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FULL LENGTH ARTICLE

Energy use and economic analysis of NPK-15:8:15 fertilizer granulation process in Iran

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Abstract Ratio of 15:8:15 (15% nitrogen, 8% phosphorus and 15% potassium) is the dominant ratio of NPK fertilizers in Iran. The aim of this present paper was to study the energy consumption of the NPK-15:8:15 granulation process, and economic analysis of NPK-15:8:15 fertilizer granulation process. For this purpose, the data on 8 NPK-15:8:15 fertilizer plants by monthly for 3 months (February, May and August) in 2014, were collected and analysed. The results indicated that a total energy input of 1659.92 MJ ton^{-1} was consumed for NPK-15:8:15 fertilizer granulation process. Electricity (with 92.05%) was the highest energy inputs for NPK-15:8:15 fertilizer granulation process. The results indicate that 0.47 and 99.53 of the total energy input were in renewable and non-renewable forms, respectively. The regression results revealed that the contribution of energy inputs on yield process (except electricity and human labour energies) was significant. The natural gas had the highest impact (0.71) among the other inputs in NPK-15:8:15 granulation process. Economic analysis indicated that the total cost of process for one ton of NPK-15:8:15 fertilizer was around 9.05 $.

1. Introduction

According to reports, 23% of potassium, 9% of nitrogen and 21% of phosphorus requirement in agriculture by using of NPK fertilizers were supplied (Yara International, 2012). Total chemical fertilizers produced in Iran have been reported 1,256,778 metric tons in 2011. Amount of NPK fertilizers produced has been 132,750 metric tons in the same year and this amount was about 10% of total of chemical fertilizers produced in Iran (Ministry of Jihad-e-Agriculture of Iran, 2012). Multi-nutrient fertilizers (such NPK) may be blended (or mechanically mixed) and compound (or chemically mixed), mechanically mixing the constituent materials which may

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Nomenclature

EE	energy equivalent	X_3	machinery energy
IE	indirect energy	X_4	human labour energy
DE	direct energy	X_5	natural gas
Y_i	yield level of *i*th plants	e_i	error term
X_1	diesel fuel energy	RE	renewable energy
X_2	electricity energy	NRE	non-renewable energy

themselves be single-nutrient or multi-nutrient fertilizers. Compound (or chemically mixed) fertilizers are produced by causing the ingredient to react with one another in a reactor to form a compound (Pozin, 1986). NPK fertilizers produced in Iran were sort of blended. Chemical fertilizers produced in Iran are under the government supervision and the government has been giving subsidies to producers. The government buys a huge amount of chemical fertilizers produced and then distributes it among the farmers. According to terms of country's farmlands, the government has considered NPK fertilizer with ratio of 15:8:15 (15% nitrogen, 8% phosphorus and 15% potassium) and buying of this ratio has ensured. Although recently because of some privatisation and marketing, NPK fertilizer with different ratios for different soils and crops has been produced, but ratio of 15:8:15 is still dominant ratio of NPK fertilizers that is produced in Iran.

Effective energy use in agriculture is one of the conditions for sustainable agriculture production, since it provides financial saving, fossil resources preservation and air pollution reduction (Uhlin, 1998). Indirect energy has a high share of energy use in agriculture. The high share of indirect energy use in agriculture included chemical fertilizers. Many researchers have studied energy and economic analysis to determine the energy efficiency of plant production in Iran, such as potato (Mohammadi et al., 2008), cucumber (Mohammadi et al., 2010) and wheat (Safa and Tabatabaeefar, 2002). However, no studies have been published on the energy and economic analysis of fertilizer production, especially granulation process of NPK fertilizer.

According to ratio of 15:8:15 is most common ratio of NPK fertilizer, the aim of the present paper was to study the energy input per ton for the granulation process of NPK-15:8:15 fertilizer, and to make a cost analysis in Iran.

1.1. NPK fertilizer granulation process

Process of NPK fertilizer production includes milling, granulation, cooling, screening and packaging. At first, urea and SSP were milled by electric mill. Unfortunately urea and SSP using in NPK plants were granulated and hence in addition to energy consumption in granulation step of urea and SSP, it uses some energy in milling step of NPK plants.

