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Measuring Economic Efficiency of Kidney Bean Production Using Non-Discretionary Data Envelopment Analysis

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ABSTRACT

Efficient use of assets in agriculture is a goal for policy-makers and farmers. Agricultural input resources are scarce and optimum use of inputs in different agricultural operations is important. Data envelopment analysis (DEA), as a mathematical programming technique, is a well-known approach for estimating the efficiency of agricultural DMUs. In this study, efficiency of kidney bean production in twelve provinces of Iran has been studied. Inputs are the cost of tillage, planting, cultivation, harvesting and land. Output consists of the total production value of the kidney bean. Land cost is a non-controllable variable. Therefore; a non-discretionary DEA approach is applied to estimate efficiency of kidney bean production. The average value of technical efficiency score of kidney bean production is 0.74. The results of benchmarking of kidney bean farms reveals that 58 percent of them are efficient. These farms are a good example for improving the performance of inefficient farms. For optimum conditions based on the proposed model, tillage, planting, cultivation and harvesting costs is decreased by 34.48%, 11.92%, 27.87% and 7.27%, respectively, without decreasing kidney bean production level.

1 Introduction

Food security is a worldwide challenge. With increasing world population and need for food with limited resources and arable land, improving the efficiency of food production has become increasingly important [1]. Assessing economic efficiency of farm products is a vital managerial activity for decision makers to improve their resources allocation strategies and strengthen their competitive advantages. Economic efficiency can be measured using mathematical programming techniques. Data envelopment analysis (DEA), originally presented by Charnes et al. [2], is a well-known family of mathematical programming tools for assessing the relative efficiency of a set of comparable processing decision making units (DMUs) [3-5]. The number of applications of DEA is large, covering fields as diverse as finance, agriculture, health, education, manufacturing, transportation [6-8]. Instances from the DEA literature include snowfall or weather in evaluating the efficiency of maintenance units, soil characteristics and topography in different farms, the number of competitors in the branches of a restaurant chain,

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local unemployment rates which affect the ability to attract recruits by different US Army recruiting stations, age of facilities in different universities, and the number of transactions in library performance [9]. DEA has been applied for assessing efficiency of different crops such as grape [10], walnut [11], maize [12], barley [13], watermelon [14], apple [15] and soybean [16]. Radial models, like CCR models, have some disadvantages like failure to recognize weak efficient DMUs [17,18]. Another type of DEA models are non-radial DEA models. These models have some advantages over radial DEA models. The main aim of the current study is assessing the economic efficiency of kidney bean production in twelve provinces in Iran by means of data envelopment analysis models. On the other hand, there is a variable such as "Land Cost" that is unchangeable. However, standard data envelopment analysis implicitly assumes that all inputs and outputs are discretionary, i.e., can be controlled by the management of each DMU and varied at its discretion. However, there may exist exogenously fixed (or non-discretionary) inputs or outputs that are beyond the control of a DMU's management, which also need to be considered [19]. In recent years, the government plans to decrease the rapidly growing energy demand in all sectors of the Iranian economy has received the attention of researchers in the agricultural sector [20]. An important issue for researchers is how efficiently farmers are using farm limited resources. Hence, in this study, we propose a non-radial DEA based model in the presence of nondiscretionary output, to measure kidney bean farms' economic efficiency. The current study unfolds as follows: Section 2 presents the literature review. In Section 3 our new DEA model in the presence of nondiscretionary output is given. Section 4 presents a case study and the final conclusion appears in Section 5.

2 Literature Review

2.1 DEA Models in Agriculture Industry

Dhungana et al. [21] measured the economic efficiency of Nepalese rice farmers using the data envelopment analysis approach. Al-Mezeini et al. [22] evaluated efficiency of greenhouse production in Oman in a two-stage model using DEA and double bootstrapping. Results revealed that 79% of greenhouse producers were inefficient. Maina et al. [23] investigated the factors affecting economic efficiency of milk production in Kenya. Their results suggested that reducing costs, proper use of hired labor and intensive use of the available land for livestock will improve economic efficiency. Khoshroo et al. [10] assessed technical efficiency of grape production in Iran using DEA and Tobit regression. Results showed that farmers' education significantly influence the efficiency of production. Khoshroo et al. [24] investigated efficiency of turnip production in Iran using a DEA approach with undesirable emission output. Izadikhah and Khoshroo [13] evaluated efficiency of barley production in Iran using a fuzzy DEA approach. Ebrahimi and Salehi [25] studied emission reduction and energy use efficiency of button mushroom production using DEA approach. Hosseinzadeh-Bandbafha et al. [26] used data envelopment analysis to estimate efficiency and reduce greenhouse gas emissions of fattening farms.

