.89 | 6.94 | 7.83 |
| Fertilizer | 156.06 | 10404.14 | 17.7 | 1615.38 | 1218.91 | 2.60 | 20.32 | 22.92 |
| Sprayer | 131.42 | 8761.38 | 16.5 | 1268.09 | 1033.79 | 2.19 | 17.23 | 19.42 |
| Mulch layer | 65.63 | 4375.22 | 17.7 | 679.31 | 512.59 | 0.53 | 4.10 | 4.63 |
| Planter | 46.57 | 3104.82 | 17.7 | 482.06 | 363.75 | 0.78 | 6.06 | 6.84 |
| Cultivator | 74.86 | 4990.49 | 17.7 | 774.84 | 584.67 | 0.60 | 4.68 | 5.28 |
| Farm truck | 8.22 | 548.27 | 0 | 0.00 | 71.00 | 0.07 | 0.57 | 0.63 |

NOTES:

1) Insurance and shelter are calculated at 1.5% of purchase price of machinery (Tayara, 1996).
2) Salvage ratio is defined as the ratio of salvage value to purchase price multiplied by 100. Ratios are adapted from Boehlje and Eidman (1984).
3) Depreciation and interest costs are calculated using the Capital Recovery method using 0.1295 as a capital recovery factor, 5% as an interest rate, and assuming a useful life of 10 years for all machinery.

## APPENDIX 4

### AGRO-CHEMICALS COSTS
### (Plasticulture System)

| Type | Quantity (kg/ha) | Price ($/kg) | Cost ($/ha) |
|---|---|---|---|
| **Fertilizer** | | | |
| Ammonium Nitrate | 205.71 | 0.60 | 124.19 |
| Triple Superphosphate | 292.13 | 0.45 | 132.33 |
| Sulphate of potash | 218.75 | 0.88 | 191.83 |
| **Subtotal** | | | 448.35 |
| **Pesticides** | | | |
| Kokcide | 4.50 | 9.62 | 43.31 |
| Zineb | 8.80 | 11.08 | 97.51 |
| Malathion | 0.50 | 12.03 | 6.01 |
| Pirimor | 0.50 | 92.39 | 46.19 |
| Ambush | 0.28 | 278.13 | 77.88 |
| Thiodan | 2.20 | 23.10 | 50.81 |
| **Subtotal** | | | 321.72 |
| **Herbicides** | | | |
| **Treflan** | 1.70 | 94.28 | 160.28 |
| **Total Cost ($/ha)** | | | 930.35 |

**NOTES:**
**1) Prices are from Plant-Prod Quebec (1996).**
**2) Prices are adjusted in $1995.**

## APPENDIX 5

### TOTAL COST OF AGRO-CHEMICALS
### (Conventional System)

| Type | Quantity (kg/ha) | Price ($/kg) | Cost ($/ha) |
|---|---|---|---|
| **Fertilizers** | | | |
| Ammonium Nitrate | 400.00 | 0.60 | 241.49 |
| Triple Superphosphate | 292.13 | 0.45 | 132.32 |
| Sulphate of potash | 218.75 | 0.88 | 191.83 |
| *Subtotal* | | | 565.64 |
| **Pesticides** | | | |
| Kokcide | 4.50 | 9.62 | 43.31 |
| Zineb | 8.80 | 11.08 | 97.51 |
| Malathion | 1.00 | 12.03 | 12.03 |
| Pirimor | 1.00 | 92.39 | 92.39 |
| Ambush | 0.28 | 278.13 | 77.88 |
| Thiodan | 2.20 | 23.10 | 50.81 |
| *Subtotal* | | | 373.93 |
| **Herbicides** | | | |
| Treflan | 0.70 | 94.28 | 66.00 |
| *Total Cost($/ha)* | | | 1005.57 |

