Energy Use and Econometric Evaluation of Sweet Sorghum in China

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Abstract. Energy productivity and consume sensitivity of sweet sorghum were investigated in comparison with maize, sunflower, and soybean at Wuyuan and Moqi County, Inner Mongolia Province, China. We got the data from 83 farmers who did grow sweet sorghum at Wuyuan and Moqi County by face-to-face survey. The sweet sorghum showed an expressively higher total energy-consume than sunflower at Wuyuan and soybean at Moqi, but less total energy-consume than maize at Moqi. Sweet sorghum had an expressively higher energy-production and net-energy than soybean, maize and sunflower. Among all the consumes, nitrogen fertilizer expended the highest portion of the total energy for almost the all crops except the diesel consume of sweet sorghum at Moqi which was a little higher than nitrogen fertilizer fraction. Compared with the conference crops, sweet sorghum showed higher diesel energy percentage at both sites (p<1%) for higher machinery level during harvesting season. The renewable energy was expending much lower than non-renewable. Same increase among all the consumes diesel will bring much more production based on Cobb-Douglas manufacture model. The sweet sorghum and conference crops displayed a growing return to scale. These means that production could be improved substantially by a modification of the nitrogen fertilizer amounts and information support systems.

Keywords. Energy crop, Energy consumption, Energy crop, Renewable energy.

1. Introduction
With the environmental concerns and accelerated depletion of fossil fuel, renewable resources for energy got great concerns recent years. Biomass was one of them which can be used for production of biofuels, since it contributes to the reduction of greenhouse gas emissions which protect our environment by avoiding global warming and protects our economy from fossil fuel price and supply changes [1-2]. As the largest developing country, China is facing an increased demand for energy and it plans to blend 10 M tones bioethanol annually by 2020. However, constrained by the food production and land resources, China encourages to develop bioenergy with non-food materials that can be planted on the marginal lands. China stopped approving bio-ethanol projects by using grains in order to ensure food security.
Sweet sorghum (Sorghum bicolor (L.) Moench) is a highly photosynthetic efficient C4 plant species with a high cellulose and soluble sugar content in its stems [3] and a good tolerance to saline-alkali and drought conditions [4-6]. It is suitable to be planted on marginal land and has been well-thought-out as a potential source for manufacture bio-fuel in China [7-8]. Farmers have been organized to demonstrate sweet sorghum performance by bioethanol companies. Shandong and Inner Mongolia have been recognized as target regions with saline-alkali land to plant sweet sorghum for ethanol production [9]. In addition, there are large areas with relative low temperatures in the east part of Inner Mongolia that are not appropriate for crop manufacture [10].

Sustainable agronomy production and biofuel production require high energy use efficient index. Energy consumes and production analysis has become an important tool to judge the energy crops. Net energy efficiency and energy use pattern have been evaluated for many crop production systems in some literatures [11-16]. In a previous study we calculated energy productivity of sweet sorghum, compared with the other plants [17]. All these studies provide beneficial methodology and references.

The purpose of this research was (1) conclude consume and production energy in sweet sorghum at a saline-alkali site and a low temperature site in Inner Mongolia Province of China from an energy use productivity point of scope, (2) calculate the consume item sensitivity by use the Cobb-Douglas (C-D) function, and (3) calculate the energy efficiency between sweet sorghum and the dominating crops sunflower, maize, and soybean at the two sites.

2. Material and Methods
We did this study at Wuyuan county (108°16’ E, 41°05’ N) and Moqi county (124°31’ E, 48°28’ N) in Inner Mongolia Province, China, which represent saline-alkali and low temperature conditions respectively. The two sites have the similar rainfall and temperature conditions. The crop was cultivated at demo fields by 67 growers at Wuyuan site in 2010 and 16 growers at Moqi site in 2008. Data were collected quantitatively from all the sweet sorghum growers by a face-to-face survey during the crop growing period and during harvesting period. In order to assess the probability of sweet sorghum cultivation, data of sunflower (Helianthus annuus L.) at Wuyuan and maize (Zea mays L.) and soybean (Glycine max (L.) Merr.) at Moqi for the same farmers were also collected, which were prevailing crops to be grown at the sites.

