Sensitivity analysis of agrochemical energy inputs and their environmental impacts in rapeseed production

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Abstract:
Agrochemicals, especially fertilizers, are the key energetic inputs in rapeseed production in Iran. In this study the relationship between agrochemicals energy inputs and rapeseed yield was investigated and the sensitivity of energy inputs on output level was analyzed using the Marginal Physical Productivity (MPP) method and partial regression coefficients of the Cobb-Douglas production function. Also, the environmental impacts of usage agrochemical energy inputs had investigated. Data were collected from 130 randomly selected rapeseed farms in Golestan province of Iran. The results of regression model estimation showed that nitrogen, herbicides, fungicides and insecticides energy inputs had the significant impacts on yield; while the impacts of phosphate, potassium and sulfur were not significant. Moreover, the herbicides, insecticides and potassium energy inputs were negatively contributed to yield; indicating that rapeseed producers have applied an excess use of these inputs, resulting in an inverse effect on yield as well as imposing risks to natural resources and environmental health. The study showed that, optimal fertilizer and chemical energy use by growing leguminous pastures or dray-land crops in rotation with rapeseed and employing integrated pest management can maximize yield and help to reduce the environmental footprints of food production.

Keywords: *Environment; Chemical fertilizer; Chemicals; Energy input; Sensitivity analysis*

1. Introduction

During the last five decades, due to population growth and on the other hand tendency to having higher standards of living it is asked to provide more food and other products. This means more solar energy is needed for conversion into chemical energy in the form of food. To increase the efficiency of photosynthesis, many technological advances and facilities as well as high level of mechanization and more use of chemical fertilizers, herbicides, insecticides and other agrochemicals had been employed. But due to insufficient knowledge and some mismanagement on utilization of these energy inputs, they do not achieve success. This means a great requirement to evaluate how energy resources are used in agriculture, especially in developing countries like Iran [1].

Sensitivity analysis is particularly useful in pinpointing which assumptions are appropriate candidates for additional data collection to narrow the degree of uncertainty in the results. In recent years many researchers have studied econometric models on energy use in agriculture [2,3]; also the sensitivity analysis of these model parameters was investigated by some of them [4,5].

The inefficient use of fertilizer and chemicals inputs leads to problems beyond the scope of agricultural production. Unconscious use of chemicals and fertilizers would be harmful not only in energy dissipation, but also they result negative effects to environment, human health, maintaining, sustainability and decreasing production costs.

Rapeseed (*Brassica napus L.*) is one of the leading oilseed crops cultivated for edible oil production. Rapeseed production in Iran has increased dramatically in recent years, increasing from 76,430 tones in 2003, to more than 390,000 tones in 2008 [6]. Rapeseed production and its supply chain are heavily dependent on inputs such as land, water, fertilizer, fuel, machines, pesticides and electricity. The expansion of this crop in Iran has generated concerns about its environmental impacts.

Considering the destructive effects of chemical fertilizers and chemicals, the main objectives of this study were to estimate a relationship between agrochemicals energy inputs and production yield of rapeseed and to analyze the sensitivity of these energy inputs on output.

2. Materials and methods

This study was conducted in Golestan province. This province is the main center of rapeseed production in the country. It is located within 36° 30' and 38° 08' north latitude and 53° 57' and 56° 22' east longitude in the north-east of Iran. Data used in this study were obtained from 130 rapeseed farms in 30 villages using face-to-face questionnaire surveys. The required sample size was determined using the simple random sampling method [7].

The data were included the amount of chemicals and chemical fertilizers used for rapeseed production in the surveyed region. Chemicals were included herbicides, fungicides and insecticides; while chemical fertilizers were nitrogen, phosphate, potassium and sulfur. Also the grain yield of rapeseed was considered as output. Therefore, the amount of inputs and output per hectare were calculated and the energy input amounts per hectare were determined by multiplying the amount of inputs by their energy equivalents.

Following the calculation of energy inputs the relation between agrochemical energy inputs and output was investigated using a prior mathematical function relation. The energy equivalencies suggested the appropriate functional form of Cobb-Douglas production function. The main objective of estimating this production function was to search for the elasticity relationships. The Cobb-Douglass function has been used by several authors to investigate the relationship between energy inputs and production yield [8-10]; it is a power function can be written as follow [4]:

$$Y_i = \alpha_0 \prod_{j=1}^{k} X_{ij}^{\alpha_j} e^{u_i} \qquad (i = 1, 2, ..., n; j = 1, 2, ..., k) \tag{1}$$

Using a linear presentation, the function to be estimated could be written as:

$$\ln Y_i = \alpha_0 + \sum_{j=1}^{k} \alpha_j \ln(X_{ij}) + u_i \tag{2}$$

where: Y_i, denotes the yield of the i^{th} farmer, X_{ij}, is the j^{th} input used by the i^{th} farmer for rapeseed production, α_0, is a constant term, α_j, represent the regression coefficients of j^{th} input, which is estimated from the model and u_i, is the error term. In this functional form the parameters to be estimated, α_i, represent the elasticity of output with respect to each input i which implies the change percentage in output augmentation from a 1% increase in input i.
Assuming that grain yield is a function of energy inputs, for investigating the impact of each input energy on rapeseed yield, the equation (2) can be expanded in the following form;

$$\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + u_i \quad (3)$$

where: Y_i is the yield at farm i (kg ha^{-1}); X_1 to X_7 with respect denote the energy equivalents of nitrogen, phosphate, potassium, sulfur, herbicides, fungicides and insecticides inputs used at farm i (MJ ha^{-1}).