**NOTES:**
**1) Prices are from Plant-Prod Quebec, 1996**
**2) Prices are in $1995.**

## APPENDIX 6

## OPERATING COSTS
(Plasticulture System)

| Operation and Machinery | Productivity (hr/ha) | Depr.& Interest ($/ha) | Total Insu. & Shelter ($/ha) | Total Fixed Costs ($/ha) | Total R & M ($/ha) | Fuel ($/ha) | Lubricant ($/ha) | Labour (($/ha) |
|---|---|---|---|---|---|---|---|---|
| Plowing | 1.0 | 15.27 | 2.06 | 17.33 | 1.37 | 7.89 | 1.18 | 8.08 |
| Harrowing | 0.27 | 4.93 | 0.66 | 5.59 | 0.48 | 2.19 | 0.33 | 2.24 |
| Fertilizing | 0.1 | 3.11 | 0.41 | 3.52 | 0.29 | 0.79 | 0.12 | 0.81 |
| Spraying | 1.4 | 39.26 | 5.15 | 44.41 | 2.42 | 10.65 | 1.60 | 11.31 |
| Mulch laying | 2.0 | 29.82 | 4.03 | 33.85 | 2.63 | 15.77 | 2.37 | 28.52 |
| Planting | 3.5 | 59.05 | 7.93 | 66.98 | 5.08 | 27.60 | 4.14 | 93.17 |
| Harvesting | 216.0 | | | | | | | 1334.86 |
| Loading | 11.1 | 126.29 | 17.25 | 143.54 | 8.33 | 87.54 | 13.13 | 379.23 |
| Hauling to market | 19.6 | | | | | | | 123.34 |
| Mulch removing | 8.0 | | | | | | | 49.44 |
| Total | | 277.44 | 37.48 | 315.22 | 20.61 | 152.43 | 22.86 | 2031.02 |

NOTES:
1) Cost per hectare for each operation is derived by multiplying the productivity of the specific operation times the corresponding hourly cost rate estimated in Appendixes 2 and 3.
2) Prices are in expressed in $1995.
3) Fuel cost is estimated based on a diesel price of 0.50$/L (Yelle, 1996 and Bleho, 1996).
4) Lubricant cost is assumed to be 15% of fuel cost (Boehlje and Eidman, 1984).

## APPENDIX 7

### OPERATIONS COSTS (Conventional System)

| Operation & Machinery | Productivity (hr/ha) | Depression & Interest ($/ha) | Insurance & Shelter ($/ha) | Total Fixed Costs ($/ha) | Total R&M ($/ha) | Fuel ($/ha) | Lubricant ($/ha) | Labour (($/ha) |
|---|---|---|---|---|---|---|---|---|
| Tractor | | | | | | | | |
| Plowing | 1.0 | 15.27 | 2.06 | 17.33 | 1.37 | 7.89 | 1.18 | 8.08 |
| Harrowing | 0.27 | 4.93 | 0.66 | 5.59 | 0.48 | 2.19 | 0.33 | 2.24 |
| Fertilizing | 0.1 | 3.11 | 0.41 | 3.52 | 0.29 | 0.79 | 0.12 | 0.81 |
| Spraying | 1.5 | 42.06 | 5.52 | 47.58 | 2.59 | 11.84 | 1.78 | 12.12 |
| Drip lines Laying | 3.0 | | | | | | | 20.51 |
| Planting | 3.5 | 59.05 | 7.93 | 66.99 | 5.08 | 27.60 | 4.14 | 93.17 |
| Cultivating | 3.75 | 58.08 | 7.83 | 65.91 | 5.26 | 29.57 | 4.44 | 30.31 |
| Hand hoeing | 52.5 | | | | | | | 324.45 |
| Harvesting | 144.0 | | | | | | | 889.91 |
| Loading | 9.0 | 102.40 | 14.00 | 116.40 | 6.79 | 70.98 | 10.65 | 295.21 |
| Hauling to market | 36.0 | | | | | | | 61.07 |
| *Total* | | *284.91* | *38.42* | *323.33* | *21.86* | *150.86* | *22.63* | *1737.87* |

NOTES:

1) Cost per hectare for each operation is derived by multiplying the productivity of the specific operation times the corresponding hourly cost rate estimated in Appendixes 2 and 3.
2) Prices are in expressed in $1995.
3) Fuel cost is estimated based on a diesel price of 0.50$/L (Yelle, 1996 and Bleho, 1996).
4) Lubricant cost is assumed to be 15% of fuel cost (Boehlje and Eidman, 1984).