Energy consumption of the crop production included seeds, plastic film, labor, machinery, diesel, fertilizers, irrigation water, and pesticides. Productions were composed of fruits (grain, bean, or achene) and the residues (e.g. straw) of individually crop. Since the consume and production were calculated in different units, we change the data into a common energy unit by using appropriate coefficient of energy equivalences (table 1). The energy conversion coefficient used for parameters were collected from literatures [17-20]. The energy conversion coefficient of irrigation water was got from articles published in international journals [15,21]. Energy productivity index and net energy were calculated by equation (1) and equation (2).

\[
\text{Energy productivity index} = \frac{\text{energy production}}{\text{energy consume}} \quad (1)
\]
\[
\text{Net energy per unit of land} = \text{energy production} - \text{energy consume} \quad (2)
\]
Table 1. Energy conversion coefficient of consume and production in sweet sorghum, sunflower, soybean and maize production.

| Consume and production | Unit | Energy equivalent (MJ unit⁻¹) | Reference |
|------------------------|------|-------------------------------|-----------|
| A. Consume             |      |                               |           |
| Labor                  | d    | 12.60                         | [33]      |
| Machinery              | h    | 209.20                        | [35]      |
| Diesel                 | l    | 36.55                         | [36]      |
| Fertilizer             |      |                               |           |
| (a) nitrogen (N)       | kg   | 92.05                         | [36]      |
| (b) phosphorus (P₂O₅)  | kg   | 13.39                         | [36]      |
| (c) potassium (K₂O)    | kg   | 9.20                          | [36]      |
| Pesticides             | kg   | 1020.90                       | [36]      |
| Water                  | m³   | 1.02                          | [16, 17, 33] |
| Plastic film           | kg   | 51.93                         | [36]      |
| Seed                   |      |                               |           |
| (a) sweet sorghum      | kg   | 59.50                         | [18]      |
| (b) sunflower          | kg   | 71.94                         | [18]      |
| (c) maize              | kg   | 103.79                        | [18]      |
| (d) soybean            | kg   | 31.73                         | [18]      |
| B. Production          |      |                               |           |
| Sweet sorghum          |      |                               |           |
| (a) fresh stem         | kg   | 3.88                          | [19]      |
| (b) fresh stem & leaf  | kg   | 4.56                          | [19]      |
| (c) grain              | kg   | 27.27                         | [19]      |
| Sunflower grain        | kg   | 20.06                         | [35]      |
| Sunflower straw        | kg   | 14.98                         | [35]      |
| Soybean grain          | kg   | 20.67                         | [35]      |
| Soybean straw          | kg   | 15.08                         | [35]      |
| Maize grain            | kg   | 16.53                         | [35]      |
| Maize straw            | kg   | 14.36                         | [35]      |

It is very important to calculate plant production system by production function. Cobb-Douglas (C-D) production function is enormously stable and excellent to other models [22-23]. The linear form of Cobb-Douglas (C-D) function was used in Model I using ordinary least square technique to determine the efficient allocation of the energy consume variables for labor, machinery, diesel, seed, nitrogen fertilizer, phosphorus fertilizer, and potassium fertilizer, pesticide, and plastic film (equation (3)). Irrigation data didn’t used for some famers did not irrigate.

Model I:

\[
\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + \\
\alpha_8 \ln X_8 + \alpha_9 \ln X_9 + \alpha_{10} d1 + \alpha_{11} d2 + \alpha_{12} d3 + e_i
\]  

where \( Y_i \) is the i th grower’s energy production and (i=1, 2, ..., 9) indicates consumption energies including labor (X₁), machinery (X₂), diesel (X₃), seed (X₄), nitrogen fertilizer (X₅), phosphorus fertilizer (X₆), potassium fertilizer (X₇), pesticide (X₈) and film (X₉); is an elasticity of consume which is estimated in the model, ei is the error term; we add d1 which is equal to 1 for Wuyuan and 0 for Moqi. Then we add d2 which is equal to 1 for maize and 0 is otherwise. And we add d3 which is equation to 1 for sunflower and 0 otherwise [24-25].