The sensitivity of energy inputs on output level was analyzed using the Marginal Physical Productivity (MPP) method and partial regression coefficients based on the response coefficients of the inputs. The MPP of a factor implies the change in the total output with a unit change in the factor input, assuming all other factors are fixed at their geometric mean level. A positive value of MPP of every input variable indicates that the total output is increasing with an increase in input level; so, the utilization of that input is better to be gone on so long as the fixed resource is not fully utilized. A negative value of MPP of any variable input indicates that every additional unit of input start to diminish the total output of previous units; therefore, it is better to keep the variable resource in surplus rather than utilizing it as a fixed resource.

The MPP of the various inputs was calculated using the α_j of the various energy inputs as follow [2,4]:

$$MPP_{xj} = \frac{GM(Y)}{GM(X_j)} \times \alpha_j \quad (4)$$

where MPP_{xj} is the marginal physical productivity of j^{th} input; α_j is the regression coefficient of j^{th} input; $GM(Y)$ denotes geometric mean of yield, and $GM(X_j)$ is the geometric mean of j^{th} input energy on per hectare basis.

3. Results and discussions

The physical quantity of fertilizer and chemical energy sources for rapeseed production are presented in Table 1. Also the energy coefficients of these inputs and their energy equivalents are shown. The results revealed that, 186.95 kg ha^{-1} chemical fertilizers were used, from which nitrogen and phosphate fertilizers were used as 111.41 and 50.65 kg ha^{-1}, respectively. Also 2.59 kg ha^{-1} chemicals were used for rapeseed production. The results of energy calculation in the last column showed that total energy input was 8698.75 MJ ha^{-1}, from which the share of chemical fertilizer energy was found to be significantly higher than the ratio of chemicals energy inputs; moreover, the output energy was estimated as 53798.46 MJ ha^{-1}.

The contributions of agrochemical energy input components are illustrated in Fig. 1. The results showed that nitrogen energy had the highest contribution to the total energy input (84.71%), followed by phosphate and herbicide energy inputs by the shares of 7.24% and 3.49%, respectively. Also, sulfur energy input had the lowest contribution by 0.15%.

Table 1. Agrochemical inputs, outputs and their energy equivalences in rapeseed production

Item (unit)	Quantity per unit area (ha)	Energy coefficient (MJ unit^{-1})	Total energy equivalent (MJ ha^{-1})
A. Inputs			
1. Fertilizer (kg)	186.95		8161.19
a. Nitrogen	111.41	66.14	7368.88
b. Phosphate (P_2O_5)	50.65	12.44	630.08
c. Potassium (K_2O)	13.39	11.15	149.35
d. Sulfur (S)	11.50	1.12	12.88
2. Chemicals (kg)	2.59		537.56
a. Herbicides	1.28	238	303.55
b. Fungicides	0.88	216	190.41
c. Insecticides	0.43	101.2	43.59
Total energy input			8698.75
B. Output			
1. Rapeseed (kg)	2151.94	25	53798.46
Total energy output			53798.46