## APPENDIX 8

### SUMMARY: Variable and Fixed Costs
### Plasticulture System

| Operation | Fixed costs (Tractor) ($/ha) | Fixed costs (machine) ($/ha) | Total fixed Cost ($/ha) | Total Variabl Cost ($/ha) | Total Cost ($/ha) |
|---|---|---|---|---|---|
| Plowing | 12.30 | 5.03 | 17.33 | 18.52 | 35.85 |
| Harrowing | 3.42 | 2.18 | 5.59 | 5.24 | 10.83 |
| Fertilizing | 1.23 | 2.29 | 3.52 | 2.01 | 5.53 |
| Spraying | 17.22 | 27.19 | 44.41 | 25.98 | 70.39 |
| Mulch Laying | 24.60 | 9.25 | 33.85 | 49.30 | 83.14 |
| Planting | 43.04 | 23.94 | 66.98 | 129.99 | 196.97 |
| Harvesting | | | | 1334.86 | 1334.86 |
| Loading in Field | 136.51 | 7.04 | 143.54 | 488.24 | 631.78 |
| Hauling to market | | | | 123.35 | 123.35 |
| Mulch removing | | | | 49.44 | 49.44 |
| Total cost ($/ha) | 238.31 | 76.91 | 315.22 | 2226.93 | 2542.15 |

NOTES:
1) Fixed costs for the tractor are calculated by multiplying productivity of the specific operation times the hourly fixed cost for the tractor (reported in Appendix 3).
2) Fixed costs for attached machinery are estimated by multiplying productivity of the specific operation times the hourly fixed cost for the specific machinery (reported in Appendix 3).
3) Total fixed costs is the summation of fixed cost (tractor) and fixed cost (machine).
4) Variable cost includes labour, fuel and lubricants, and repairs and maintenance (tractor and machinery
5) Total cost is the sum of variable costs and fixed costs.

## APPENDIX 9

### SUMMARY: VARIABLE AND FIXED COSTS
### ( Conventional System)

| Operation | Fixed Costs (Tractor) ($/ha) | Fixed Costs (Machine) ($/ha) | Total Fixed Cost ($/ha) | Total Var. Cost ($/ha) | Total Costs ($/ha) |
|---|---|---|---|---|---|
| Plowing | 12.30 | 5.03 | 17.33 | 18.52 | 35.85 |
| Harrowing | 3.42 | 2.18 | 5.59 | 5.24 | 10.83 |
| Fertilizing | 1.23 | 2.29 | 3.52 | 2.01 | 5.53 |
| Spraying | 18.45 | 29.13 | 47.58 | 28.33 | 75.91 |
| Drip lines laying | | | | 20.51 | 20.51 |
| Planting | 43.05 | 23.94 | 66.98 | 129.99 | 196.97 |
| Cultivating | 46.12 | 19.79 | 65.91 | 69.57 | 135.49 |
| Hand hoeing | | | | 324.45 | 324.45 |
| Harvesting | | | | 889.91 | 889.91 |
| Loading in Field | 110.70 | 5.70 | 116.40 | 383.63 | 500.03 |
| Hauling to market | | | | 61.68 | 61.68 |
| ***Total costs ($/ha)*** | ***235.27*** | ***88.06*** | ***323.33*** | ***1933.84*** | ***2257.17*** |

NOTES:

1) Fixed costs for the tractor are calculated by multiplying productivity of the specific operation times the hourly fixed cost for the tractor (shown in Appendix 3).
2) Fixed costs for attached machinery are estimated by multiplying productivity of the specific operation times the hourly fixed cost for the specific machinery (shown in Appendix 3).
3) Total fixed costs is the summation of fixed cost (tractor) and fixed cost (machine).
4) Variable cost includes labour, fuel and lubricants, and repairs and maintenance (tractor and machinery
5) Total cost is the sum of variable costs and fixed costs.