Each of raw materials are powdered and decanted into the big cone-shaped containers. Usually there are three or four cone-shaped containers and the bigger rectangular-shaped container was embedded under the cone-shaped containers. The regulation valves were under the cone-shaped containers in order to having the proper ratio. The raw materials were decanted into the rectangular-shaped container and mixed by electric agitator. The mixing was done by humans in smaller plants that causes non-uniform mixture. Water is added at the same time with the mixing.

In the next step that was most important step, the raw materials that were mixed in the proper ratio deliver to the drum granulators. Rotation of drum granulators and heat by burners cause granulation. Number of drum granulators differs between 1 and 4 in the plants.

The NPK fertilizer (granulations) leaving the drum granulator having moisture content in the range 4–5% was sent by conveyer to the dryer, while in a few of the smaller plants, this work was done by humans. The dryer was used where that moisture content was reduced to 2%. The temperature of NPK leaving the dryer was about 70 °C and should be decreased. The temperature reduction was achieved by cooler unit. Furthermore at the same time and place with cooling, the NPK fertilizer is passed on the vibrating screen where it is subjected to a screening process. The result of this process was separation of NPK fertilizer with two different sizes namely on-size and oversize. The oversize NPK fertilizer first goes to the crusher and then was recycled directly to the drum granulator. Finally, NPK fertilizer was packed by humans and then was sent to the warehouse by liftrac or loader tractors. There were usually several elevators in the warehouse in order to arranging NPK packets. Approximately these steps were the same in the NPK fertilizer plants in Iran. These steps were also the same for different ratios of NPK and difference was only in energy consumption of milling step.

2. Material and results

Data were collected from 8 NPK fertilizer plants producing NPK-15:8:15 by using a face-to-face questionnaire and surveys performed by monthly for 3 months (February, May and August) in 2014. Number of NPK fertilizer plants of member in fertilizer manufacture association of Iran (FMAI) that produced NPK-15:8:15 was population of this study. The number of population was 8 and data were collected by the enumeration. Number of NPK-15:8:15 fertilizer plants from Iran was more than 8, but these weren't the precise number and some NPK plants were closed at this time. The NPK fertilizer plants of member in FMAI are located in all over Iran and it is appreciable for better estimating of energy consumption of NPK-15:8:15 fertilizer granulation process in Iran. These were reasons for choosing of NPK-15:8:15 fertilizer plants of member in FMAI as population. Data were averaged for 3 months to obtain monthly mean. The selected plants were producing only NPK-15:8:15 fertilizer at the time of data collecting.

The inputs that were utilized in the NPK fertilizer plants were natural gas, electrical, human energies and machinery. The diesel fuel was used for transporting the raw materials

Table 1 Energy equivalent of input.

Energy inputs	Unit	EE (MJ unit^{-1})	Ref.
Natural gas	m^3	49.5	Kitani (1999)
Machinery	h	13.06	Ozkan and Fert (2007), Singh (2002)
Electricity	kW h	12	Kitani (1999), Nassiri and Singh (2009)
Diesel fuel	l	56.31	Nabavi-Pelesaraei et al. (2013), Erdal et al. (2007)
Human labour	h	1.96	Nabavi-Pelesaraei et al. (2014)

and outputs into the plants by liftrac or loader tractors. The energy equivalent (EE) of energy inputs is shown in Table 1. Energy demand can be divided into direct and indirect energies or alternatively as renewable and non-renewable energies (Kizilaslan, 2009). Indirect energy (IE) includes energy embodied in machinery while direct energy (DE) covered human labour, diesel fuel, natural gas and electricity used in NPK-15:8:18 fertilizer granulation process. Non-renewable energy (NRE) includes machinery, diesel fuel, electricity and natural gas and renewable energy (RE) consisted of human labour.

