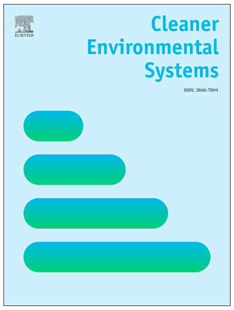
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Efficiency analysis of watermelon under plastic film mulching systems

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Abstract:

Iran is the main watermelon producer in the world after China and Turkey. However, there is no practical information on which region, tillage and cultivation systems can achieve the most efficient watermelon production system in Iran. This study was conducted to assess the most efficient ways of watermelon production in three agroecosystems (cold, moderate, warm) of Iran using Data Envelopment Analysis. The data were collected from two tillage systems (reduced and conventional) and two groups of watermelon cultivations (conventional system and plastic film mulching system). Accordingly, twelve watermelon production systems were under the study including all inputs and outputs. Finally, an Analytical Hierarchy Process model was used to determine the best region and the best combination of cultivation and tillage systems for watermelon production. The technical and pure technical efficiencies of watermelon production systems were respectively 89% to 100%. The Analytical Hierarchy Process model determined that the most efficient watermelon production systems were from combination of plastic film mulching system and reduced tillage in cold and moderate agroecosystem which reduced water and diesel fuel consumption by 500 to 2500 m^3/ha followed by fertilizers by 100 to 150 kg/ha while efficiencies are enhanced by 20% to 32%.

Keywords: technical efficiency, low input production, Analytical Hierarchy Process.

1. Introduction

Different inputs such as fertilizers, pesticides, fuel, water and machinery are used in agriculture and all have some related carbon footprints. Nitrogen fertilizers are the most important direct source of GHG emissions, accounting for around 30% in agricultural fields [1]. Fuel use in different farm operations is also another main source of GHG emissions. Unreasonable application of inputs into agriculture leads to higher economic costs and higher GHG emissions which in turn will cause a warmer Earth, and unwanted irreversible climate changes [2].

An efficient production means that all inputs are used properly with minimum waste. In this regard, an efficient food production system is essential for sustainable agriculture and to meet the requirements of growing population in the world. The efficiency criterion is a potentially rich concept, with a wide range of interpretations, from the ratio of output/ inputs to Pareto efficiency. It forms the bedrock of policy, planning and business approaches to sustainable development and generally defined as the ratio of outputs to inputs [3].

Water saving cultivation systems such as plastic film mulching (PFM) are popular in Iran especially in cold areas. Indeed, Iranian farmers consider the effect of PFM on the improvement of soil temperature more than its effect on the soil moisture conditions [4]. Generally, farmers believe that watermelon production under PFM is better than conventional cultivation. Lovell [5] defines the efficiency of a production unit in terms of a comparison between observed and optimal values of its output and input. The DEA is a linear programming-based efficiency evaluation method which considers each DMU (Decision Making Unit; *i.e.* watermelon farmers in this study) separately [6]. This technique aims to measure how efficiently a DMU uses the resources available to generate a set of outputs [7]. In addition, the efficiency can be assessed by including several inputs and outputs while the unit of data is not necessarily similar [8]. The efficiencies estimated by using DEA are relative, not absolute (*i.e.* relative to the best performing DMU) [9]. These factors, besides focusing on individual observations, make the DEA more useful compared to some parametric approaches like regression [10].

The DMU's efficiency can be measured with regard to inputs (input-oriented), outputs (output-oriented) or both inputs and outputs in the DEA models. Input-oriented models, for instance, determine the efficiency in such a way that the levels of inputs are minimized while the levels of outputs are maintained constant [11]. However, it seems that the reduction in an input and gaining a fixed level of an output is possible in firms; *i.e.* banks, factories or industrial conditions. Since the agricultural conditions are not as stationary as a firm or an industrial factory, the reduction in inputs may change the levels of outputs. A large number of agricultural studies have mainly focused on technical, pure technical and scale efficiencies while very few studied other types of efficiencies [12-14].

Watermelon is an economically important crop worldwide and is among the top five consumed fresh fruits with a planting area of about 3.5 million hectares in the world (http://www.fao.org/). The variation in inputs and yield is high among agroecosystems even with similar soil and weather conditions from one farm to another in Iran. Farmers use different types of tillage and cultivation systems. The combined effects of these factors should be analyzed correctly with suitable models to guide farmers toward efficient production.

To answer this challenge, in this study, the DEA modeling was employed to measure the efficiency of watermelon production. The main contribution of the first step is to show how watermelon production can be produced with lower burdens on the environment by using optimum inputs considering combination of agroecosystems, cultivation and tillage systems in the framework of 12 treatments.

Since different efficiency scores were obtained for each treatment in the present study, an important goal was to understand which treatment is the best choice for the watermelon production. AHP is combined with DEA to estimate, for instance, the weights of different objectives for decision makers or to rank DMUs [15]. Indeed, AHP which needs the “ordinal” pair-wise comparisons of attributes [16], is applied in this stage of study to rank the 12 treatments. In the second step, the analytical hierarchy process (AHP) was employed to rank the treatments based on all efficiency scores to determine the best treatment for watermelon production. This step was essential to reveal the best decision for watermelon production.

2. Methodology

This study was undertaken to evaluate the optimum range of inputs for watermelon production in the farming year 2021 in three agroecosystems of Fars province, Southwest Iran. The agroecosystems are Abadeh (cold), Marvdasht (moderate) and Jahrom (warm) and have distinctive climatic characteristics. Fars province was chosen since it is the top watermelon producer in the country including 15000 ha of watermelon [17].

The province is located within $27^{\circ}\ 03'$ and $31^{\circ}\ 40'$ north latitude and $50^{\circ}\ 36'$ and $55^{\circ}\ 35'$ east longitude. The selected agroecosystem in this study is known as the best watermelon producing area of the province. Marvdasht agroecosystem has a moderate temperature in summer ranging from 15 to 37 degrees centigrade. Due to this suitable weather and the existence of medium to high irrigation water and fertile soil, the agroecosystem has the highest average yield in the country. However, the mean annual precipitation of this agroecosystem is around 300-500 mm/year. Abadeh agroecosystem of the province is not warm with temperature ranging from 15 to 37 degrees centigrade in summer with mean annual precipitation of 500-700 mm/year. Jahrom is located in the warm agroecosystem of the province and the mean, minimum and maximum temperatures of the agroecosystem are 20.8˚C, 11˚C and 44˚C, respectively. The mean annual precipitation of Fars province is around 400-600 mm/year, but in the warm climate of Jahrom (south of Fars) it reaches up to 100 mm/year.

Watermelon growing farmers were chosen from these three agroecosystems as: Marvdasht (G1), Abadeh (G2), Jahrom (G3). Two tillage systems were considered as: conventional (T1) and reduced tillage (T2) systems, and two cultivation systems as: conventional (S1) and plastic film mulching (S2)(Fig. 1). The machinery used in conventional tillage system are: moldboard plow + disk harrow + row crop planter; the machinery used in reduced tillage system are: chisel plow combined with roller + row crop planter. The working depth of tilling machines in both the systems is around 30 cm.

Accordingly, 12 groups of farmers were arranged as treatments in the experiments (*i.e.* 3×2×2). The nested factorial design was applied in this study to assess the individual (G, S and T) and bivariate effects (G×S, G×T, S×T and G×S×T) of factors on efficiency scores. Using ANOVA, the means were compared by the Duncan post-hoc test. All the statistical analyses of variances were made by SPSS 21.