The marginal physical productivity (MPP) was calculated to analyze the sensitivity of energy consumes (equation (4)).
\[
\text{MMP}_{ij} = \frac{\text{GM}(Y)}{\text{GM}(X_j)} \times \alpha_j
\]

(4)

where \(\text{MMP}_{ij}\) is the MPP of \(j^{th}\) consume; \(\alpha_j\) an elasticity of \(j^{th}\) consume; \(\text{GM}(Y)\) geometric mean of yield; and \(\text{GM}(X_j)\) geometric mean of \(j^{th}\) consume on per hectare basis.

We deal with the data by Excel 2007 and simulated by Eviews 5.1. Analysis of Variance (ANOVA) was used SAS [26]. Autocorrected the model by Durbin-Watson (DW) test. We used Duncan’s multiple range test to determine the statistical significance of the differences between means. The coefficient of determination \(R^2\) was analyzed using Eq (5) to decide the fitness of the C-D models we built.

\[
R^2 = \frac{\sum_{i=1}^{n} (\text{SY}_i - \overline{\text{OY}})^2}{\sum_{i=1}^{n} (\text{OY}_i - \overline{\text{OY}})^2}
\]

(5)

where \(\text{SY}_i\) and \(\text{OY}_i\) are the simulated and original energy production of the \(i^{th}\) farmer; while \(\overline{\text{OY}}\) are the average values of the data arrays of \(\text{OY}_i\).

3. Results and Discussions

3.1. Energy Consume

Consume energy during sweet sorghum producing process was significantly higher at Wuyuan (43,239 MJ ha\(^{-1}\)) than that at Moqi (27,126 MJ ha\(^{-1}\)) mainly because the higher nitrogen fertilizer consumes at Wuyuan. Compared with the reference crops, the total amount of energy consume for sweet sorghum was lower than for maize (36,044 MJ ha\(^{-1}\)) at Moqi, however, higher than either sunflower (29,014 MJ ha\(^{-1}\)) at Wuyuan or soybean (9,338 MJ ha\(^{-1}\)) at Moqi (table 2). The reason for the difference was also mainly because the higher nitrogen fertilizer consumes contributing the higher energy consume for the crops. Among all the consumes, nitrogen fertilizer was almost the largest (\(p<1\%\)) share ranging between 24.46 % and 60.73 % for four crops at the two sites, only with the exception of diesel which was higher (45.93 %) than nitrogen fertilizer share (35.55 %) for sweet sorghum at Moqi. Sweet sorghum showed a significant higher diesel energy percentage compared with other crops at both sites (\(p<1\%\)). Diesel, nitrogen fertilizer and seed energy consumption contributed to over 70% of entire energy consume for the crops at both sites (table 3, figure 1). Besides, the energy crop consumed the more machinery energy (2,279 MJ ha\(^{-1}\) and 2,610 MJ ha\(^{-1}\)) and labor (1,355 MJ ha\(^{-1}\) and 875 MJ ha\(^{-1}\)) compared with conference crops at Wuyuan and Moqi, respectively (table 2).
Table 2. Means and standard errors of energy consume and production in sweet sorghum, maize, sunflower, and soybean production at Wuyuan and Moqi sites.

| Consume/production (MJ ha\(^{-1}\)) | Wuyuan | Moqi |
|-------------------------------------|--------|------|
| **A. Total Consume**                |        |      |
| Labor                              | 43239±1745a | 27126±998b |
| Machinery                          | 1355±172a | 875±50a |
| Diesel                             | 2279±308a | 2610±355a |
| Fertilizers                        | 6622±276a | 12458±298a |
| (a) Nitrogen                       | 28194±1292a | 10548±936b |
| (b) Phosphorus                     | 62±18 | 231±13b |
| (c) Potassium                      | 615±31a | 635±61b |
| Seed                               | 476±15b | 765±717 |
| Water                              | 3116 | 0b |
| Plastic film                       | 3116 | 0b |
| Pesticides                         | 293±71a | 9643±962b |
| (a) Insecticide                    | 2044±129a | 10458±1352a |
| (b) Herbicide                      | 62±18 | 231±13b |
| **B. Total Production**            |        |      |
| Stalk                              | 204500±13524a | 204500±13524a |
| Grain                              | 204500±13524a | 204500±13524a |
| **C. Net energy**                  |        |      |

* Significance at p<5% level; ** Significance at p<1% level; ns denotes no significant effect.
The value indicated with the lower-letter (a) is significantly higher than the value indicated with (b) at p < 5% between the two crops at the same site. The value indicated with (b) is significantly higher than the value indicated with (c).