2.2 DEA Models with Nondiscretionary Data

Operating conditions are variously referred to in the literature as non-discretionary, uncontrollable, environmental, exogenous or contextual variables/inputs [27]. In any realistic situation, however, there may exist ‘‘exogenously fixed’’ or non-discretionary factors that are beyond the control of a DMU's management, which also needs to be considered [28]. As a result, non-discretionary factors need to be excluded or treated as normal discretionary factors, which may lead to a biased view of efficiency. A number of different approaches have been developed to overcome this weakness. Syrjanen [29] presented the interpretation of exogenously fixed, non-discretionary factors in data envelopment analysis and suggested a generalized model for incorporating different types of inputs and outputs in DEA. Lotfi et al. [28] discussed and reviewed the use of super-efficiency approach in data envelopment analysis and sensitivity analyses when some inputs are non-discretionary. Saen [30] developed a DEA based model for ranking suppliers in the presence of weight restrictions, nondiscretionary factors, and cardinal and ordinal data. Azizi and Ganjeh Ajirlu [31] proposed a pair of data envelopment analysis models for measurement of relative efficiencies of decision-making units in the presence of non-discretionary factors and imprecise data. Harrison et al. [27] compared the performance of the standard BCC model as a base case with two single-stage models and performed a simulation analyses using a shifted Cobb-Douglas function, with one output, one non-discretionary input, and two discretionary inputs. Aliakbarpoor and Izadikhah [32] reviewed articles which incorporated undesirable or non-discretionary data into slack-based models and some radial DEA models. Khoshandam et al. [33] investigated the focus~~es~~ on estimating the marginal rates of substitution in DEA models in the presence of nondiscretionary factors in performance measurement of a group of production units. Shabani et al. [34] by considering discretionary, non-discretionary, desirable, and undesirable factors, proposed DEA models for evaluating the individual and overall environmental performance of countries. Soltani and Lozano [35] proposed a new approach to the problem of efficiency assessment that could take into account undesirable outputs, nondiscretionary variables and preference structures. Taleb et al. [36] proposed a two-stage approach of super efficiency slack-based measure in non-discretionary factors and mixed integer requirements to make the projection of an efficient decision making unit Strongly-Pareto efficient. Galagedera [37] developed a DEA based mode to assess mutual fund performance in a multi-dimensional framework with ethical level as one of its performance measures. In that study, ethical level was modelled as a non-discretionary output at the operational management stage. Queiroz et al. [39] investigated the efficiency of Brazilian primary education with a dynamic DEA model in which socioeconomic levels were treated both as discretionary and non-discretionary variables in dynamic DEA models and their results were compared.

3 New Efficiency Measure with Non-Discretionary Input

This section, first, proposes a scheme where the non-discretionary input are incorporated into DEA models. For this aim, inspired by the generic directional distance model [40], a novel non-oriented model is presented. Assume that there are *n* DMUs that each DMU$_j$ uses m_1 discretionary inputs $x_{ij}^{D}, (i = 1, \dots, m_1)$ and m_2 non-discretionary inputs $x_{ij}^{ND}, (i = 1, \dots, m_2)$ to produce s outputs $y_{rj}, (r = 1, \dots, s)$. In order to evaluate the efficiency score of DMU$_p$ under variable returns to scale (VRS), the following direction vector is considered:

$$d_p = \left(-\left|x_p^D\right|, \left|y_p\right|\right) = \left(-\left|x_{ip}^D\right|, i = 1, \dots, m_1;\ \left|y_{rp}\right|, r = 1, \dots, s\right) \tag{1}$$

This vector is based on the absolute values of data. Note that this direction vector is an extension of the [38, 41, 42] direction vector. Our new direction guarantees that the new model always projects the DMUs on the strong efficient frontier. Therefore, initially the following non-radial efficiency model that considers non-discretionary inputs is presented.