The desired sample size of farmers was calculated by Equation 1 [18]:

$$n = \frac{(N\times Z^2\times p\times q)}{(N\times d^2+Z^2\times p\times q)} \qquad (1)$$

Where: n is the required sample size; N is the number of holdings in target population; Z is the reliability coefficient (1.96 which represents the 95% reliability); p is equal to 0.5; q is equal to 0.5; d is the precision ($\bar{x}$-$\bar{X}$) which is equal to 0.05 in this study. Accordingly, 300 farmers were selected from a total of 1326 watermelon growing farmers as following:

$$n = \frac{(1326 \times 1.96^2 \times 0.5 \times 0.5)}{(1326 \times 0.05^2 + 1.96^2 \times 0.5 \times 0.5)} \approx 300$$

[Insert Fig. 1]

2.1. DEA technique

To assess the efficiency of each watermelon farmer, the DEA technique was applied. Four models were employed to evaluate technical, pure technical, scale, slack based, mix and super efficiencies using the DEA Excel Solver professional 4.1 (SAITECH, Inc., USA). The efficiencies are explained in sections 2.1.1 and 2.1.2.

The DEA was used by three and two inputs and outputs, respectively. In DEA model watermelon yield was considered as good output and carbon emission as bad output. It means that lower carbon emission and higher watermelon yield increase the efficiency of farmers. The inputs of DEA models were: fertilizers (F), seed and chemicals (SC) and water and diesel fuel (WF), while the combined inputs were used with the same unit. Human power was not considered as an input in DEA models since all the agroecosystems used similar range of human power. The input-oriented models were employed in this study.

2.1.1. Technical, Pure technical and scale efficiencies

Technical efficiency is the ability of conversion inputs to outputs [19]. This efficiency is the ratio of sum of weighted outputs to the sum of weighted inputs in a fractional form [20]. This fractional ratio was developed in a linear form using linear programming (LP) which called CCR[1] model as follows [21]:

$$Max:\ \theta = u_1 y_{1i} + u_2 y_{2i} + \cdots + u_r y_{ri} \quad (2)$$

$$Subject\ to:\ V_1 X_{1i} + V_2 X_{2i} + \cdots + V_S X_{Si} = 1 \quad (3)$$

$$u_1 y_{1j} + u_2 y_{2j} + \cdots + u_r y_{rj} \leq V_1 X_{1j} + V_2 X_{2j} + \cdots + V_S X_{Sj} \quad (4)$$

$$u_1, u_2, \ldots, u_r \geq 0 \quad (5)$$

$$V_1, V_2, \ldots, V_S \geq 0, and\ (i\ and\ j = 1, 2, \ldots, K) \quad (6)$$

where ‘θ’ is the technical efficiency, ‘i’ and ‘j’ are the ith and jth DMUs, ‘x’ and ‘y’ are the input and output, and ‘v’ and ‘u’ are the input and output weights, respectively, ‘s’ is the number of inputs (s = 1,2,. . .,m) and ‘r’ is the number of outputs (r = 1,2,..,n).

Technical efficiency includes pure and scale efficiencies. The BCC[2] model measures the pure technical efficiency [22]. This efficiency has also been called management efficiency [13, 23, 24] which shows the share of DMU’s management on the technical efficiency. The BCC model can be expressed by Dual Linear Program (DLP) as [22]:

$$Max: Z = uy_i - u_i \quad (7)$$

$$Subject\ to: VX_i = 1 \quad (8)$$

$$-vX + uY - u_o e \leq 0 \quad (9)$$

$$v \geq 0, u \geq 0 \quad (10)$$

Where z and u_o are scalar and free in sign, ‘i’ and ‘j’ are the ith and jth DMUs, ‘x’ and ‘y’ are the input and output, and ‘v’ and ‘u’ are the input and output weights.

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[1] . CCR: Charnes, Cooper and Rhodes

[2] . BCC: Banker, Charnes and Cooper.

The efficiency is calculated in CCR with the assumption that return to scale is constant while return to scale is assumed to be variable in the BCC. Generally, the CCR efficiency does not exceed BCC efficiency [20]. Both the CCR and BCC models were applied in input-oriented forms since the aim was to reduce the level of inputs in the watermelon production. Another part of technical efficiency depends on the DMU's working conditions which is called scale efficiency. This efficiency represents the effect of conditions on the DMU's efficiency and is defined as follows [25]:

$$Scale\ efficiency = \frac{Technical\ efficiency}{Pure\ technical\ efficiency} \tag{11}$$

The working conditions for economic firms (such as banks) are considered as the firm size, the number of clerks and so on [26]. It is proposed that the conditions in agriculture can be divided into two groups. The first group of conditions is under farmers' control and changeable; *i.e.* the size of farms, the farming technology including farm machines and irrigation system etc. The second group of conditions is uncontrollable; *i.e.* the weather, soil texture and structure and so on.

1.1.2. SBM, mix and super efficiencies

The model SBM[3] considers both inputs and outputs to measure the DMUs' efficiencies. This would be beneficial since the decrease and increase respectively in inputs and outputs are achieved simultaneously.

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[3] . SBM: Slack Based Measure.

The SBM is introduced to evaluate the efficiency based on the slack values [27]. The SBM efficiency score is less than CCR efficiency score, and CCR inefficient DMU never becomes SBM efficient. The SBM model is formulated as follows [28]:

$$Max: \sum_{i=1}^{m} S_{i^-} + \sum_{r=1}^{s} S_{r^+} \tag{12}$$

$$Subject\ to: \sum_{j=1}^{n} \lambda_j x_{ij} + S_{i^-} = x_{io} \qquad i = 1,2, \dots, m; \tag{13}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - S_{r^+} = y_{ro} \qquad r = 1,2, \dots, s; \tag{14}$$

$$\lambda_j, S_{i^-}, S_{r^+} \geq 0 \tag{15}$$

Where ${S_i}^-$ and ${S_r}^+$are the excess and shortfall in inputs and outputs, respectively. Various SBM models have been developed so far, although there may be some differences between the analytical methods used [27].

The SBM includes technical and mix efficiencies. The mix inefficiency appears when only some (but not all) inputs (or outputs) are identified as displaying efficient behavior. In other words, mix efficiency shows the best combination of inputs. The mix efficiency is:

$$Mix\ efficiency = \frac{SBM}{Technical\ efficiency} = \frac{SBM}{Pure\ technical\ efficiency \times Scale\ efficiency} \tag{16}$$

Super efficiency allows the efficiency scores to be more than 100% to rank the efficient DMUs. However, this efficiency was used in this study to determine the best farmers which were called “excellent farmers”. The super efficiency model is formulated as follows [20, 29]:

$$Min: \theta^{super} \tag{17}$$

$$Subject\ to\colon \sum\nolimits_{j=1,j\neq 0}^{n} \lambda_j x_{ij} \leq \theta^{super} x_{io} \qquad i = 1,2,\dots,m; \tag{18}$$

$$\sum\nolimits_{j=1,j\neq 0}^{n} \lambda_j y_{rj} \geq y_{ro} \qquad r = 1,2,\dots,s; \tag{19}$$

$$\lambda_j\,, j\ \neq 0 \tag{20}$$

Where ‘θ^{super}’ is the super efficiency. It was expected that sustainability and efficiency scores would remarkably be enhanced by following excellent farmers since such the farmers produce the highest level of outputs using the lowest level of inputs.