## APPENDIX 10

## ENERGY REQUIREMENTS FOR MACHINERY

| Machine | Mass (kg) | Manuf. Energy (MJ) | Transport Energy (MJ) | Repair Energy (MJ) | TER (MJ) | Total Energy per hour (MJ/h) | Life time (h) |
|---|---|---|---|---|---|---|---|
| Tractor: John Deere 6300, 76hp, cabin | 2800.00 | 242956.00 | 24640.00 | 119048.44 | 386644.44 | 32.22 | 12000.00 |
| Plower: John Deere 3-16 furrow plow | 465.00 | 40348.05 | 4092.00 | 31874.96 | 76315.01 | 30.53 | 2500.00 |
| Harrower: John Deere 12" | 1466.67 | 127262.67 | 12906.67 | 64903.96 | 205073.29 | 82.03 | 2500.00 |
| Sprayer: John Deere 50" | 1111.11 | 96411.11 | 9777.78 | 35672.11 | 141861.00 | 118.22 | 1200.00 |
| Fertilizer: MS R1915 Spreader | 888.89 | 77128.89 | 7822.22 | 28537.69 | 113488.80 | 56.74 | 2000.00 |
| Mulch Layer Model 2500 | 533.33 | 46277.33 | 4693.33 | 25452.53 | 76423.20 | 30.57 | 2500.00 |
| Tunnel Layer Model 95 | 600.00 | 52062.00 | 5280.00 | 28634.10 | 85976.10 | 34.39 | 2500.00 |
| Planter Model 1400 | 266.67 | 23138.67 | 2346.67 | 9949.63 | 35434.96 | 29.53 | 1200.00 |
| Row Cultivator | 1111.11 | 96411.11 | 9777.78 | 55918.44 | 162107.33 | 64.84 | 2500.00 |
| Farm Truck | 177.78 | 15425.78 | 1564.44 | 8484.18 | 25474.40 | 10.19 | 2500.00 |

NOTES:

1) Manufacturing energy = machine mass * 86.77, where 86.77 (MJ/kg) is the manufacturing coefficient (Bowers, 1992).
2) Transport energy = machine mass * 8.8, where 8.8 (MJ/kg) is the transport coefficient (Bowers, 1992).
3) Repair energy = Manufacturing energy * Ratio. This ratio varied form one machine to another. Different ratios are estimated by Fluck (1985).
4) Total energy requirements (TER) = Manufacturing energy + Transport energy + Repair energy.
5) Total energy requirement per hour = Total energy requirements / total life time (hours).

## APPENDIX 11

### ENERGY REQUIREMENTS FOR OPERATIONS WITH PLASTICULTURE SYSTEM

| Operations & Machinery | Times Over | Productivity (h/ha) | Energy.Req. Mach.+ Trac. (MJ/h) | TER Machinery (MJ/ha) | Fuel (L/ha) | TER Fuel (MJ/ha) | Labour (h/ha) | TER for Labour (MJ/ha) |
|---|---|---|---|---|---|---|---|---|
| Tractor | | | | | | | | |
| Plowing | 1 | 1.00 | 62.75 | 62.75 | 16.83 | 804.14 | 1.00 | 74.25 |
| Harrowing | 1 | 0.27 | 114.25 | 31.74 | 4.67 | 223.37 | 0.27 | 20.05 |
| Spraying | 14 | 0.10 | 150.44 | 210.61 | 23.56 | 1125.79 | 1.40 | 103.95 |
| Fertilizing | 1 | 0.10 | 88.96 | 8.90 | 1.68 | 80.41 | 0.10 | 7.43 |
| Mulching | 1 | 2.00 | 62.79 | 125.58 | 33.66 | 1608.27 | 4.00 | 297.00 |
| Planting | 1 | 3.50 | 61.75 | 216.12 | 58.90 | 2814.48 | 14.00 | 1039.50 |
| Harvesting | # | 216.00 | | | | | 216.00 | 16038.00 |
| Loading Harvest | # | 11.10 | 42.41 | 470.75 | 186.81 | 8925.93 | 57.95 | 4302.79 |
| Hauling to market | # | 19.60 | | | | | 19.60 | 1455.30 |
| Mulch removing | 1 | 8.00 | | | | | 8.00 | 594.00 |
| *Total* | | | | 1126.44 | 326.128 | 15582.40 | 322.32 | 23932.26 |