$$
\begin{aligned}
&\sigma_p^* = \min 1 - \frac{1}{2}\left(\frac{1}{m_1}\sum_{i=1}^{m_1}\frac{\theta_i}{\bar{\theta}_p} + \frac{1}{s}\sum_{r=1}^{s}\frac{\varphi_r}{\bar{\varphi}_p}\right) \\
&s.t. \\
&\sum_{j=1}^{n}\lambda_j x_{ij}^D \le x_{ip}^D - \theta_i |x_{ip}^D|\,, && i = 1,\dots,m_1 \\
&\sum_{j=1}^{n}\lambda_j x_{ij}^{ND} \le x_{ip}^{ND}\,, && i = 1,\dots,m_2 \\
&\sum_{j=1}^{n}\lambda_j y_{rj}^D \ge y_{rp}^D + \varphi_r |y_{rp}^D|, && r = 1,\dots,s_1 \\
&\sum_{j=1}^{n}\lambda_j = 1, \\
&\lambda_j, \theta_i, \varphi_r \ge 0, && \forall j,i,r
\end{aligned}
\tag{2}
$$

In the first group of constraints the DMU under evaluation moves towards efficient frontier by decreasing its discretionary inputs in direction d_p. In the third group of constraints the DMU under evaluation moves towards efficient frontier by increasing its discretionary outputs in direction d_p. Notably, the non-discretionary inputs are treated like the discretionary inputs with the exception that the non-radial efficiency measure $\theta_i|x_{ip}^D|$ is excluded from the right-hand side of the constraint. Additionally, the non-discretionary inputs do not have any effect in objective function.

Model (2) measures the relative efficiency of DMU$_p$ where σ_p^* shows our proposed efficiency score and θ_i shows discretionary input contraction. φ_r shows output extension. λ_j is the intensity amount for DMU$_j$. The following definitions are used in model (2):

$$\bar{\theta}_p = \max_i\left\{\frac{x_{ip}^D - x_{iI}^D}{|x_{ip}^D|}, x_{ip}^D \ne 0; i = 1,\dots,m_1\right\} \tag{3}$$

$$\bar{\varphi}_p = \max_r\left\{\frac{y_{rI} - y_{rp}}{|y_{rp}|}, y_{rp} \ne 0; r = 1,\dots,s_1\right\} \tag{4}$$

$$x_{iI}^D = \min_j\{x_{ij}^D\};\ i = 1,\dots,m_1, \tag{5}$$

$$y_{rI} = \max_j\{y_{rj}\}; r = 1,\dots,s, \tag{6}$$

If $\bar{\theta}_p = 0$, then the statement(s) $\frac{\theta_i}{\bar{\theta}_p}, (\forall i)$ will be ignored. The following definition shows the optimal values of each input and output. Actually, this definition shows the projected values.

Definition 1: (Projection Point): For DMU_p, assume that $(\theta_i^*, i = 1,\dots,m_1; \varphi_r^*, r = 1,\dots,s; \lambda_j^*, j = 1,\dots,n)$ is the optimal solution obtained from model (2). Hence, the projection of DMU_p is defined as follows:

$$\left(\hat{x}_i^D = x_{ip}^D - \theta_i^*|x_{ip}^D|; \hat{x}_i^{ND} = x_{ip}^{ND}; \hat{y}_r = y_r + \varphi_r^*|y_r|\right),\ \ \forall i,r \tag{7}$$

The projection point is also known as a target value for data. Theorem 1 proves that model (2) is always feasible, and thus, it can be used without extra consideration.

Theorem 1: Model (2) is always feasible.
Proof:
Evidently, the vector $(\lambda_p = 1, \lambda_j = 0, (\forall j, j \neq p);\ \theta_i = 0, \forall i;\ \varphi_r = 0, \forall r)$ is a feasible solution for model (2). This fact completes the proof. □

Theorem 2: If $\bar{\theta}_p = 0$ then $\forall i,\ \theta_i = 0$.
Proof:
Clearly, from the convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$, we have

$$x_{il}^D = \min_j x_{ij}^D \leq \sum_{j=1}^{n} \lambda_j x_{ij}^D \leq \max_j x_{ij}^D \tag{8}$$

And from the first constraint of model (2) and the definition $\bar{\theta}_p$, we have

$$0 \leq \theta_i \leq \frac{x_{ip}^D - \sum_{j=1}^{n} \lambda_j x_{ij}^D}{\left|x_{ip}^D\right|} \leq \frac{x_{ip}^D - x_{il}^D}{\left|x_{ip}^D\right|} \leq \bar{\theta}_p \tag{9}$$