2.2. AHP

The AHP was employed to determine the most secure system for watermelon production. Since the basic of AHP can be found in many books and previous studies, it is not repeated here. The ranking of production systems, as the main objective of this study, stays in the first level or main goal in the AHP model (Fig. 2). The twelve treatments were considered as the alternatives. The ‘efficiency models’ was put on a hierarchical structure as the criteria:

Efficiency criteria:

SC1: Technical efficiency (TE);
SC 2: Pure technical efficiency (PTE);
SC 3: Scale efficiency;
SC 4: Slack based measure efficiency (SBM);
SC5: Mix efficiency;
SC6: Super efficiency.

[Insert Fig. 2]

17 experts in agriculture, environment and economy were asked to make the pairwise comparisons between the efficiency sub-criteria to obtain the weights. All the inconsistency indices were lower than 0.1 which was important to avoid inconsistent pairwise comparisons [30]. The judgment of each expert was entered into the AHP model and the average of the final weights was considered as the main weight. The Expert Choice software (version 11, Expert Choice Inc.) was used to calculate the weight of each criterion and finally the ranks of alternatives; *i.e.* treatments.

3. Results and discussion

3.1. Inputs and output of watermelon production systems

The data show that the highest watermelon yield is produced in treatment G1.S2.T2 with 20.94 ton/ha (Table 1). The yield is higher in PFM farms (S2) and conservation tillage system (T2) by around 1.2 ton/ha in each agroecosystem. Water use is also lower in PFM farms by around 3300 m^3/ha (around 560 kg CO_2) due mainly to water saving under plastic films. Although higher seed is used in agroecosystem 3, lower yield is produced in this agroecosystem which would lead to lower efficiency in this agroecosystem. Fewer farm machines are used in T2 system, especially at soil tilling stages, which leads to around 35 L/ha lower diesel fuel consumption and 177 kg/ha lower carbon emission in conservation tillage systems.

[Insert Table 1]

Chisel plow is the common equipment used in T2 systems which works deeper than usual tillage equipment like moldboard plow. Using flood irrigation systems combined with chisel plow would lead to higher water consumption and lower yield since most irrigation water infiltrated into deeper soil layers. Large amounts of fertilizers are currently used and wasted in

Iranian farms since most farmers use various types of fertilizers without conducting soil sampling. This problem is annoying particularly in small farms using conventional cultivation system.

Many studies evaluated the amounts of inputs and outputs of different crops while there are few studies on the inputs and outputs of watermelon production. A study revealed that the highest energy inputs for watermelon production in Hamedan province of Iran were nitrogen, water and diesel fuel of around 61.6%, 20% and 8.6%, respectively [31]. Another study in Hamedan province of Iran showed that energy consumption of owners and non-owners of farm machinery was 67674.24 MJ/ha and 68788.37 MJ/ha, respectively [32]. Rostami et al., (2018) stated that watermelon production needed 79601.66 MJ/ha and 78163.86 MJ/ha under custom tillage and conservation tillage application, respectively [33]. A study in Guilan province of Iran showed that 40228.98 MJ/ha energy is consumed in watermelon production with the highest energy input of nitrogen fertilizer and diesel fuel of around 69.6% and 8.6%, respectively [34].

A study in Turkey evaluated that fertilizer and diesel fuel are the main inputs for watermelon production. The consumption of nitrogen fertilizer in Turkey is close to that of Iran at around 60 kg/ha, while Turkish watermelon growing farmers consumed around 100 L/ha diesel fuel, 40 L/ha more than that of Iranian farmers [35]. Nitrogen, electricity and diesel fuel are consumed more than other inputs in watermelon production in northeast of Iran [36] . A study in India stated that the cost of seed, manure and fertilizer and irrigation water were more than other inputs for watermelon production [37]. The Nigerian farmers consume around 25 kg/ha fertilizer to obtain around 650 kg/ha of watermelon [38].

3.2. Efficiency analysis using DEA

The results of the DEA models show that the averages of technical efficiencies are almost high, ranging from 89% to 97% (Table 2). The highest technical efficiency belongs to treatment G1.S2.T2 with 97% and the lowest come from treatments G1.S1.T1 and G1.S1.T2 with 89%.

In spite of the close average technical efficiencies in the treatments, the percentages of efficient farmers (100% efficiency) are much different between the treatments. Treatments G1.S2.T2 and G3.S1.T2 contain the highest and the lowest percentage of efficient farmers with 86.62% and 28.57%, respectively. Since the model CCR includes both the BCC and scale efficiencies, technical inefficiency is due to farmers' management (pure technical inefficiency) or agricultural conditions (scale inefficiency). Hence, the BCC and scale efficiencies should be analyzed carefully to find the reasons of farmers' technical inefficiencies.

[Insert table 2]

The output of model BCC shows that 97% to 99% of farmers are highly pure technical efficient (Table 2). High pure technical efficiency displays two aspects: the first is that the farmers are able to manage their farms properly, and the second is that the large portions of technical inefficiencies are because of scale inefficiencies rather than pure technical inefficiencies. In other words, it can be said that farmers' technical efficiencies are affected by agricultural conditions (scale efficiency) not their management.

The scale inefficiency in each agroecosystem come from some variables such as farm size, cultivation type, irrigation technology, farm machinery and tillage systems. The other variables such as type of seed, chemical and fertilizer would affect the scale efficiency, but they are ignored in this study since similar chemicals, fertilizers and seed variety are used in the study area. Although some comments are not supported by data given in Tables 1-6, the comments are given based on the local authors' experiences. The averages of scale efficiencies are rather higher in T2 compared to T1 (G1.S1.T1 versus G1.S1.T2 and G1.S2.T1 versus G1.S2.T2) and S2 compared to S1 (G1.S1.T1 versus G1.S2.T1 and G1.S1.T2 versus G1.S2.T2). Statistically, Table 3 confirms that scale efficiency is significantly affected by agroecosystems (G) and cultivation systems (S) at $P < 0.01$ and $P < 0.001$ significance levels, respectively. Although the effect of tillage (T) is not statistically significant, it is near to 0.05 probability level by 0.065. It is clear that scale efficiencies must be different between the agroecosystems since the agroecosystems have different soil and weather characteristics which is not under farmers' control. However, the cultivation and tillage system are controllable variables which can be changed in the favor of higher efficiency.

[Insert table 3]

The highest scale efficiencies in each agroecosystem are obtained when the reduced tillage (T2) is employed in PFM farms (S2); *i.e.* the treatments G1.S2.T2 (98%), G2.S2.T2 (97%) and G3.S2.T2 (95%). Consequently, the highest technical efficiencies are also obtained from these three treatments by 97%, 96% and 93%, respectively. The obvious difference between conventional and PFM farms may be related to irrigation systems since tube system is more used in PFM farms while furrow irrigation is mainly employed in conventional farms. Some previous studies confirm that PFM farming achieve higher yield and efficiency [39].

