

Energy Balance in Modern Agroecosystems; Why and How?

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Abstract

Improvements in energy use efficiency are keys for sustainable energy management. Increasing the use of energy inputs in agro systems led to numerous environmental problems like greenhouse gas (GHG) emissions, loss of biodiversity, high consumption of non-renewable energy resources and pollution of the environment. Based on the total energy equivalents of the inputs and output in agroecosystems, the energy ratio (energy use efficiency), energy productivity, net energy and specific energy are calculated for energy analysis. To increase energy efficiency, energy input should be reduced without affecting the crop yield level or increase the production yield. Furthermore, in modern agroecosystems, burning fossil fuels results in the emission of CO₂, nitrous oxide (N₂O) and methane (CH₄) that act as barriers to thermal radiation and prevent it from leaving the earth's atmosphere. In general, agricultural GHG emissions account for 10-12% of all anthropogenic GHG emissions. According to this, the identification of crop production methods that maximize energy efficiency and minimize greenhouse gas emissions is vital in agro systems.

Keywords: Agro ecosystem; Energy analysis; GHG emissions; Renewable energy

Introduction

Energy management is an important issue in terms of efficient, sustainable and economic use of energy and it is one of the important elements in modern agroecosystems as it heavily depends on fossil and other energy resources. Energy consumption in agriculture has been increasing in response to the limited supply of arable land, increasing population, technological changes, and a desire for higher standards of living [1,2]. The relation between agriculture and energy use is very close. Irregular use of inputs in agriculture to access the higher amount of yield will along strike rapidly decreasing of natural resources, considerably increasing the amount of contaminants in the environment and enhancement concentration of greenhouse gases [3]. Energy sources used in agriculture consist of two main groups: natural and auxiliary. Natural energy is essential for plant growth and includes solar energy and various forms of chemical energy stored biologically in the soil [4]. To support natural agricultural production processes, auxiliary energy inputs are used by humans so that a given area of land or water produces more than it would do otherwise [5]. Nowadays, modern agroecosystems have become very energy intensive. However, there is a great need to balance the use and availability of energy, especially in the field operations and inputs.

Discussion

Input-output analysis

The energy input-output analysis is usually used to evaluate the efficiency and environmental impacts of agroecosystems. Researchers have performed detailed energy balances for different crops and farm management systems all over the world in attempts to assess the efficiency and environmental impact of production systems [6]. The energetic efficiency of the agricultural system has been evaluated by the energy ratio between output and input. Human labor, machinery, fuel, fertilizer, chemicals, water for irrigation and seed amounts and output yield values of crops have been used to estimate the energy ratio (energy use efficiency). Energy equivalents are used for estimate the input and output energy. Based on the total energy equivalents of the inputs and output, the energy ratio, energy productivity, net energy and specific energy are calculated using following equations (1-4) [3-7]:

$$\text{Net energy} = \text{Energy Output} \left(\text{MJ ha}^{-1} \right) - \text{Energy Input} \left(\text{MJ ha}^{-1} \right) \dots\dots(1)$$

$$\text{Energy productivity} = \frac{\text{Output} \left(\text{kg ha}^{-1} \right)}{\text{Energy Input} \left(\text{MJ ha}^{-1} \right)} \dots\dots(2)$$

$$\text{Specific energy} = \frac{\text{Energy Input} \left(\text{MJ ha}^{-1} \right)}{\text{Grain output} \left(\text{kg ha}^{-1} \right)} \dots\dots(3)$$

$$\text{Energy use efficiency} = \frac{\text{Energy Output} \left(\text{MJ ha}^{-1} \right)}{\text{Energy Input} \left(\text{MJ ha}^{-1} \right)} \dots\dots(4)$$

The direct energy input is the energy consumption of physical energy resources for physical work during field operations. Field operations consume significant amounts of energy in agricultural production, with most being fuel usage [8]. The input energy is divided into direct, indirect, renewable and non-renewable forms. Indirect energy included energy embodied in seed, fertilizers, chemicals and machinery while direct energy covered human labor and diesel fuel are used in the crop production.