NOTES:

1) Energy.Req.(MJ/h) is the summation of gross energy requirements for both tractor and attached implement, on hourly basis, estimated in Appendix 10.
2) TER for machinery(MJ/ha) = Energy requirements (MJ/h) * Productivity(h/ha).
3) Fuel consumption are manufacturer's data (John Deere, 1996).
4) TER for fuel (MJ/ha) = Fuel(L/ha) * 47.78 (MJ/L). Where 47.78 is the gross energy requirement for diesel fuel (Cervinka, 1980).
5) TER for labour (MJ/ha) = Labour(h/ha) * 594 MJ/d. (Fluck, 1992)

#: As required.

APPENDIX 12

TOTAL ENERGY REQUIREMENTS FOR OPERATIONS IN CONVENTIONAL SYSTEM

| Operations & Machinery | Times over | Productivity (h/ha) | Energy.Req. Mach.+ Trac. (MJ/h) | TER Machinery (MJ/ha) | Fuel (L/ha) | TER Fuel (MJ/ha) | Labour (h/ha) | TER for Labour (MJ/ha) |
|---|---|---|---|---|---|---|---|---|
| Tractor | | | | | | | | |
| Plowing | 1 | 1.00 | 62.75 | 62.75 | 16.83 | 804.14 | 1.00 | 74.25 |
| Harrowing | 1 | 0.27 | 114.25 | 31.74 | 4.67 | 223.37 | 0.27 | 20.05 |
| Spraying | 15 | 0.10 | 150.44 | 225.66 | 25.25 | 1206.21 | 1.50 | 111.38 |
| Fertilizing | 1 | 0.10 | 88.96 | 8.90 | 1.68 | 80.41 | 0.10 | 7.43 |
| Planting | 1 | 3.50 | 61.75 | 216.12 | 58.90 | 2814.48 | 14.00 | 1039.50 |
| Drip lines laying | 1 | 3.00 | | | | | 3.00 | 222.75 |
| Row Cultivating | 3 | 1.25 | 97.06 | 363.99 | 63.11 | 3015.52 | 3.75 | 278.44 |
| Hand hoeing | # | 52.50 | | | | | 52.50 | 3898.13 |
| Harvesting | # | 144.00 | | | | | 144.00 | 10692.00 |
| Loading | # | 9.00 | 42.41 | 381.69 | 151.47 | 7237.24 | 45.00 | 3341.25 |
| Hauling to market | # | 9.98 | | | | | 9.98 | 741.02 |
| | | | | | | | | |
| ***Total Energy (MJ)*** | | | | ***1290.83*** | ***321.92*** | ***15381.36*** | ***275.10*** | ***20426.18*** |

NOTES:

1) Energy.Req.(MJ/h) is the summation of gross energy requirements for both tractor and attached implement, on hourly basis, estimated in Appendix 10.
2) TER for machinery(MJ/ha) = Energy requirements (MJ/h) * Productivity(h/ha).
3) Fuel consumption are manufacturer's data (John Deere, 1996).
4) TER for fuel (MJ/ha) = Fuel(L/ha) * 47.78 (MJ/L). Where 47.78 is the gross energy requirement for diesel fuel (Cervinka, 1980).
5) TER for labour (MJ/ha) = Labour(h/ha) * 594 MJ/d. (Fluck, 1992)