The distinct difference between T1 and T2 is due to the farm preparation machines in addition to the higher stubble and consequent hard furrow irrigation in T2. T2 leads to higher efficiency in PFM farms mainly due to modern irrigation technology, better soil temperature and humidity since similar tractors and equipment are used in S1 and S2 farms.

Adversely, T2 in S1, which furrow irrigation is commonly used, results in a lower efficiency (the treatments G1.S1.T2, G2.S1.T2 and G3.S1.T2) which implies the importance of soil and water management [40].

The efficiency scores are reduced by around 10% to 20% in the model SBM compared to the CCR. As discussed, the SBM includes the results of both technical and mix efficiencies which display that the SBM inefficiency contains pure technical, scale and mix inefficiencies. The ranges of mix efficiencies show that inefficiencies in the SBM are due mainly to mix, not technical inefficiencies. The mix inefficiency explains that mixes of inputs are not properly applied or some (but not all) inputs or outputs are identified as exhibiting inefficient behavior. Following the result of SBM is practically essential to reach higher mix efficiencies, since the model suggests all necessary decreases and increases in inputs and outputs. The excesses and shortfalls respectively in inputs and outputs are shown in Fig. 3 which guides inefficient farmers to improve their efficiency up to 100%. The “excesses in inputs” shows which inputs are consumed extravagantly. The ‘shortfall in output” means that the yield should be increased according to the inputs.

Fig. 4 shows that the highest reduction should be applied on water and diesel fuel (WF) by 500 to 2500 m^3/ha followed by fertilizers (F) by 100 to 150 kg/ha. This result is similar to a study in West of Iran where fertilizer and water are over-utilized in watermelon production [32]. Another study in North of Iran shows that nitrogen and fuel are used extravagantly [33].

Additionally, the yield should be increased by 3.2 to 4.6 ton/ha in all treatments which imply higher income and consequent economic sustainability. Although the averages are discussed here, the DEA help inefficient farmers one by one to increase their efficiencies. The detailed results of the SBM model in Table 4 show that the inefficient farmer 37 should follow the efficient farmer 28 to be an efficient one. It clearly guides the inefficient farmer to decrease F, CS and WF by 50 kg/ha, 4 kg/ha and 2400 m^3/ha, respectively to reach the farmer 28. These reduction lead to less GHG emissions accordingly.

[Insert Fig. 3]

[Insert Fig. 4]

The result of super efficiency determines the excellent farmers who have the highest outputs with the lowest inputs. The super efficient farmers prove that highly efficient watermelon production is possible. Despite high averages of super efficiencies in different treatments, only 10-30% of farmers are super efficient. Hence, noticeable enhancements in efficiency scores of watermelon production are expected if inefficient farmers follow the super efficient ones properly.

[Insert table 4]

3.2.1. Efficiency analysis based on tillage systems (T)

Efficiency scores based on tillage systems in Table 4 show that T2 leads to higher technical and scale efficiencies by 1% to 5% compared to T1 (G1-T2, G2-T2 and G3.T2 versus G1.T1, G2-T1 and G3.T1, respectively). The highest technical and scale efficient farmers are located in the treatment G1 and T2 with 36.99% and 39.73%, respectively. The higher average of technical and scale efficiencies of T2, in addition to higher efficient farmers, both display that the reduced tillage system is a more secure technology for the watermelon production. The frequencies of farmers show that all the technical, pure technical and scale efficiencies are above 50%. However, higher percentages of T1 farmers are pure technical efficient by around 6% to 9% which indicates that farmers cannot manage the reduced tillage system as well as the conventional. As the last section shows, the PFM farmers (S2) have higher technical and scale efficiencies. As Table 4 shows, the farmer 79 should follow the farmer 26 to be efficient by decreasing CS and WF by 4.44 kg/ha and 4514.65 m^3/ha, respectively. The detailed analysis also shows that in T1 and T2 groups, a higher percentage of PFM farmers, by 60% to 70%, are determined as efficient particularly when T2 is applied.Therefore, it can be again confirmed that T2 is a suitable tillage system for the agroecosystem especially when farmers use plastic film to mulch watermelons.

The model SBM reveals that higher SBM scores are obtained from T2 in G1 and G2. Both the models SBM and super efficiency indicate higher percentages of efficient farmers in T2. To practically increase the efficiency, Fig. 4 shows that T1 needs higher reduction on water and fuel (WF) and fertilizers (F) in G1 and G2 (treatments G1-T1 and G2-T1 versus G1-T2 and G2-T2, respectively).

3.2.2. Efficiency analysis based on cultivation systems (S)

The result of DEA models explains that PFM farms lead to higher technical, scale, SBM, mix and super efficiency scores by around 2% to 14% (G1-S1 to G3-S2 in Table 5). Pure technical efficiencies show that farmers have almost similar managements in conventional and PFM farms. Despite this, higher scale efficiencies are obtained in PFM farms of 3% to 7%. Hence, this suggests that watermelon production is more beneficial when PFM is applied.

[Insert table 5]

The SBM scores are higher in PFM farms. Since both cultivation systems have similar pure technical efficiencies, it is clear that the SBM inefficiency is due, mainly, to scale and mix inefficiencies. To enhance the efficiencies based on the model SBM, Fig. 5 shows that necessary reduction in water and diesel fuel (WF) consumption is higher in conventional cultivation system (S1) by around 100-3400 m^3/ha.

As discussed, the PFM farmers use more modern irrigation systems, especially tube, which leads to lower water consumption. Watermelon yield is expected to increase by around 2.5-4.8 ton/ha (Fig. 5). Detail assessments revealed that the high cost of modern irrigation systems inhibits some farmers from using them. Based on the agricultural experts' idea, low interest government loans may be an effective way to support farmers to use modern irrigation systems.

The averages of super efficiencies indicate that higher percentages of excellent farmers are in PFM farms. Despite this, only 15% to 40% of farmers are super efficient which display that high numbers of inefficient farmers in both groups (S1 and S2) have to follow the efficient ones if reaching to higher efficiency is desired.

[Insert Fig. 5]

3.3. Most efficient system to produce watermelon

As described, the efficiency scores (Table 6) were entered into the AHP model based on the weights from experts' pair-wise comparisons. The weights of 'efficiency' criteria including TE, PTE, scale, SBM, mix and super efficiencies are 0.143, 0.163, 0.152, 0.152, 0.275 and 0.116, respectively.

The results show that the most secure watermelon production system is the combination of G1-S2-T2 (Fig. 6). It means that the best combination of region, cultivation and tillage system for watermelon production is using conservation tillage system with mulching by plastic film in region 1.

Close consideration of Fig. 6 reveals that the focus should be on the T2 and S2 (first two choices) while PFM (S2) is more important even when the farmers use T1 (compare the first and the second choices versus the third and the forth ones).

[Insert table 6]

The higher ranks of the third and the fourth treatments versus the fifth and the sixth treatments indicate that the watermelon production by conventional tillage system in PFM farms; *i.e.* S2-T1 is more suitable than the conservation tillage in conventional farms; *i.e.* S1-T2. Since the four last ranks are related to G3, it is strongly suggested that some suitable crops should be introduced to farmers to be planted as the substitute for watermelon.