Production functions are central to the determination of the efficient allocation of resources. In order to obtain a relationship between inputs and yield, a mathematical function needs to be specified. For this purpose, different functions were investigated and with respect to the initial tests related to selecting optimized functions as well as the expected signs of parameters. Overall, Cobb-Douglas production function yielded better estimates in terms of statistical significance and expected signs of parameters. The Cobb-Douglas production function is expressed as follows:

$$Y = f(x)\exp(u) \tag{1}$$

This function has been used by several authors to examine the relationship between energy inputs and yields (Singh et al., 2004; Hatirli et al., 2006, 2005). Eq. (1) can be linearized and be further re-written as follows:

$$\ln\ Y_i = a + \sum_{j=1}^{n} x_j \ln(X_{ij}) + e_i \quad i = 1, 2, \ldots, n \tag{2}$$

where Y_i denotes the yield of the ith farmer, X_{ij} the vector of inputs used in the production process, a the constant term, x_j represent coefficients of inputs which are estimated from the model and e_i is the error term. Assuming that when the energy inputs is zero, the crop production is Eq. (2) reduces to (Hatirli et al., 2006; Yamane, 1967):

$$\ln \mathrm{Y}_i = \sum_{j=1}^{n} x_j \ln(X_{ij}) + e_i \tag{3}$$

Eq. (3) is expanded in accordance with the assumption that the yield is a function of energy inputs:

$$\ln\ Y_i = x_1 \ln\ X_1 + x_2 \ln\ X_2 + x_3 \ln\ X_3 + x_4 \ln\ X_4 + x_5 \times \ln\ X_5 + e_i \tag{4}$$

where X_i (i = 1,2, ... ,5) stand for diesel fuel (X_1), electricity (X_2), machinery (X_3), human labour (X_4), and natural gas (X_5).

With respect to this pattern, by using (4), the input of energy of each input on the output energy was studied. Basic information on energy inputs and NPK-15:8:15 fertilizer yields was obtained with 3 different data from 8 plants (24 data). Data were entered into Excel's spreadsheet and EViews 7.0 software program. The input analysis was also applied in economic analysis. 1 ton of production was the basic unit for analysis. The economic input of this system included the following: diesel fuel, electricity, machinery, human labour, natural gas. All prices of input were market prices (average prices of year 2013–2014).

3. Results and discussion

3.1. Analysis of energy consumption in NPK-15:8:15 fertilizer granulation process

According to Table 2, the total energy consumption was obtained 1659.92 MJ for 1 ton of output. The average ECPW of the plants was obtained 1.66 MJ kg^{-1}. This amount was considered as the ECPW of NPK-15:8:15 fertilizer granulation process in Iran. The amount of human labour, electricity, natural gas, machinery and diesel fuel for 1 ton of NPK-15:8:15 fertilizer production was 4.05 h, 127.33 kW h, 0.92 m^3, 0.06 h and 1.38 l, respectively. The lowest used energy was for machinery with 0.79 MJ and share of 0.04% from total energy consumption. The highest used energy was for electricity with 1527.96 MJ and share of 92.05% from total energy consumption. The machinery was only used in the transportation into the plants. The majority of human labour was used in the transportation, feeding granulations and packaging. The natural gas was consumed for the heating in the granulation step and the drying step. The electricity was used for the handling of granulations, cooler unit, milling, screening process and lighting. The diesel fuel was consumed only as machinery purpose.

Table 3 shows the distribution of total energy input as direct, indirect, renewable and non-renewable forms. As it can be seen from the table, the total energy input consumed could be classified as direct energy (99.96), indirect energy (0.04) and renewable energy (0.47) and non-renewable energy (99.53).

3.2. Econometric model estimation of NPK-15:8:15 granulation process

Relationship between the energy inputs and yield was estimated using Cobb-Douglas production function for the

Table 2 The amounts of inputs, the share of inputs and the total equivalent energy for 1 ton output plants.

Inputs	Unit	Quantity of the inputs per ton	EE (MJ ton^{-1})	Percentage
Natural gas	m^3	0.92	45.54	2.74
Electricity	kW h	127.33	1527.96	92.05
Human labour	h	4.05	7.93	0.47
Machinery	h	0.06	0.79	0.04
Diesel fuel	l	1.38	77.70	4.7
Total EE	–	–	1659.92	100

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Table 3 Total energy input in form of direct, indirect, renewable and non-renewable for NPK-15:8:15 production.

Form of energy	Total of EE (MJ ton^{-1})	[a]%
Direct energy[b]	1659.13	99.96
Indirect energy[c]	0.79	0.04
Renewable energy[d]	7.93	0.47
Non-renewable energy[e]	1651.99	99.53
Total energy input	1659.92	100

[a] Indicates percentage of total energy input.
[b] Includes human labour, diesel, natural gas, electricity.
[c] Includes machinery.
[d] Includes human labour.
[e] Includes machinery, diesel, natural gas, electricity.