# : As required.

## APPENDIX 13

### SUMMARY : TOTAL ENERGY REQUIREMENTS FOR FIELD OPERATIONS
### (Plasticulture System)

| Operation | Ene.Req. Tractor (MJ/ha) | Ene.Req. Machine (MJ/ha) | TER Machinery (MJ/ha) | TER Fuel (MJ/ha) | TER Requirements (MJ/ha) | TER for Labour (MJ/ha) | TER Incl.labour (MJ/ha) |
|---|---|---|---|---|---|---|---|
| Plowing | 32.22 | 30.53 | 62.75 | 804.14 | 866.88 | 74.25 | 941.13 |
| Harrowing | 8.95 | 22.79 | 31.74 | 223.37 | 255.11 | 20.05 | 275.15 |
| Spraying | 48.33 | 162.28 | 210.61 | 1125.79 | 1336.40 | 103.95 | 1440.35 |
| Fertilizing | 3.22 | 5.67 | 8.90 | 80.41 | 89.31 | 7.43 | 96.74 |
| Mulching | 64.44 | 61.14 | 125.58 | 1608.27 | 1733.85 | 297.00 | 2030.85 |
| Planting | 112.77 | 103.35 | 216.12 | 2814.48 | 3030.60 | 1039.50 | 4070.10 |
| Harvesting | | | | | | 16038.00 | 16038.00 |
| Loading Harvest | 357.64 | 113.11 | 470.75 | 8925.93 | 9396.68 | 4302.79 | 13699.46 |
| Hauling to market | | | | | | 1455.30 | 1455.30 |
| Mulch removing | | | | | | 594.00 | 594.00 |
| ***Total Energy Req.(MJ/ha*** | ***627.57*** | ***498.87*** | ***1126.44*** | ***15582.40*** | ***16708.83*** | ***23932.26*** | ***40641.09*** |

NOTES:

1) Ene.Req.for tractor (MJ/ha) = Energy requirement for tractor (MJ/h) * productivity (h/ha) of the specific operation.
2) Ene.Req.for machine (MJ/ha) = Energy requirement for machine (MJ/h) * productivity(h/ha) of the specific operation.
3) TER for machinery (MJ/ha) = Energy Requirements for machine (MJ/ha) + Energy requirement for machine (MJ/ha).
4) TER for specific operation (MJ/ha) = Energy requirements for machinery (MJ/ha) + TER for Energy of fuel used in this operation (MJ/ha).
5) TER for labour (MJ/ha)= labour requirements for operation (h/ha) * 594 (MJ/d). where 594 MJ is the energy value of human day work, 8 hours (Fluck, 1992).

APPENDIX 14

SUMMARY : TOTAL ENERGY REQUIREMENTS
FOR FIELD OPERATION (CONVENTIONAL SYSTEM)

| Operation | Ene.Req. Tractor (MJ/ha) | Ene.Req. Machine (MJ/ha) | TER Machinery (MJ/ha) | TER Fuel (MJ/ha) | TER Requirements (MJ/ha) | TER for Labour (MJ/ha) | TER Incl.labour (MJ/ha) |
|---|---|---|---|---|---|---|---|
| Plowing | 32.22 | 30.53 | 62.75 | 804.14 | 866.88 | 74.25 | 941.13 |
| Harrowing | 8.95 | 22.79 | 31.74 | 223.37 | 255.11 | 20.05 | 275.15 |
| Spraying | 48.33 | 177.33 | 225.66 | 1206.21 | 1431.86 | 111.38 | 1543.24 |
| Fertilizing | 3.22 | 5.67 | 8.90 | 80.41 | 89.31 | 7.43 | 96.74 |
| Planting | 112.77 | 103.35 | 216.12 | 2814.48 | 3030.60 | 1039.50 | 4070.10 |
| Drip Lines laying | | | | | | 222.75 | 222.75 |
| Row Cultivating | 120.83 | 243.16 | 363.99 | 3015.52 | 3379.50 | 278.44 | 3657.94 |
| Hand hoeing | | | | | | 3898.13 | 3898.13 |
| Harvesting | | | | | | 10692.00 | 10692.00 |
| Loading Harvest | 289.98 | 91.71 | 381.69 | 7237.24 | 7618.93 | 3341.25 | 10960.18 |
| Hauling to market | | | | | | 741.02 | 741.02 |
| ***Total Energy Req.(MJ/ha)*** | ***616.30*** | ***674.53*** | ***1290.83*** | ***15381.36*** | ***16672.19*** | ***20426.18*** | ***37098.37*** |