The energy consumes during crop production would be departed into renewable part which consists of seed, labor and water and non-renewable part which included equipment, diesel, film, fertilizers and chemical pesticides [12, 13, 20, 21, 27]. Non-renewable energy of the four plants have much more than renewable part, which is fitness with the earlier study [17].

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**Table 3.** Percentage of dominating energy consume for four crops at two sites.

| Region | Crop          | Labor | Machinery | Diesel | Nitrogen | Seed |
|--------|---------------|-------|-----------|--------|----------|------|
| Wuyuan | Sweet sorghum | 3.13% | 5.27%     | 15.31% | 60.33%   | 1.42%|
|        | Sunflower     | 1.65% | 7.04%     | 9.00%  | 60.73%   | 1.64%|
| Moqi   | Sweet sorghum | 3.23% | 9.62%     | 45.93% | 35.55%   | 2.34%|
|        | maize         | 1.17% | 6.76%     | 10.51% | 60.21%   | 17.62%|
|        | soybean       | 2.98% | 8.88%     | 23.29% | 24.46%   | 18.94%|

* Data resource: calculated by author according to table 2.

### 3.2. Energy Production

In this study, the production of energy includes not only grain energy but also stalk energy. The stalks have a lot of energy production which can also be converted into ethanol like agriculture residues [19, 28]. Moreover, crop stalks have been widely recognized as a bio-resource for multipurpose, especially of bio-energy, in the world nowadays [29-30]. So, we as well included sunflower straw and soybean stover and maize stover as a part of production because the residues embodied energy beyond doubt just as investigated at previous study [14,15, 17].
Figure 1. Components of energy consume in sweet sorghum, maize, sunflower, and soybean production at Wuyuan and Moqi sites.

The bars represent standard error. Lower-case letters indicate significant differences at p<5% level between the crops at the same site.

The energy productions of sweet sorghum at Wuyuan (204,500 MJ ha\(^{-1}\)) and at Moqi (387,297 MJ ha\(^{-1}\)) were significantly higher than for sunflower (173,326 MJ ha\(^{-1}\)) at Wuyuan (p<1%) and soybean (73,451 MJ ha\(^{-1}\)) (p<1%) and maize (215,386 MJ ha\(^{-1}\)) at Moqi (p<1%), respectively (table 2). As for the composition of energy production, the sweet sorghum produced significantly more stalk energy than grain energy at both sites (p<1%).

3.3. Energy Production
Comparing the energy consume and production of the crops, we found that in spite of the higher energy consume for sweet sorghum, it still exhibited significantly higher net energy production than sunflower, maize, and soybean (figure 2), which is in agreement with study on net energy research of sweet sorghum, corn, and soybean of Sander [16].
Figure 2. Net Energy for production of sweet sorghum, sunflower, maize and soybean at Wuyuan and Moqi sites.

The bars represent standard error. Lower-case letters indicate significant differences at p<5% level between the crops at the same site.

3.4. Sensitivity Analysis

The model (I) to evaluate the relationships between energy consume and production was established by the C-D production function for crops at the two sites and the results were shown as below (table 4).

According to the Model I, diesel energy consumes turned out to have the significantly highest impact (1.24, p<1%) on the energy production. It means that an increase 1% diesel consumption could rise additional energy production by 1.24%. The MPP value indicated that increase use 1 MJ diesel consume could lead to an additional energy production of 41.75 MJ. Contrarily, consumes by seed, plastic film, nitrogen and phosphorus showed negative effects with the elasticity of -0.03, -0.21, -0.03 and -0.02. That means the additional consume of seeds, plastic film, nitrogen and phosphorus not only couldn’t increase the energy production, but also could decrease the energy production. The sum of the nine energy consumes elasticity values added up to bigger than one which suggests a rising return to scale for sweet sorghum production.