So, if $\bar{\theta}_p = 0$, then we concluded that $\theta_i = 0$ and the proof is completed. □
From Theorem 2, the following corollaries can directly be found that their proofs are straightforward.
Corollary 1: If $\bar{\varphi}_p = 0$ then $\forall r, \varphi_r = 0$.
Theorem 3 guarantees that model (2) sets efficiency score between 0 and 1 for inefficient DMUs.
Theorem 3: $\mathbf{0} \leq \sigma_p^* \leq 1$.
Proof:
According to Theorem 1, for each *i* we have $0 \leq \theta_i \leq \bar{\theta}_p$, then we have $0 \leq \frac{\theta_i}{\bar{\theta}_p} \leq 1$. Similarly, we have $0 \leq \frac{\varphi_r}{\bar{\varphi}_p} \leq 1$. Therefore, for each feasible solution we have

$$0 \leq 1 - \frac{1}{2}\left(\frac{1}{m}\sum_{i=1}^{m} \frac{\theta_i}{\bar{\theta}_p} + \frac{1}{s_1}\sum_{r=1}^{s_1} \frac{\varphi_r}{\bar{\varphi}_p}\right) \leq 1 \tag{10}$$

And hence the proof is completed. □

4 A Real Application: Efficiency Estimation of Kidney Bean Production

Pulses are edible dry grains that belong to the legume family. Beans are the most important member of the legume family. Ripe and dried seeds of beans have high nutritional value, good shelf life and a high percentage of protein. The appropriate combination of bean~~s~~ protein with cereals can eliminate malnutrition and amino acid deficiency. Modern Production of kidney beans require~~s~~ a significant amount of farm finite resource. Managing the cost of kidney bean production and efficient use of farm resources helps the farmers to reduce the expenses and enhance their benefits. Therefore, it improves the quality of life of farmers in rural areas.

4.1 Data Collection

In this study, data were obtained from kidney beans production farms in 12 provinces of Iran during 2014-2015. Five economic inputs were considered in the study consisting of costs of tillage, planting, cultivation, harvesting and land cost. The model output consisted of the total production value of kidney beans.

Dataset of inputs and output variables in kidney bean production are presented in Table 1. The wide variation in economic inputs and the total production value of kidney beans in different provinces indicated inefficient management of resources between farmers, implying a great scope for improving resource consumption in kidney beans production.

Table 1: Dataset of Cost and Benefits of Kidney bean Production in Different Provinces of Iran (in 10 Rials)

Provinces	**DMU**	**Tillage**	**Planting**	**Cultivation**	**harvesting**	**Land**	**Total value production**
West Azarbayjan	DMU1	184601	783152	936052	981051	609601	5634058
Isfahan	DMU2	348718	857306	988291	984615	1858974	1873334
Razavi Khorasan	DMU3	152175	317338	1521412	462608	247826	3002174
Northern Khorasan	DMU4	153846	582308	2080001	943961	250769	2730769
Zanjan	DMU5	171412	1401594	2994157	816625	1182028	5268260
Fars	DMU6	321876	859405	3087469	379125	1534375	3056250
Ghazvin	DMU7	190000	529100	1170000	503300	1000000	5750000
Gilan	DMU8	766667	896999	3113333	984666	1600000	3916667
Lorestan	DMU9	134146	946748	1027035	349024	1158537	5792683
Markazi	DMU10	316666	1527500	2565666	993334	708333	6016667
Kerman	DMU11	369999	803334	983333	991716	800000	5000000
Kohgilouyeh-BoyerAhmad	DMU12	176000	704800	979200	946080	460000	5960000

It must be noted that, in this study the input "Land Cost" is assumed to be non-changeable and hence is considered as the only non-discretionary variable. The results of running the suggested model for efficiency estimation of kidney bean production is presented in Table 2.

Table 2: Efficiency and Reference set of Kidney bean Production in Iran

Province	**DMU**	**Efficiency**			
West Azarbayjan	DMU1	1	1 (1.000)		
Isfahan	DMU2	0.395442	9 (0.190)	12 (0.810)	
Razavi Khorasan	DMU3	1	3 (1.000)		
Northern Khorasan	DMU4	1	4 (1.000)		
Zanjan	DMU5	0.410897	9 (0.217)	12 (0.783)	
Fars	DMU6	0.390022	3 (0.018)	7 (0.182)	9 (0.8)
Ghazvin	DMU7	1	7 (1.000)		
Gilan	DMU8	0.266263	8 (1.000)		
Lorestan	DMU9	1	9 (1.000)		
Markazi	DMU10	1	10 (1.000)		
Kerman	DMU11	0.427087	12 (1.000)		
Kohgilouyeh-BoyerAhmad	DMU12	1	12 (1.000)		
	Average Efficiency Score:	0.740809			

Data were analysed using the suggested model and the efficiency scores for these 12 provinces were determined and the results are shown in the Fig. 1. Seven DMUs were recognized as efficient and the others as inefficient. Therefore, 58% of all DMUs performed efficiently and the rest performed inefficiently.