NPK-15:8:15 fertilizer. NPK-15:8:15 fertilizer granulation process yield (endogenous variable) was assumed to be a function of electricity, human labour, machinery, and natural gas energy (exogenous variables). In validating the model, autocorrelation was performed using Durbin-Watson test (Hatirli et al., 2006). This test revealed that Durbin-Watson value was 1.03 for model. There was no autocorrelation at the 5% significance level in the estimated model. The coefficient of determination (R^2) was 0.91 for this model.

The impact of energy inputs on process was also investigated by using Eq. (4). Regression result for this model is shown in Table 4. It can be seen from Table 4 that the contribution of natural gas is significant at the 1% level. This indicates that with an additional use of 1% for each of these inputs would lead to 0.71 increase in yield process. Because of using Cobb-Douglas function in the estimation, the coefficient of variables in Log form can be regarded as elasticities. The elasticities of diesel fuel and machinery were estimated as −0.35 and 0.54, respectively (significant at the 5% level). The impact of human labour energies on process yield was estimated statistically insignificant with a negative sign.

3.3. Economic analysis of NPK-15:8:15 fertilizer granulation process

The cost of each input is given in Table 5. Fixed and variable costs within total process costs were calculated independently. The total mean expenditures for the production was 9.05 \$ ton^{-1}. About 51% of the total expenditures were variable costs, whereas 49% was fixed expenditure. The highest cost for granulation process was for human labour and electricity that were 4.50 and 4.40 \$ ton^{-1} with the share of 49% and 48% from the total expenditures, respectively. The lowest cost for granulation process was for natural gas, machinery and diesel fuel that were 0.02, 0.06 and 0.07 \$ ton^{-1} with the share of 0.003%, 0.007% and 0.008% from the total expenditures, respectively.

Table 4 Econometric estimation results of inputs.

Endogenous variable: yield Exogenous variable	Coefficient	*t*-ratio
Model: $\ln Y_i = x_1 \ln X_1 + x_2 \ln X_2 + x_3 \ln X_3 + x_4 \ln X_4 + x_5 \ln X_5$		
1. Diesel fuel	−0.35	−2.31*
2. Electricity	0.29	0.85
3. Human labour	−0.13	−0.33
4. Machinery	0.54	2.34*
5. Natural gas	0.71	3.50**
Durbin-Watson	1.03	
R^2	0.91	

* Significant at 5% level.
** Significant at 1% level.

Table 5 Economic analysis of process.

Cost components	Unit	Value	%
Human labour	\$ ton^{-1}	4.50	0.49
Electricity	\$ ton^{-1}	4.40	0.48
Natural gas	\$ ton^{-1}	0.02	0.003
Diesel fuel	\$ ton^{-1}	0.07	0.008
Machinery	\$ ton^{-1}	0.06	0.007
Fixed cost	\$ ton^{-1}	4.50	0.49
Variable cost	\$ ton^{-1}	4.55	0.51
Total cost of process	\$ ton^{-1}	9.05	100

Optimum energy use is reflected in two ways, i.e. an increase in productivity with the existing level of energy inputs or conserving energy without affecting the productivity. In practice, NPK-15:8:18 granulation process has limited resources for the total cost of various inputs (human labour, electricity, etc.).

4. Conclusions

Based on the present paper following conclusions are drawn:

1. NPK-15:8:15 fertilizer production consumed a total energy of 1659.92 MJ ton^{-1}, which was mainly due to electricity. The energy input of diesel fuel (4.7%) and natural gas (2.74%) has the secondary and tertiary share within the total energy inputs.
2. The direct and indirect energy inputs were 99.96 and 0.04 of total energy input, respectively. Renewable energy source among the inputs had a share of 0.47% of the total energy input, which was smaller than that of non-renewable resources.
3. The regression results revealed that the contribution of energy inputs on yield process (except electricity and human labour energies) was significant. The total mean expenditures for the production was 9.05 \$ ton^{-1}. About 51% of the total expenditures were variable costs, whereas 49% was fixed expenditure. The highest cost for granulation process was for human labour and electricity that were 4.50 and 4.40 \$ ton^{-1} with the share of 49% and 48% from the total expenditures, respectively.

Conflict of interest

There is no conflict of interest.

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