Improvements in energy use efficiency are keys for sustainable energy management. To increase energy efficiency, energy input should be reduced without affecting the crop yield level or increase the production yield [9]. For example balancing N fertilization with actual crop requirements and adopting minimum tillage are the most efficient techniques to reduce energy inputs [10]. Qiao et al. [11] suggested that in rainfed agricultural systems (maize–soybean–wheat rotation) in Northeastern China, the application of manure supplemented with NPK can simultaneously achieve higher grain yield and lower global warming potential compared to mineral fertilizers alone. Furthermore, integrated pest control techniques should be put in practice to improve pesticide use. It can be expected that all these measurements would be useful not only for reducing negative effects to environment, human health, maintaining sustainability and decreasing production costs, but also for providing higher energy use efficiency [12].

There are both financial and environmental reasons to improve energy use efficiency in agricultural systems. Increasing the use of energy inputs in cropping systems led to numerous environmental problems like GHG emissions, loss of biodiversity, high consumption of non-renewable energy resources and pollution of the environment [10-13]. From an environmental viewpoint, energy use in agriculture is associated with carbon dioxide (CO₂) emission which has serious implications for climate change. From a financial viewpoint, energy generally cost money [14]. Analysis of energy consumption for the rice crop in three provinces of Iran showed that energy use efficiency was low and this index varied from 1.39 to 1.67. It is possible to conclude that the energy ratio can be increased by raising the crop yield and/or by decreasing energy input consumption. The results of this study confirmed the importance of diesel fuel and chemical fertilizer consumption on total energy input in these regions. It seems to be possible to reduce energy use, especially fuel and fertilizer, by using better management and more efficient methods [15].

One of the main reasons for high consumption of diesel fuel is a temporal depreciation of machinery. In order to improve the energy consumption as well as reduction of diesel fuel in all cropping systems, it is powerfully suggested that the machinery's efficiency is raised with new machineries and equipments such as tractor, tiller and irrigation pumps [16]. Mousavi-Awal et al. [17].suggested that for improving energy efficiency in Iran, the farmers should be educated with regard to the optimal use of inputs such as fertilizers, chemicals and irrigation water as well as technologies. In addition, local agricultural institutes have an important role to inform the farmers with respect to more efficient use of energy resources and providing more sustainable agricultural production systems in the region. Connor et al. [18] believe that shortage of energy for agriculture is not a major issue in the foreseeable future, because agriculture uses only a small portion (3-5%) of the total energy consumed in developed countries and less in the world as a whole, but rising prices for energy will bring conservation in all of sectors as well as in agriculture.

Significant gains in energy efficiency were a rose in agriculture following the phenomenal increase in energy prices in the 1970s [18]. Greater use of diesel motors, larger tractors, using conservation tillage methods and optimized fertilizer use efficiency were the main causes. Higher yields in line with considerable reduction in embodied energy of labor through greater labor productivity were the main reasons for increased energy efficiency, but it seems that small-scale farming systems could enrich more from conservation tillage methods, especially if further improvements could be achieved to enhance these conservative methods feasibility. Indigenous knowledge-based technologies, especially investment on site-specific machinery could help farmers to match their activities with proper facilities and this could in turn help farmers to reduce diesel fuel consumption in parallel with more conservative farming [15].

Renewable and non-renewable energies

For the growth and development, energy demand in agriculture can be divided into renewable and nonrenewable energies [19]. Renewable energy consists of human labor, water and seed, whereas non-renewable energy includes diesel fuel, fertilizers, chemical, machinery and electricity [15]. Several researchers have demonstrated that the ratio in non-renewable energy is higher than that in renewable energy [3,7,8,12,15,20,21]. The energy in the agriculture sector can be used for providing extensively mechanical energy, heating and lighting, drying and cleaning by direct and indirect. High inputs of diesel fuel and other non-renewable energy sources based on fossil fuel resource would result in more emissions of carbon dioxide, a major greenhouse gas contributing to global warming with extensive impacts on environment [16].