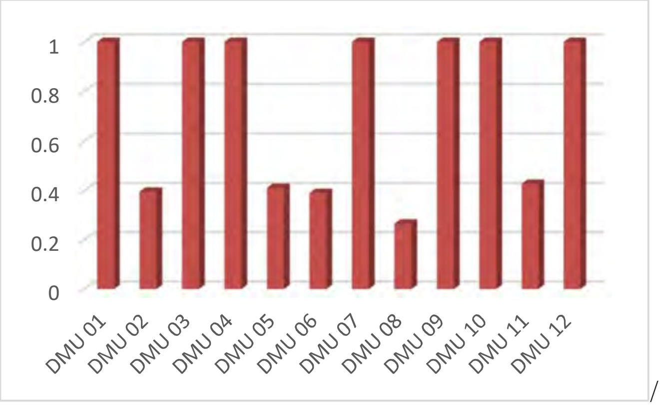

Fig. 1: Efficiency Score of Kidney bean Production

The average value of technical efficiency score of kidney bean production was 0.74. The results of benchmarking of kidney beans show that seven provinces out of 12 provinces are efficient in kidney bean production (Table 2). These farms are a good example for improving the performance of inefficient DMUs.

Table 3: Target Cost for Kidney bean Production in Iran

Province	DMUs	Tillage	Planting	Cultivation	harvesting	Land	Total value production
West Azarbayjan	DMU 01	184601	783152	936052	981051	609601	5634058
Isfahan	DMU 02	168045.7	750782	988291	832610	1858974	5928201.6
Razavi Khorasan	DMU 03	152175	317338	1521412	462608	247826	3002174
Northern Khorasan	DMU 04	153846	582308	2080001	943961	230769	2730769
Zanjan	DMU 05	166925.1	757259.7	989571.7	816625	1182028	5923722
Fars	DMU 06	144623.7	859405	1062006.5	379125	1534375	5734172.6
Ghazvin	DMU 07	190000	529100	1170000	503300	1000000	5750000
Gilan	DMU 08	190000	529100	1170000	503300	1600000	5750000
Lorestan	DMU 09	134146	946748	1027035	349024	1158537	5792683
Markazi	DMU 10	316666	1527500	2565666	993334	708333	6016667
Kerman	DMU 11	176000	704800	979200	946080	800000	5960000
Kohgilouyeh-BoyerAhmad	DMU 12	176000	704800	979200	946080	460000	5960000

In Table 2, the benchmark DMU for DMU 6 is expressed as 3 (0.018), 7 (0.182), 9 (0.8), where 3, 7 and 9 are the DMU numbers while the values between parentheses are the intensity vector λ for the respective DMUs. That is, the DMUs #3, #7 and #9 are recognized as benchmarks for DMU #9 and this DMU should try to make its inputs and outputs levels much closer to benchmarks ones. The intensity values indicate that what portion DMU #6 should receive from each benchmark DMU to become an efficient DMU. For instance, the target inputs/outputs for DMU #6 can be calculated as follows:

Target input/output for DMU #6 = 0.018 * (input/output of DMU #3) +0.182 * (input/output of DMU #7) + 0.8 * (input/output of DMU #9).

The obtained target inputs and target outputs are presented in Table 3. It is important for decision makers to know the optimal values of their inputs and outputs. As mentioned before, these optimal values are known as the target values for data. Each decision maker needs to know the optimum use of input resources and find the distances between their inputs and outputs and the target values to improve their performance. According to Table 4, the average target (optimum) value for "Tillage cost" is 179419.04, while the present value is 273842.16 for the observed period. Result of Table 4 reveals that costs of other operations are reduced using the suggested model.