We took autocorrelation test for the model. The result showed DW values was between 1.72 and 2.15 for the model (table 5). It indicated the model got rid of significant autocorrelation (p<1 %). The measurement of determination (R2) was 0.77 for reference crops and 0.99 for sweet sorghum, which all were highly significant according to statistical analysis (p<1%). Please see the table 4.
Table 4. Sensitivity analysis of energy consumes based on model I for sweet sorghum, maize, sunflower, and soybean production at Wuyuan and Moqi sites.

| Variable        | Sweet sorghum | Reference crops |
|-----------------|---------------|-----------------|
|                 | Elasticity    | MPP  T-Ratio    | Elasticity    | MPP  T-Ratio    |
| Labor ($\alpha_1$) | 0.04          | 7.37  1.09      | -0.09         | -30.01 -1.19    |
| Machinery ($\alpha_2$) | 0.01          | 0.92  0.34      | 0.11          | 8.77  1.59      |
| Diesel ($\alpha_3$) | 1.24          | 41.75 17.49**   | 0.12          | 6.91  1.32      |
| Seed ($\alpha_4$) | -0.03         | -15.43 -0.83    | 0.19          | 36.73 2.60*     |
| Film ($\alpha_5$) | -0.21         | -20.49 -4.31    | 0.41          | 0.11  4.61**    |
| Nitrogen ($\alpha_6$) | -0.03       | -0.39 -0.83     | 0.13          | 19.63 2.43*     |
| Phosphorus ($\alpha_7$) | -0.02       | -3.82 -0.59     | 0.17          | 4.38  2.40*     |
| Potassium ($\alpha_8$) | 0.00         | -0.81 -0.15     | 0.02          | 1.61  2.03*     |
| Pesticides ($\alpha_9$) | 0.01         | 2.83 1.09**     | 0.01          | 25.74 1.31      |
| Return to scale ($\Sigma_{i=1}^n \alpha_i$) | 1.01         |                  | 1.07          |                  |

MPP denotes marginal physical productivity; * Significance at p<5% level; ** Significance at p<1% level.

As for the conference crops, the film exhibited significantly highest impact (0.41, p<1%) among all the consumes on energy production. Seeds, nitrogen, phosphorus and potassium consumes also exhibited positive elasticity values (0.19, 0.13, 0.17, 0.02) which suggests significant (p<5%) impacts. It is shown as table 5.

Table 5. Durbin-Watson (DW) and measurement of determination ($R^2$) of the Model I for sweet sorghum, maize, sunflower, and soybean production at Wuyuan and Moqi sites.

| Sweet sorghum | Reference crops |
|---------------|-----------------|
| $R^2$         | $R^2$          |
| 1.72          | 2.15           |
| 0.99**        | 0.85**         |

4. Conclusions and Implications
This investigation focused on the plantation feasibility of sweet sorghum with the data collected face to face from demonstration fields. The sweet sorghum consumed higher energy consume than the conference crops except the maize at Moqi. In spite of that, sweet sorghum exhibited more net energy than other crops because of its highest energy production. We found sweet sorghum is worthy to be invested as energy crop for its higher net energy.

Among all the consumes, nitrogen fertilizer took highest portion of the all energy inputs for almost all the crops except the diesel consume of sweet sorghum at Moqi which was a little higher than nitrogen fertilizer fraction. However sweet sorghum in the C-D production model analysis exhibited that nitrogen fertilizer consumes exhibited a negative influence on energy production. That means the nitrogen fertilizers have been over-applied in these regions. Nitrogen has been overused since the early 1980s in China [31]. Sweet sorghum used more N, P and K fertilizer than the other plants [32]. Crop yield can be falling short if the mineral nutrients was beyond need. As a result, we recommend adjusting the nitrogen fertilizer rate based on a further study of optimal fertilization regimes.

Compared with the conference crops, sweet sorghum showed higher diesel energy percentage at both sites (p<1%). The reason mainly was because more machine was used especially during harvesting period. As we all know, the energy crop compress be a bigger size and higher moisture content at harvest season than the stems of sunflower, maize and soybean, which results in much
higher consumption for transportation [33]. Excitingly, the C-D models revealed that diesel consumption had the significantly highest positive influence on energy production of sweet sorghum among all the energy consumes. It suggests that an increase of diesel fuel consumption contributed the higher to increase the energy production of sweet sorghum. Accordingly, human labor energy consume can be reduced by using machine, which agrees with Ren [17].