The usage of mechanical energy is more preferred than others and it leads to high consumption of petroleum to obtain mechanical energy. On the other hand, electricity, natural gas and

other sources, such as wind, solar and biomass within renewable energy are less compared to petroleum for providing mechanical energy. Mostly, mechanical energy is needed for agricultural activities, such as land preparation, threshing, harvest, transportation, freight, irrigation, cultivation and milking [22]. Hopper [23] for example, estimated that Canadian prairie agriculture required about 4.5 MJ of non-renewable energy to produce 1 kg of wheat in 1981; but this indicator varies with the cropping system and management practices being used. In Italy, it has been estimated that the energy consumption in agriculture amounts to around 0.42 - 109 GJ year⁻¹, of which 55% is related to arable crops [24]. To approach to sustainable development, our viewpoint on the assessment of cropping patterns should have a tendency to those inputs which will not affect future generation's welfare and income. It is undeniable that lack of renewable inputs will force us to find alternative energy inputs. This is not the case pending when we could achieve and provide these sources throughout the world. Input application optimization, especially in the agriculture section could be considered as a hopeful case to direct our world in a safe and healthy atmosphere.

Greenhouse gases emissions

Nowadays, Greenhouse gases (GHG) emissions are one of the most important issues. GHG emissions are determined and expressed in CO₂ equivalent. GHG emission values from inputs per hectare are calculated using CO₂ emissions coefficient of agricultural inputs. The amount of produced CO₂ is also calculated by multiplying the input application rate (diesel fuel, chemical fertilizers, pesticides, and machinery) by its corresponding emission coefficient. [25-28]. Burning fossil fuels results in the emission of CO₂, nitrous oxide (N₂O) and methane (CH₄) that act as barriers to thermal radiation and prevent it from leaving the earth's atmosphere [29]. Agricultural GHG emissions account for 10-12% of all anthropogenic GHG emissions. So, use of different forms of energy and its negative effects are indivisible [25].

Reducing the energy derived from fossil fuels within agricultural systems has important implications for decreasing atmospheric emissions of greenhouse gases, thus assisting the arrest of global warming. The identification of crop production methods that maximize energy efficiency and minimize greenhouse gas emissions is vital [30]. In fact, lower fossil fuel inputs for crop management can determine substantial and long-term GHG emission reductions [31]. Wang et al. [32] reported that reduced inorganic N fertilizer followed by no-tillage would be advantageous for mitigating global warming without decreasing rice-wheat annual rotation crop yields in china. It is explained that in most previous studies the kind of irrigation system (sprinkler or flooding) effects energy consumption and GHG emissions were not considered and the same type of system are intended for different scenarios with different tillage systems. Zhang et al. [33] studied on GHG emissions from rice nursery in China. In this study, CH₄ and N₂O fluxes were determined from different nurseries under major rice cropping systems. Results

showed that flooded nursery and moist nursery decreased total CH₄ emissions by 74.2%, 72.1% and 49.6% under the rice-upland rotation cropping system, and the double rice cropping system for the early rice and the late rice, respectively. Generally, three steps are required for successful and efficient reduction of GHG emissions from agricultural production: (1) identification of the most highly polluting farms in terms of GHG, (2) determination of appropriate mitigation options for these farms, and (3) selection of options according to cost effectiveness [34].

Conclusion

The energetic efficiency of the agricultural system has been evaluated by the energy ratio between output and input. It seems to be possible to reduce energy consumption by better management and more efficient methods in the world. This paper suggested and recommend that the consumption of chemical fertilizers, chemical pesticides and diesel fuels is scientifically managed in modern agroecosystems, so that they can be effectively used, resulting in a reduction of soil and environment population, a possible decrease in energy input and a financial saving. In fact, lower chemical inputs for crop management can determine substantial and long-term GHG emission reductions. Ecological intensification is one of the most promising strategies to provide food for foreseen population in the future; therefore, sustainable intensification is tightly dependent on our knowledge of energy consumption state of agroecosystems to provide feasible and reasonable methods for confronting against future food challenges.

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