Table 4. Cost Saving in Kidney Bean Production

	Present use	**Target use**	**Cost saving**	**Saving Percentage**	**Percentage of total Cost**
Tillage	273842.16	179419.04	94423.12	34.48	12.58
Planting	850798.66	749357.73	101440.93	11.92	13.52
Cultivation	1787162.42	1289036.27	498126.15	27.87	66.37
Harvesting	778008.75	721424.84	56583.91	7.27	7.54
Input Cost	3689812.00	2939237.87	750574.13	20.34	100.00
Total value production	4500071.83	5348537.27	848465.46	18.85	

Table 8 demonstrates the present cost use, target cost use and potential cost saving for kidney bean production. When farmers use the input resources efficiently, tillage, planting, cultivation and harvesting costs decrease by 34.48%, 11.92%, 27.87% and 7.27%, respectively, without influencing kidney bean production level.

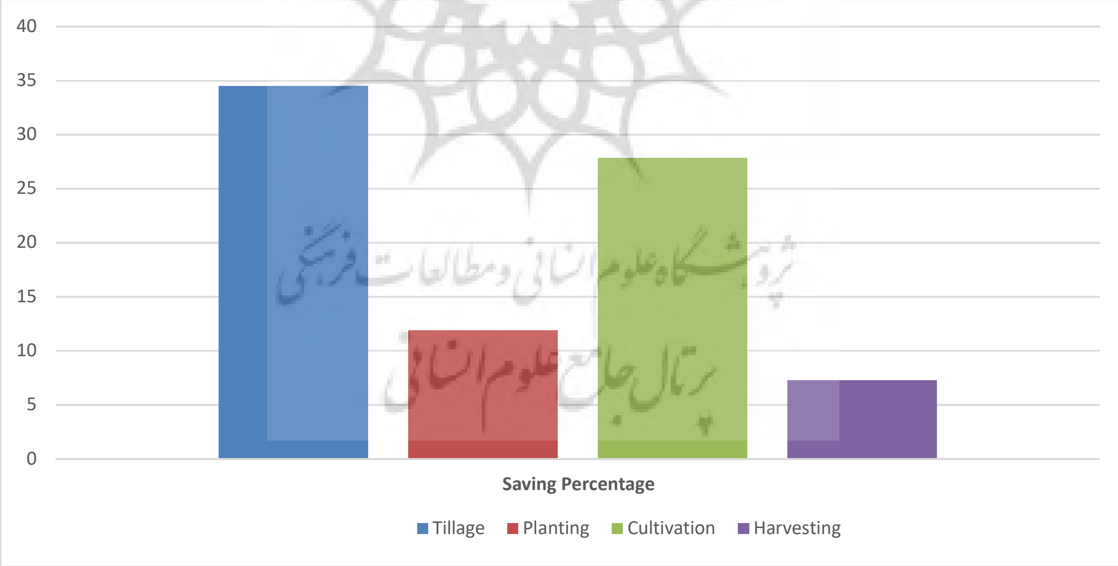

Fig. 2: Saving Percentage of Different Agricultural Operations in Kidney bean Production

5 Conclusions

The various modern approaches of kidney bean production require a significant amount of production costs. The optimum use of agricultural input resources results in increasing efficiency and decreasing production costs. The main aim of this paper is assessing the economic efficiency and benchmarking of Iranian kidney bean farms over the period 2013-2014. Other purposes of the current paper are calculating the optimal use of resources. Data envelopment analysis (DEA) is a well-known mathematical programming approach for determining efficiencies and assessing the performances of the farms. So, DEA methodology was selected to measure the efficiency of kidney bean production. For this purpose, this paper proposed a new non-radial DEA efficiency model considering non-discretionary inputs. In the case study section, the proposed model is applied to evaluate the efficiency of 12 Iranian kidney bean producing provinces. In order to compare the performances of these farms, five inputs were considered. Inputs included cost of tillage, planting, cultivation, harvesting and land. Output consisted of the total production value of the kidney bean. Land cost is a non-controllable variable. Therefore; a non-discretionary DEA approach was applied to estimate efficiency of kidney bean production. The results showed that the average value of technical efficiency score of kidney bean production in Iran was 0.74. The results of benchmarking of kidney bean farms reveals that seven farms out of twelve farms are efficient. These farms are a good example for improving the performance of inefficient farms. When farmers use input resources efficiently, the target cost of tillage, planting, cultivation and harvesting is decreased by 34.48%, 11.92%, 27.87% and 7.27%, respectively, without decreasing kidney bean production level. As for future research, it would be interesting to extend the proposed methodology to cases where fuzzy and stochastic data could be incorporate into the model.

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