[Insert Fig. 6]

4. Conclusion

Four DEA models were used in the study to assess the efficiency of watermelon production. Plastic film mulching (S2) and reduced tillage system (T2) led to higher scale efficiencies. However, finding the optimum farm size for watermelon production is recommended for future studies. When reduced tillage was used in PFM farms (*i.e.* T2 in S2), the efficiency, particularly scale efficiency, was enhanced. Accordingly, it is suggested that employing plastic film technologies would result in higher scale and consequently technical efficiencies. Water and fuel (WF) and fertilizers (F) were used extravagantly by the highest excess of 500 to 2500 m^3/ha and 50 to 150 kg/ha, respectively according to the SBM results. The inefficient use of water, fuel and fertilizers by watermelon farmers can be explained, at least in part, by the Iranian government's policies of subsidizing farm input. These subsidies were meant to boost the outputs whereas the results from the present study showed that they are often ineffective, causing a waste of resources. The outcome of the AHP model showed that the best treatment for the watermelon production was G1-S2-T2, i.e. using reduced tillage system with PFM in agroecosystem 1. The four first ranks of AHP analysis displayed that the focus should be on the production in PFM farms accompanied with reduced tillage system.

Agriculture is responsible for a remarkable environmental impact, Nevertheless, there is still room for improvement. However, the possibility to identify solutions able to increase the efficiency and/or reduce the environmental impact of agricultural systems relies on the analysis of the actual situation for the different production systems. An advantage of the current study is that the result of the research offers substantial insight into the empirical assessment of the efficiency at farm level, which is essential for policy making. Indeed, policy makers may need farm-level indicators for a variety of reasons, including the evaluation of competing green claims from the farming community and the identification of the need for new policies to mitigate the environmental impacts of agricultural policies [41]. Another advantage of this study is that different DEA models were considered to evaluate efficiencies from different aspects. However, efficiency analysis of several years may open new windows for policy makers which is recommended for future studies.

Our article, therefore, shows that efficiency scores constitute a first step in the design of policy measures aimed at enhancing efficiency at the farm and local farming level. In addition, it is suggested that the combined effects of tillage systems and cultivation systems on the sustainability and efficiency should be investigated in detail in future studies.

There are some uncontrolled inputs in agriculture such as weather, soil conditions, etc. One shortfall of this study was that these inputs were not considered in the efficiency analyses which can be used in DEA models as “uncontrolled inputs” in future studies. Another shortfall of the study is that the inputs of the DEA models could have been energy data. The energy use for plastic production can be considered in the analyses. This idea is suggested for future studies.

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Table 1: Inputs and yield of watermelon farms

Item	Treatments [a]											
	G1_S1_T1	G1_S1_T2	G1_S2_T1	G1_S2_T2	G2_S1_T1	G2_S1_T2	G2_S2_T1	G2_S2_T2	G3_S1_T1	G3_S1_T2	G3_S2_T1	G3_S2_T2
Diesel fuel (L/ha)	104.77	65.92	102.38	63.41	110.24	72.67	107.73	68.31	116.03	76.06	114.75	68.85
Nitrogen (kg/ha)	254.47	241.05	257.5	227.86	261.1	269.39	269.29	237.86	200.71	253.57	212.14	243.57
phosphate, potash and micro fertilizers (kg/ha)	88.99	81.18	98.95	91.9	74.49	72.5	75.3	87.23	52.39	58.2	58.23	64.4
chemical pesticides (kg/ha)	3.98	3.82	3.16	3.91	3.78	4.57	3.87	4.43	3.84	4.1	3.27	3.98
Water (1000 m^3/ha)	7.78	8.76	6.69	6.59	7.73	9.01	6.76	6.76	8.1	9.81	8.62	9.11
Seed (kg/ha)	9.43	9.53	8.91	9.74	9.19	10.14	9.8	9.4	10.8	11.23	10.46	11.03
Yield (ton/ha)	19.03	19.54	20.22	20.94	18.14	19.2	20.13	20.77	14.23	15.75	14.88	16.16

[a] G1, G2 and G3 are moderate, cold and warm agroecosystems, respectively; T1 and T2 are conventional and reduced tillage systems, respectively; S1 and S2 are conventional cultivation and plastic film mulching, respectively.

Table 2: The mean of farmers' efficiency scores according to each treatment

		Treatments											
		G1_S1_T1	G1_S1_T2	G1_S2_T1	G1_S2_T2	G2_S1_T1	G2_S1_T2	G2_S2_T1	G2_S2_T2	G3_S1_T1	G3_S1_T2	G3_S2_T1	G3_S2_T2
No. of farmers		55	22	26	20	34	20	20	20	20	20	20	20
CCR model (technical efficiency)	Efficient	18	6	13	12	17	7	11	9	8	6	8	7
Inefficient	> 80%	27	10	11	7	14	12	9	10	9	13	10	13
	50-80%	10	5	2	1	3	1	0	1	3	1	2	0
	< 50%	0	1	0	0	0	0	0	0	0	0	0	0
	Mean (%)	89	89	94	97	93	93	96	96	91	92	91	93
BCC model (pure technical efficiency)	Efficient	36	10	18	14	21	13	15	14	15	15	16	15
Inefficient	> 80%	19	12	8	6	13	7	5	6	5	5	4	5
	50-80%	0	0	0	0	0	0	0	0	0	0	0	0
	< 50%	0	0	0	0	0	0	0	0	0	0	0	0
	Mean (%)	98	97	98	98	99	99	99	99	99	99	99	98
SE (scale efficiency)	Efficient	18	8	14	13	20	8	12	10	8	6	8	8
Inefficient	> 80%	27	12	11	7	12	11	8	9	10	13	10	12
	50-80%	9	2	1	0	2	1	0	1	2	1	2	0
	< 50%	0	0	0	0	0	0	0	0	0	0	0	0
	Mean (%)	90	92	95	98	95	94	96	97	92	93	92	95
SBM (slack based model)	Efficient	15	3	11	9	10	4	8	5	5	2	6	6
Inefficient	> 80%	10	4	5	7	11	6	4	9	7	5	7	4
	50-80%	30	14	10	4	13	10	8	6	7	12	7	10
	< 50%	0	1	0	0	1	0	0	0	1	1	0	0
	Mean (%)	79	73	85	91	82	82	83	84	82	75	80	82
Mix Efficiency	Efficient	15	3	11	9	10	5	8	5	5	2	6	6
Inefficient	> 80%	28	9	9	11	20	10	6	11	13	10	8	8
	50-80%	12	10	6	0	4	5	6	4	2	8	6	6
	< 50%	0	0	0	0	0	0	0	0	0	0	0	0
	Mean (%)	88	81	91	94	88	87	86	88	89	81	87	87
Super Efficiency	Super efficient	10	3	6	6	6	2	3	3	3	1	2	3
	Efficient	9	4	6	7	8	6	5	5	6	3	5	3
Inefficient	> 80%	27	12	10	7	19	12	9	11	8	11	11	14
	50-80%	8	3	4	0	1	0	3	1	3	5	2	0
	< 50%	0	0	0	0	0	0	0	0	0	0	0	0
	Mean (%)	92	90	93	96	96	93	93	94	93	89	93	95

[a] G1, G2 and G3 are moderate, cold and warm agroecosystems, respectively; T1 and T2 are conventional and reduced tillage systems, respectively; S1 and S2 are conventional cultivation and plastic film mulching, respectively.