According to the C-D production function, sweet sorghum and the reference crops exhibited increasing return to scale (will be named ‘IRS’). The returns to scale due to technologically not to economic decisions or market conditions and IRS can be realized through operational efficiencies. However, sweet sorghum is still in infancy stage as an energy crop nowadays and the production technologies need to be further optimized. So, we should increase the energy production of sweet sorghum substantially through further crop improvement and management practices.

Besides, we found the renewable energy consumed less than non-renewable energy in all four crops, which is in agreement with the previous reports we searched [12, 13, 21, 34]. The lower ratio of renewable energy among energy consume produces harmful effect on sustainability in the energy plant cultivation. Therefore, we recommend utilizing additional renewable energy resources and fewer non-renewable energy to decrease environmental pollution and higher energy safety. Because of no large-scale multiple-year production for sweet sorghum nowadays, we only questionnaire one-seson sweet sorghum cultivation in north China. More research and experiment should be conducted before sweet sorghum is spread large scale in China.

Acknowledgments
This study was co-funded by the National Key R&D Program of China (2018YFF0213502-32018YFF0213501-4), Science and Technology Major Projects of Anhui Province (18030701190); Natural science Research Program in Universities in Anhui (KJ2018A0527); Anhui Provincial Education Department's Revitalization Program for 2019 (gxyq2019061); Commonwealth Section (Agriculture) Research Program (nyhyzx07-011). We gratefully acknowledge Mr. Mo Shi and Shuai Xue for their help in data collection and Prof. Ruihua Yang, Prof. Qijie Gao, Mr. Zuxin Liu, and Mr. Zhongpeng Lv for their help in data analysis.

References
[1] Berndes G, Hoogwijk M and Broek R 2003 The contribution of biomass in the future global energy supply: A review of 17 studies Biomass Bioenergy 25 1-28
[2] Spiertz J H J and Ewert F 2006 Crop production and resource use to meet the growing demand for food, feed, and fuel: Opportunities and constraints NJAS-Wageningen Journal for Life Sciences 56 281-300
[3] Zhao Y L, Dolat A, Steinberger Y, Wang X, Osman A and Xie G H 2009 Biomass yield and changes in chemical composition of sweet sorghum cultivars grown for biofuel Field Crop Res. 111 (1-2) 55-64
[4] Tsuchihashi N and Goto Y 2004 Cultivation of sweet sorghum (sorghum bicolor (L.) Moench) and determination of its harvest time to make use as the raw material for fermentation, practiced during rainy season in dry land of Indonesia Plant Prod Sci. 7 (4) 442-8
[5] Gnansounou E, Dauriat A and Wyman C E 2005 Refining sweet sorghum to ethanol and sugar: Economic trade-offs in the context of North China Bioresource Technol 96 (9) 985-1002
[6] Tian Y S, Zhao L X, Meng H B, Sun L Y and Yan J Y 2009 Estimation of un-used land potential for biofuels development in (the) People’s Republic of China Appl. Energ. 86 (SUP1) 77-85
[7] Gao C F, Zhai Y, Ding Y and Wu Q Y 2010 Application of sweet sorghum for biodiesel production by heterotrophic microalg Chlorella protothecoides Appl. Energ. 287 (3) 756-761
[8] Li S Z, Chan H and Ethanol C 2009 Production in (the) People’s Republic of China: Potential and technologies Appl. Energ. 86 (SUP1) 162-9
[9] Xie G H, Zhuang H Y, Wei W L, Zhuo Y and Guo X Q 2011 Non-food Energy Plants: Production Principle and Technique in Marginal Land China Agricultural University Press 121-128

[10] Zhuang D F, Jiang D, Liu L and Huang Y H 2011 Assessment of bioenergy potential on marginal land in China Renewable and Sustainable Energy Reviews 15 (2) 1050-1056

[11] Singh G, Singh S and Singh J 2004 Optimization of energy inputs for wheat crop in Punjab Energ. Conv. Manage. 45 (3) 453-65

[12] Heidari M D and Omid M 2011 Energy use patterns and econometric models of major greenhouse vegetable productions in Iran Energy 36 (1) 220-5