NOTES:

1) Ene.Req.for tractor (MJ/ha) = Energy requirement for tractor (MJ/h) * productivity (h/ha) of the specific operation.
2) Ene.Req.for machine (MJ/ha) = Energy requirement for machine (MJ/h) * productivity(h/ha) of the specific operation.
3) TER for machinery (MJ/ha) = Energy Requirements for machine (MJ/ha) + Energy requirement for machine (MJ/ha).
4) TER for specific operation (MJ/ha) = Energy requirements for machinery (MJ/ha) + TER for Energy of fuel used in this operation (MJ/ha).
5) TER for labour (MJ/ha)= labour requirements for operation (h/ha) * 594 (MJ/d). where 594 MJ is the energy value of human day (Fluck, 1992).

## APPENDIX 15

## ENERGY REQUIREMENTS FOR FERTILIZERS AND PESTICIDES (PLASTICULTURE SYSTEM)

| Type | Quantity (kg/ha) | Energy Coefficient (MJ/kg) | Energy Req. (MJ) |
|---|---|---|---|
| Fertilizers | | | |
| N | 72 | 78.1 | 5623.2 |
| P2O5 | 130 | 17.4 | 2262.0 |
| k2O | 105 | 13.7 | 1438.5 |
| Subtotal | | | 9323.7 |
| | | | |
| Pesticides | | | |
| Kokcide | 4.5 | 93 | 418.5 |
| Zineb | 8.8 | 93 | 818.4 |
| Malathion | 0.5 | 229 | 114.5 |
| primor | 0.5 | 153 | 76.5 |
| Ambush | 0.28 | 153 | 42.8 |
| Thiodan | 2.2 | 153 | 336.6 |
| Subtotal | | | 1807.3 |
| | | | |
| Herbicides | | | |
| Treflan | 1.7 | 150 | 255 |
| | | | |
| *Total Energy* | | | *11386.0* |

NOTES:
1) Energy coefficients are from Green (1987).