Table 3: Statistical analysis of efficiency scores from DEA models

DEA models	Source of variance[a]						
	G	**S**	**T**	**G×S**	**G×T**	**S×T**	**G×S×T**
CCR model (technical efficiency)	0.003**	0.000***	0.150 ns	0.015*	0.583 ns	0.509 ns	0.725 ns
BCC model (pure technical efficiency)	0.000***	0.390 ns	0.377 ns	0.280 ns	0.063 ns	0.957 ns	0.076 ns
SE (scale efficiency)	0.009**	0.000***	0.065 ns	0.025*	0.223 ns	0.482 ns	0.940 ns
SBM (slack based model)	0.111 ns	0.000***	0.443 ns	0.002**	0.707 ns	0.007**	0.268 ns
Mix efficiency	0.168 ns	0.001**	0.038*	0.001**	0.158 ns	0.000***	0.145 ns
Super efficiency	0.146 ns	0.248 ns	0.553 ns	0.104 ns	0.646 ns	0.091 ns	0.607 ns

G1, G2 and G3 are moderate, cold and warm agroecosystems, respectively; T1 and T2 are conventional and reduced tillage systems, respectively; S1 and S2 are conventional cultivation and plastic film mulching, respectively.

[a] , The numbers are P values.

* , ** and ***: Show significant difference at 0.05, 0.01 and 0.001 probability level, respectively.

Table 4. Guiding the inefficient farmers 37 and 79 how to be efficient based on the SBM results

DMU No.	DMU Name	Input Slacks			Output Slacks
		(I) F	(I) CS	(I) WF	(O) Yield
28 (efficient)	1-2-1	0.000	0.000	0.000	0.000
37 (inefficient)	1-2-1	50.000	4.000	2400.026	6.200
26 (efficient)	2-1-1	0.000	0.000	0.000	0.000
79 (inefficient)	2-1-2	0.000	4.445	4514.656	3.455

Table 5: The mean of farmers' efficiency scores according to tillage systems (T) and cultivation systems (S)

		Treatments											
		Tillage systems (T)						**Cultivation systems (S)**					
Model	**Item**	**G1_T1**	**G1_T2**	**G2_T1**	**G2_T2**	**G3__T1**	**G3__T2**	**G1_S1**	**G1_S2**	**G2_S1**	**G2_S2**	**G3_S1**	**G3_S2**
No. of farmers		81	42	55	41	41	41	77	46	55	41	41	41
CCR model (TE)	Efficient	21	16	18	13	10	9	12	16	16	14	8	11
Inefficient	> 80%	41	19	30	25	22	29	39	27	31	26	24	22
	50-80%	19	7	7	3	9	3	26	3	8	1	9	8
	< 50%	0	0	0	0	0	0	0	0	0	0	0	0
	Mean (%)	88	91	91	93	88	91	85	92	91	94	88	90
BCC model (PTE)	Efficient	48	22	27	22	28	28	40	27	28	23	27	28
Inefficient	> 80%	33	20	28	19	13	13	37	19	27	18	14	13
	50-80%	0	0	0	0	0	0	0	0	0	0	0	0
	< 50%	0	0	0	0	0	0	0	0	0	0	0	0
	Mean (%)	98	97	98	98	98	98	97	97	98	98	99	98
SE	Efficient	22	17	19	15	10	10	13	19	17	16	9	12
Inefficient	> 80%	44	21	31	24	24	28	46	27	33	24	25	22
	50-80%	15	4	5	2	7	3	18	0	5	1	7	7
	< 50%	0	0	0	0	0	0	0	0	0	0	0	0
	Mean (%)	89	93	93	95	89	92	88	94	92	96	89	91
SBM	Efficient	17	9	12	8	6	5	8	13	11	8	4	8
Inefficient	> 80%	15	11	12	11	10	9	10	14	17	14	11	9
	50-80%	45	21	30	20	21	25	50	19	26	19	24	25
	< 50%	4	1	1	2	4	2	9	0	1	0	2	0
	Mean (%)	76	79	78	79	76	77	69	83	80	81	75	77
Mix Eff.	Efficient	17	9	12	8	6	5	8	13	11	8	4	8
Inefficient	> 80%	39	23	27	18	23	22	33	23	33	22	25	20
	50-80%	25	10	16	15	11	14	36	10	11	11	12	13
	< 50%	0	0	0	0	0	0	0	0	0	0	0	0
	Mean (%)	86	87	85	85	83	87	81	90	88	88	84	86
Super Eff.	Super efficient	12	7	9	5	5	3	8	8	10	6	3	5
	Efficient	11	10	8	7	6	5	10	12	9	7	4	5
Inefficient	> 80%	39	18	32	22	23	28	44	21	31	20	25	29
	50-80%	19	7	6	7	7	5	15	5	5	8	9	2
	< 50%	0	0	0	0	0	0	0	0	0	0	0	0
	Mean (%)	89	93	92	91	91	90	90	93	93	94	89	90

[a] G1, G2 and G3 are moderate, cold and warm agroecosystems, respectively; T1 and T2 are conventional and reduced tillage systems, respectively; S1 and S2 are conventional cultivation and plastic film mulching, respectively.

Table 6: Efficiency scores used in the AHP model

		Treatments											
	Item*	G1_S1_T1	G1_S1_T2	G1_S2_T1	G1_S2_T2	G2_S1_T1	G2_S1_T2	G2_S2_T1	G2_S2_T2	G3_S1_T1	G3_S1_T2	G3_S2_T1	G3_S2_T2
Efficiency	TE	0.89	0.89	0.94	0.97	0.93	0.93	0.96	0.96	0.91	0.92	0.91	0.93
	PTE	0.98	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98
	SE	0.90	0.92	0.95	0.98	0.95	0.94	0.97	0.97	0.92	0.93	0.92	0.95
	SBM	0.79	0.73	0.85	0.91	0.82	0.82	0.83	0.84	0.82	0.75	0.80	0.82
	Mix	0.88	0.81	0.91	0.94	0.88	0.87	0.86	0.88	0.89	0.81	0.87	0.87
	Su.E	0.92	0.90	0.93	0.96	0.96	0.93	0.93	0.94	0.93	0.89	0.93	0.95

[a] G1, G2 and G3 are moderate, cold and warm agroecosystems, respectively; T1 and T2 are conventional and reduced tillage systems, respectively; S1 and S2 are conventional cultivation and plastic film mulching, respectively.

[*] TE: Technical Efficiency; PTE: Pure Technical Efficiency; SE: Scale Efficiency; SBM: Slack Based Measure efficiency; Mix: Mix efficiency; Su.E: Super Efficiency.