[13] Zangeneh M, Omid M and Akram A 2010 A comparative study on energy use and cost analysis of potato production under different farming technologies in Hamadan province of Iran Energy 35 (7) 2927-2933

[14] Mandal K G, Saha K P, Ghosh P K, Hati K M and Bandyopadhyay K K 2002 Bioenergy and economic analysis of soybean-based crop production systems in central India Biomass Bioenerg. 23 (5) 337-345

[15] Kallivroussis L, Natsis A and Papadakis G 2002 The energy balance of sunflower production for biodiesel in Greece Biosyst. Eng. 81 (3) 347-354

[16] Sander C, Gerrie W J, Martin K and Ken E G 2010 Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques Biomass and Bioenergy 34 588-601

[17] Ren L T, Liu Z X, Wei T Y and Xie G H 2012 Evaluation of energy use in sweet sorghum plantation demonstration at coastal saline-alkali lands Energy 47 166-73

[18] Wen D Z 1986 The research method of agricultural energy fluent system (Third) Rural Eco-Environ. 2 48-51

[19] Hatirli S A, Ozkan B and Fert C 2005 An econometric analysis of energy input-output in Turkish agriculture Renew Sustain. Energy Rev. 9 (6) 608-623

[20] Hatirli S A, Ozkan B and Fert C 2006 Energy inputs and crop yield relationship in greenhouse tomato production Renewable Energy 31 (4) 427-438

[21] Banaeian N, Omid M and Ahmadi H 2011 Energy and economic analysis of greenhouse strawberry production in Tehran province of Iran Energ. Conv. Manage. 52 (2) 1020-1025

[22] Pickard L, Kitchenham B and Jones P 1999 Comments on: Evaluating alternative software production function IEEE Trans. Software Eng. 25 (2) 282-5

[23] Pendharkar P C, Rodger J A and Subramanian G H 2008 An empirical study of the Cobb-Douglas production function properties of software development effort Inform. Software Technol. 50 (50) 1181-8

[24] Hervani A A 2005 Can oligopsony power be measured? The case of U S old newspapers market Resources, Conservation and Recycling 44 343-80

[25] Ito J 2006 Economic and institutional reform packages and their impact on productivity: A case study of Chinese township and village enterprise Journal of Comparative Economics 34 167-190

[26] SAS Institute 1999 SAS Version 9.02 SAS Institute Incorporated, Cary (NC: USA) 136-149

[27] Erdal G, Esengun K, Erdal H and Gunduz O 2007 Energy use and economical analysis of sugar beet production in Tokat province of Turkey Energy 32 (1) 35-41

[28] Xin Z G, Wang M L, Burow G and Burke J 2009 An Induced sorghum mutant population suitable for bioenergy research Bioenerg. Res. 2 10-16

[29] Goldemberg J and Johansson T B 2004 World Energy Assessment Overview 2004 Update (New York: United Nations Development Programme) 45-66

[30] US Department of Energy 2011 US Billion-ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry (Oak Ridge TN: Oak Ridge National Laboratory) 52-86
[31] Guo J H, Liu X J, Zhang Y, Shen J L, Han W X, Zhang W F, Cheristie P, Goulding K W T, Vitousek P M and Zhang F S 2010 Significant acidification in major chinese croplands *Science* **327** (5968) 1008-10

[32] Han L P, Steinberger Y, Zhao Y L and Xie G H 2011 Accumulation and partitioning of nitrogen, phosphorus, and potassium in different varieties of sweet sorghum *Field Crop Res.* **120** (2) 230-40

[33] Chen F 2001 *Agroecology* (Beijing: China Agricultural university Press) 260-264 (In Chinese)

[34] Mobtaker H G, Keyhani A, Mohammadi A, Rafiee S and Akram A 2010 Sensitivity analysis of energy inputs for barley production in Hamedan province of Iran *Agr. Ecosyst. Environ.* **137** (3-4) 367-72

[35] Luo S M 2000 *Agroecology* (Beijing: China Agriculture Press) 447-478 (in Chinese)

[36] Aide M and Mueller W 2016 Nutrient uptake patterns of five sweet sorghum varieties to estimate harvest removal rates *International Journal of Applied Agricultural Research* **11** (2) 159-171