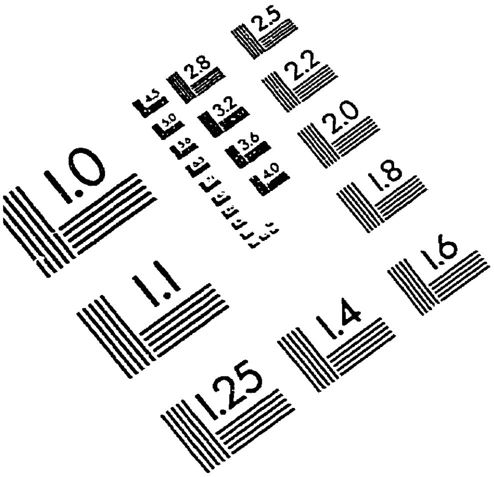
## APPENDIX 16

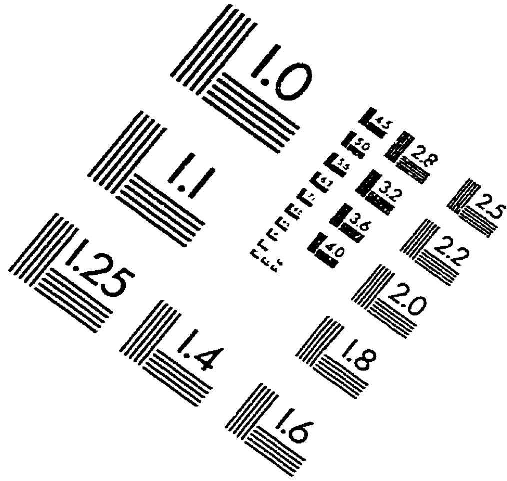
### ENERGY REQUIREMENTS FOR FERTILIZERS AND PESTICIDES (CONVENTIONAL SYSTEM)

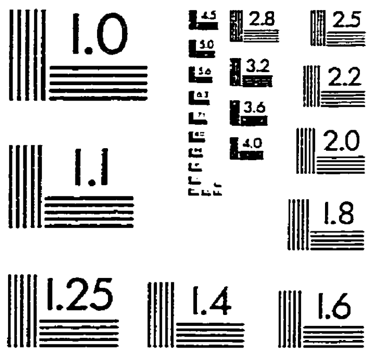
| Type | Quantity (kg/ha) | Energy Coefficient (MJ/kg) | Energy Req. (MJ/ha) |
|---|---|---|---|
| Fertilizers | | | |
| N | 130 | 78.1 | 10153 |
| P2O5 | 130 | 17.4 | 2262 |
| k2O | 105 | 13.7 | 1438.5 |
| Subtotal | | | 13853.5 |
| | | | |
| Pesticides | | | |
| Kokcide | 4.5 | 93 | 418.5 |
| Zineb | 8.8 | 93 | 818.4 |
| Malathion | 1.0 | 229 | 229.0 |
| primor | 1.0 | 153 | 153.0 |
| Ambush | 0.28 | 153 | 42.8 |
| Thiodan | 2.2 | 153 | 336.6 |
| Subtotal | | | 1998.3 |
| | | | |
| Herbicides | | | |
| Treflan | 0.6 | 150 | 90.0 |
| | | | |
| *Total Energy* | | | *15941.8* |

NOTES:
1) Energy coefficients are from Green (1987).

# IMAGE EVALUATION TEST TARGET (QA-3)

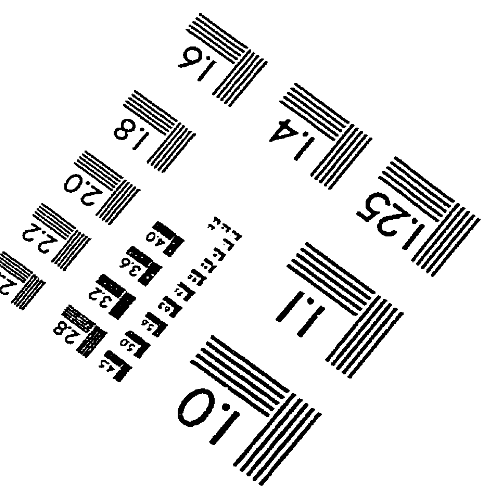


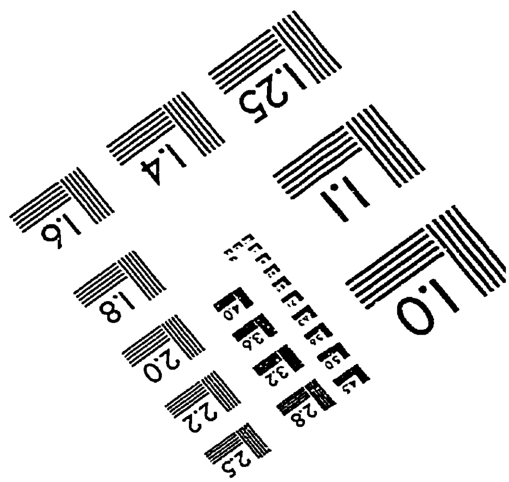




150mm

6"





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