Fig. 1. Plastic film mulching (PFM) and conventional watermelon cultivation

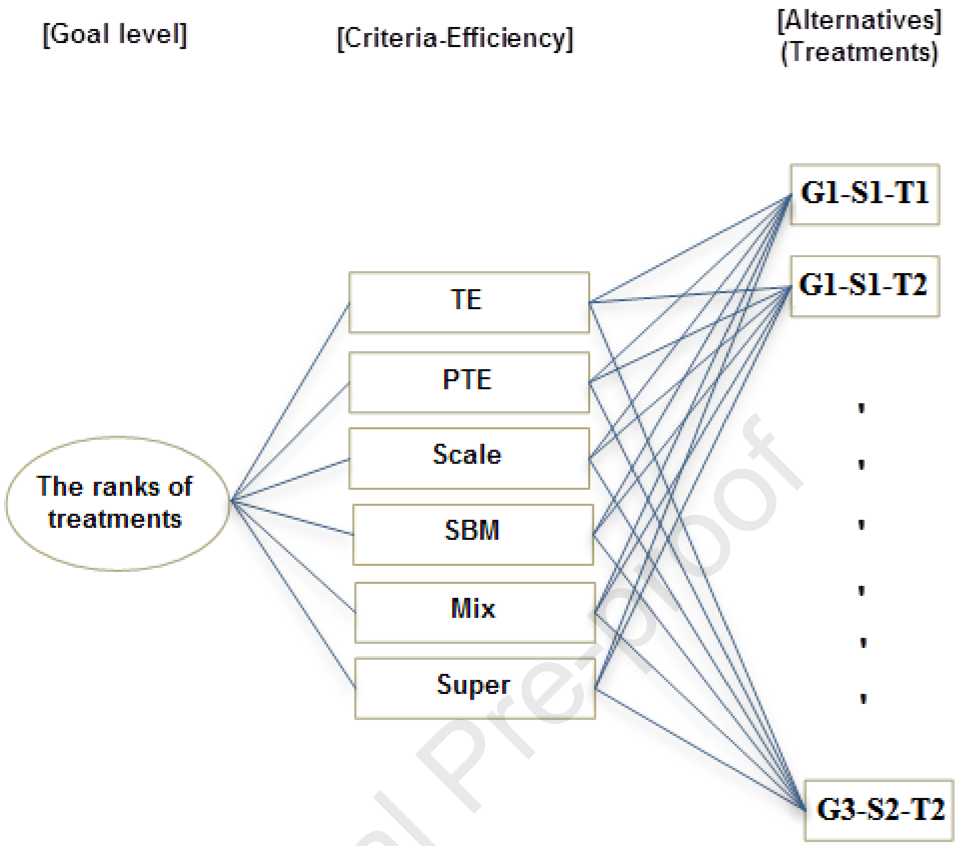

Fig. 2. **AHP decision tree to determine the ranks of the treatments**

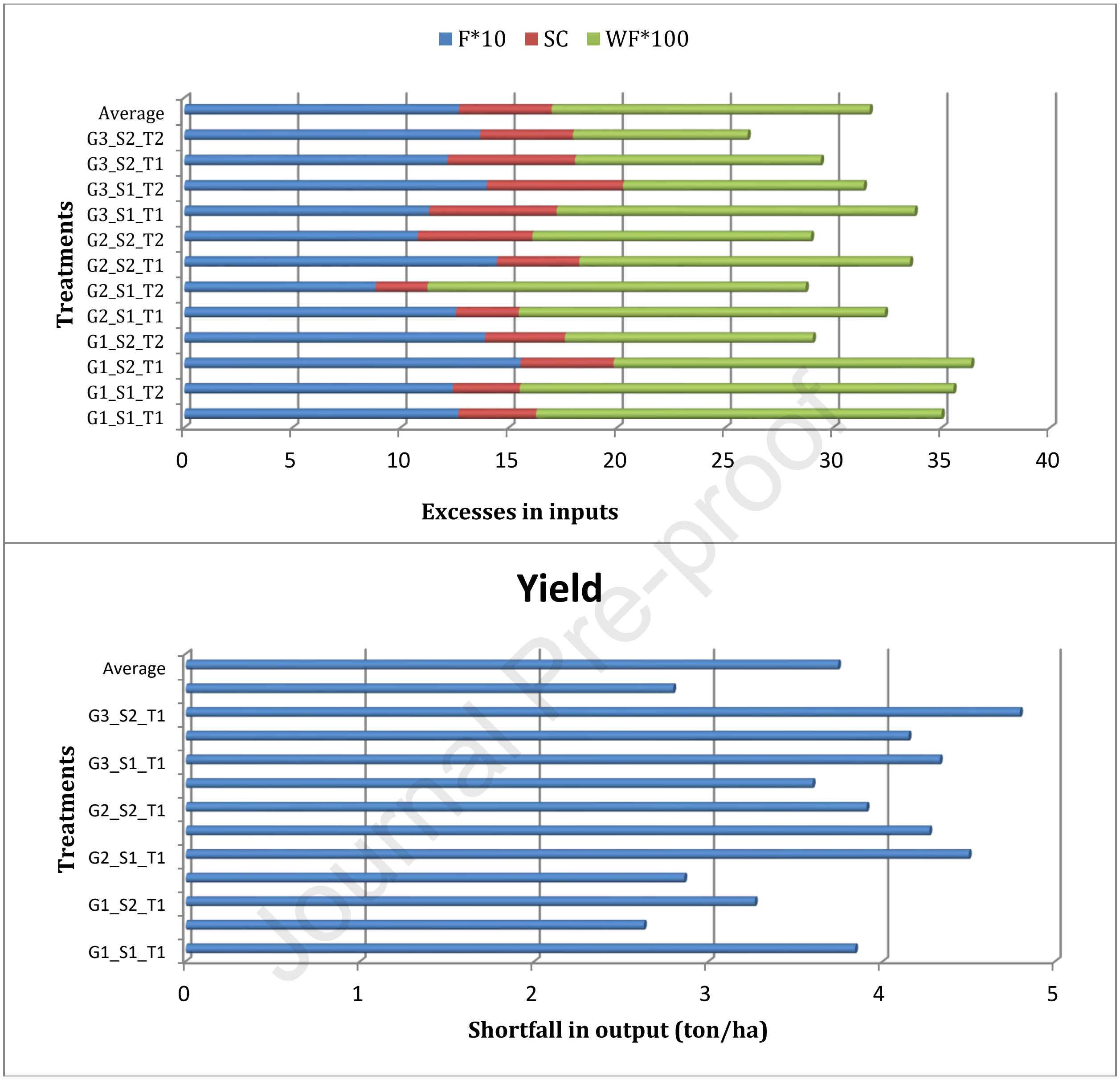

Fig. 3. The average excesses in inputs and shortfall in yield.

[*] F: fertilizers (kg/ha); SC: seed and chemicals (kg/ha); WF: water and fuel (m^3/ha); Yield: ton/ha