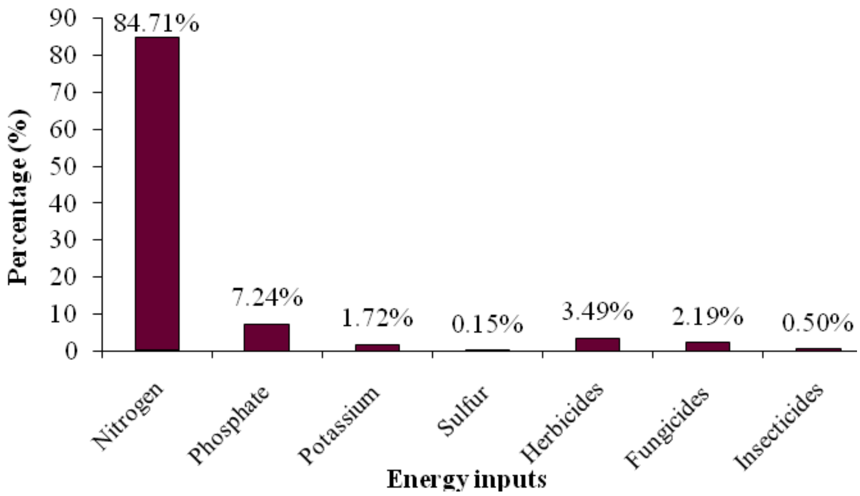

Fig. 1. The shares of chemical and chemical fertilizer energy input components

In addition, following disaggregation of the impact of energy on relevant inputs, for specifying a relationship between the energy inputs and yield of rapeseed production, the Cobb–Douglas the production function was estimated using the input energy equivalent of chemicals and chemical fertilizers (exogenous variables) against grain production yield (endogenous variable). The presence of autocorrelation in the residuals from the regression analysis was tested using the Durbin–Watson statistic test [8]. This test results revealed that Durbin–Watson value was as 2.1 for Eq. (3), indicating that there was no autocorrelation in the estimated model. The R^2 (coefficient of determination) was as 0.72 for this linear regression model, indicating that all the exogenous variables included in the regression equation had contributed to the rapeseed production by 72%, which was relatively low; it was because that some of energy inputs used for rapeseed production in the region including human labor, machinery, farmyard manure and other supported energy inputs were not aimed to be considered in this study. The results of regression model estimation are tabulated in Table 2. The results revealed that, nitrogen, herbicides, fungicides and insecticides energy inputs had the significant impacts on yield; while the impacts of phosphate, potassium and sulfur were not significant. Insecticides energy had the highest elasticity on output, followed by nitrogen and fungicides energy inputs. This indicates that by increase in the energy obtained from insecticide inputs, the amount of yield improves in present condition. Moreover, the results revealed that, the herbicides, insecticides and potassium energy inputs were negatively contributed to yield; indicating that rapeseed producers have applied an excess use of these inputs, resulting in an inverse effect on yield as well as imposing risks to natural resources and environmental health. The study showed that, optimal fertilizer and chemical energy use by growing leguminous pastures or dray-land crops in rotation with rapeseed and employing integrated pest management can maximize yield and help to reduce the environmental footprints of food production. With respect to the assessed results, decreasing 10% in the obtained energy from insecticides, herbicides and potassium would result to 1.1%, 0.17% and 0.04% increase in rapeseed grain production, respectively. Many researchers had reported that the impacts of chemicals and fertilizer energy inputs were negatively contributed to yield of agricultural production. Singh et al. [4] investigated a regression model for wheat crop in Punjab. They reported that the use of chemicals energy inputs in zone 3 and the fertilizer energy input in zone 2 and 4 were in excess in wheat production enterprises.

Table 2. Econometric estimation results of inputs.

Endogenous variable: yield Exogenous variables	Coefficient	t-ratio	MPP
Model 1: $\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + e_i$			
Constant	7.299	40.42^{**}	
Nitrogen	0.052	2.72^{**}	0.02
Phosphate (P_2O_5)	0.009	1.10	0.03
Potassium (K_2O)	-0.004	-0.44	-0.11
Sulfur (S)	0.003	0.17	0.29
Herbicides	-0.017	-2.16^{*}	-0.11
Fungicides	0.021	2.93^{**}	0.19
Insecticides	-0.110	-14.14^{**}	-21.46
Durbin-Watson	2.1		
R^2	0.72		

* and ** Indicate significance at 5% and 1% level, respectively.

The sensitivity of various energy inputs was analyzed using the MPP method and partial regression coefficients on output level. The results are presented in Table 2. These results of sensitivity analysis indicate which variables should be identified and measured most carefully to assess the state of the environmental system, and which environmental factors should be managed preferentially [11]. As it is seen, the major MPP value was drown by insecticides energy by a negative sign (-21.46), followed by sulfur (0.29) and fungicides (0.19). This implies that an additional use of 1 MJ ha^{-1} of each of the insecticides, sulfur and fungicides energy inputs would lead to the changes in grain production yield by decreasing 21.46 kg ha^{-1}, increasing 0.29 kg ha^{-1} and increasing 0.19 kg ha^{-1}, respectively. In other words, this indicates that there is a great scope for increasing output by additional use of sulfur and fungicides; while additional use of insecticides, potassium and herbicide energies would decrease the output level.

4. Conclusions

This study focused to investigate the energy consumption of chemical fertilizers and chemicals energy inputs per hectare of rapeseed grain production in Golestan province of Iran, and to find a relationship between these energy inputs and rapeseed grain yield. In addition, the sensitivity of energy inputs on output level was analyzed using the marginal physical productivity (MPP) method and partial regression coefficients. The results revealed that nitrogen energy had the highest contribution to the agrochemical energy input (84.71%), followed by phosphate and herbicides energy inputs by the shares of 7.24% and 3.49%, respectively.

On the other hand, the results of regression model estimation showed that nitrogen, herbicides, fungicides and insecticides energy inputs had the significant impacts on yield; Moreover, the herbicides, insecticides and potassium energy inputs had contributed to yield by a negative sign; indicating that the utilization of these energy inputs were in excess for rapeseed production and they were used inefficiently; so the continues use of these inputs would led to energy dissipation as well as imposing negative effects to environment, human health, maintaining and sustainability.

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