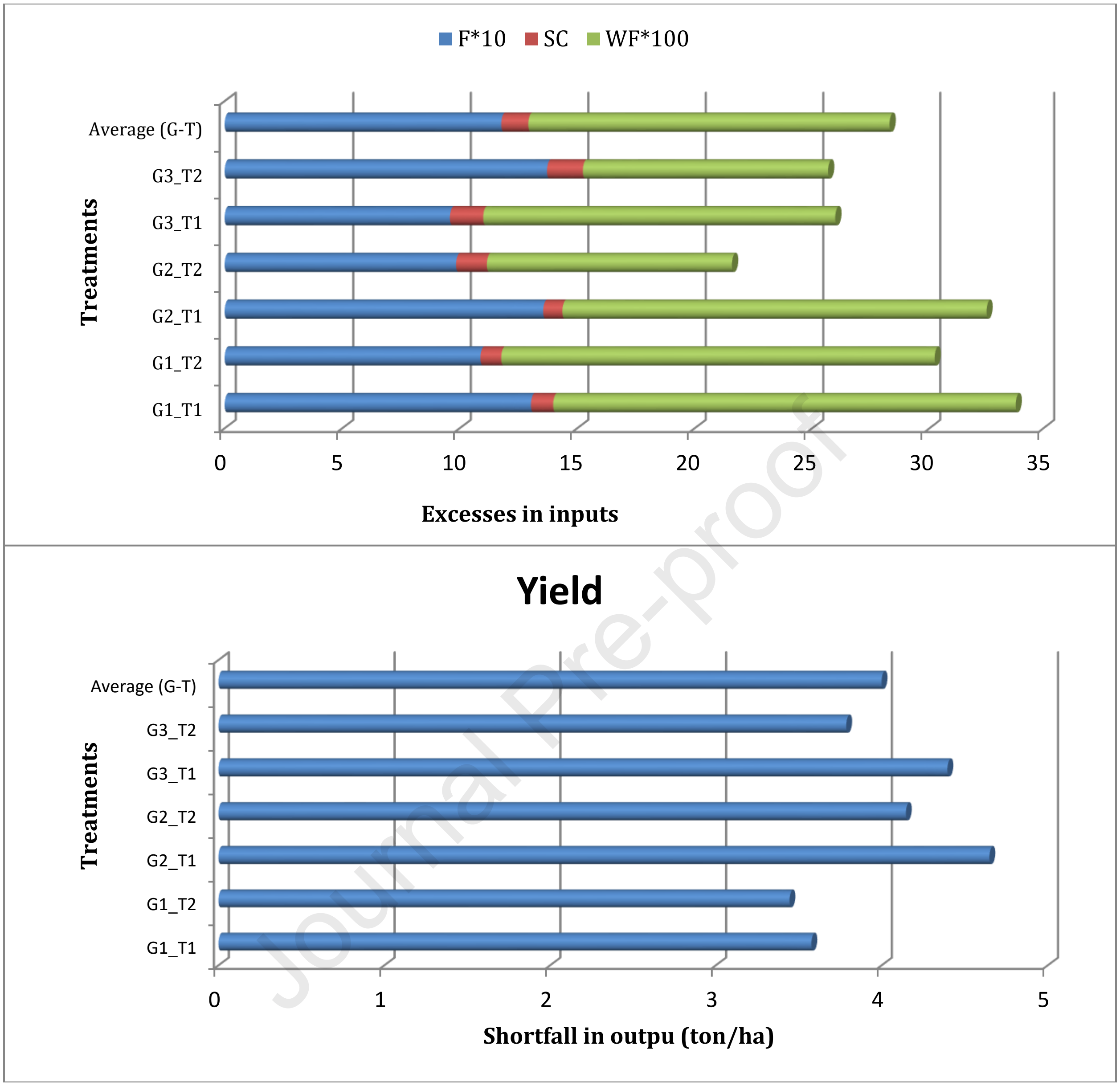

Fig. 4. **The average excesses in inputs and shortfall in yield with regard to region and tillage system (G-T)**
[*] F: fertilizers (kg/ha); SC: seed and chemicals (kg/ha); WF: water and fuel (m^3/ha); Yield: ton/ha

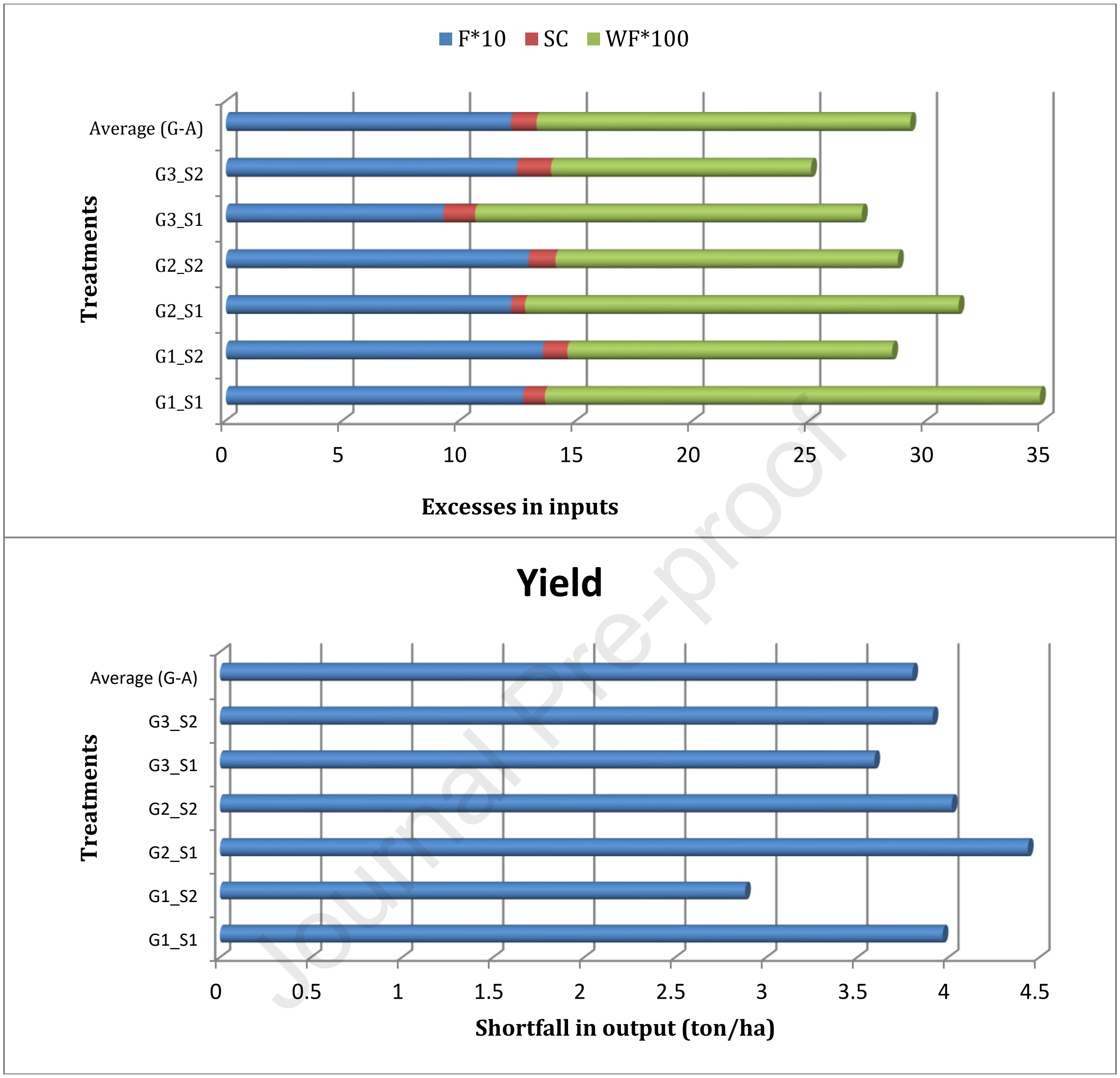

Fig. 5. The average excesses in inputs and shortfall in yield with regard to agroecosystems and cultivation systems (G-S).

*** F: fertilizers (kg/ha); SC: seed and chemicals (kg/ha); WF: water and fuel (m^3/ha); Yield: ton/ha**

Fig. 6. The ranks of the treatments from AHP model

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Dear Editor,

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We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Best regards,
E. Houshyar
Ehsan Houshyar