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Mechanization planning for tillage of saffron fields using multiple criteria decision-making technique as a policy framework in Iran

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Abstract

Though Iran is already the world's largest producer of saffron, current methods of production may benefit significantly from improved mechanization. Consequently, as the Iranian government looks to set policy for the next twenty years, in its forthcoming National Mechanization Policy, saffron production will be of central concern. Along with techno-economic factors, environmental and social impact must also be taken into consideration if any proposed strategy is to be sustainable. One important step in the process of saffron cultivation is crust crushing, whereby the hard surface of the soil is crushed to facilitate germination. In this paper, based on multi-criteria decision-making (MCDM) techniques, an innovative policy framework was developed for the mechanization of crust crushing in saffron fields. Five harrowing systems (two full mechanized systems, semi-mechanized and two traditional systems) were defined as harrowing candidates. Six key factors (time, cost, energy, availability, quality of work and employment) were considered as technical attributes. As a case study, the required information and data were taken from farmers and contractors of Mianjolge-Neyshabour city, Iran. Applying MCDM techniques, results indicate that for this specific region, employment is likely the most important criterion for decision making and tiller is the optimal system. It is worth noting that this same dynamic decision-making framework will flexibly accomodate any innovations in future production systems.

Key words: Mechanization, multi-criteria decision-making, saffron, sensitivity analysis, soil harrowing.

Abbreviations: MCDM_Multi-Criteria Decision-Making

Introduction

Saffron is a naturally derived plant product from the dried stigma of the Crocus sativus flower, family Iridaceae, (Gresta et al., 2009). Flower stigma is indicated by arrows in Fig 1. This plant acts as an antispasmodic, diaphoretic, carminative, emmenagogic and sedative (Das et al., 2010). It has been used for medicinal purposes, as a spice and condiment for food and as a dye since ancient times (Gresta et al., 2009; Das et al., 2010; Baghalian et al., 2010; Lage and Cantrell, 2009). Nowdays, saffron is used almost exclusively for cooking purposes to give colour, flavour and aroma to food (Gresta et al., 2009). The dried red stigmas, introduces unique colour, taste and fragrance and therefore is currently considered the world's most expensive spice (Baghalian et al., 2010; Moraga et al., 2009). Lage and Cantrell have presented a brief and to the point description on cultivation of this plant; Saffron is a perennial crop well adapted to arid and semi-arid lands which produce stigmas annually. It is also adaptable to temperate and sub-tropical climates, and can be grown on soils varying from sandy to well-drained clay loams. It blooms in autumn with a long period of dormancy (aestivation) in the summer. It is said to be native to the Mediterranean environment that is characterized by cool to cold winters, with autumn–winter–spring rains, and warm dry summers with very little rainfall. The Mediterranean environment is recognized as producing the best quality saffron. This is attributed to a variety of factors (Lage and Cantrell, 2009). Crust crushing after the first irrigation, before flowering time, is an important stage in saffron farming, as the hard surface of the soil is broken down to facilitate germination of the tender flowers. This operation must be done right at the point when soil reaches its field capacity. Studies confirm that correct time management in irrigation and crust crushing can increase yields to more than one kg/ha. Fig 1 clearly shows the differences between a harrowed and a non-harrowed land. Fig 1. Harro wed land versus non-harrowed one. Germination difficulties are apparent in the left image. The thick arrows show how the hard surface of the soil resists flower germination.

Socio-economic aspects of saffron production in Iran

Iran has a long history of saffron production (Baghalian et al., 2010). To date, Iran has been the largest saffron exporter, producing more than 90% of global production from more than 50000 ha under cultivation. Producers of saffron gener-

Table 1. Five major systems for Crust crushing operation in Neyshabour-Iran

Systems factors	Cost (USD/ha)	Time (hr/ha)
Full mechanized (4WD garden tractor)	80	6.75
Semi-mechanized (Animal draft)	18	12
Traditional (labor)	210	240
Full mechanized (2WD garden tractor)	50	8
Semi-mechanized (tiller)	25	10

ate, on average, more than 70% of their household income from this single crop.

The total annual value of Iranian saffron exports rose from 43.5 million USD in 2000 to 100 million USD in 2006 (Ghorbani, 2007). In Europe however, especially in the Mediterranean basin, saffron production faces a crisis. The production of saffron has decreased due to a rise in labor costs, making production unprofitable, in spite of its high market price (Lage and Cantrell, 2009). On the other side, according to the report of trade promotion organization of Iran, the overall production in 2007 was 37 tons (Afghahi, 2009). Meanwhile the domestic price of this crop increased sharply (from 300$/kg in 2005 to more than 4000$/kg in 2009). Price increases resulting from decreased production, caused some people to substitute alternative spices. These changing circumstances illustrate the need for production management decision-making suitable to establishing a balance between supply and demand. Such a balance is vital for both for sustainable production in Iran, and to create more consistant consumer demand. As a vital industry, it is imperative that Iranian policy makers effectively plan increasing the saffron production in order to reduce the universal price and thereby support a sustainable worldwide market.

Multi-criteria decision making in policy planning

Strategic decision making based only on economic factors alone might produce wide-ranging and deleterious social and environmental consequences. Therefore, social-environmental variables should be explicitly recognized as factors in the mechanization planning process. Common management methods in the field of farm machinery generally do not take these factors into consideration. Complications of social, cultural and natural context, as well as the expected economic criteria (Gómez-Limón and Martínez, 2006) generate complex interrelationships. Consequently, effective strategic policy-making requires decision processes suitable to multi-criteria analysis. MCDM, as presented here, is one promising technique (Nik et al., 2009). Similar applications of this technique have already been tried in agriculture and irrigation (Gómez-Limón and Martínez, 2006; Riesgo and Gómez-Limón, 2006), sustainable rural development (Meyer-Aurich, 2005; Zavadskas and Antucheviciene, 2007) and in Agricultural mechanization (Nik et al., 2009). In another study, Jafar Bigloo and Mobaraki, (2009) utilized MCDM to investigate the suitability of Iran's Qazvin province for saffron cultivation. In this case MCDM will be used as a policy framework aimed at maximizing saffron production within a specific regional context of environmental and socio-economic factors, sensitive to potential consequences for rural welfare and employment (Ghorbani, 2007).

Materials and method

Case study

The required information and data were taken from farmers and contractors of Mianjolge. Mianjolge is the name of a large plain in Southern Neyshabour city, Khorasan province-Iran. Most of the saffron farms in this region are owned by small landowners. The same as many other rural societies in Iran, Mianjolge is partly suffering from some social troubles (e.g. unemployment and poverty). Therefore any decision on agricultural mechanization in this region should consider these critical problems, recognizing that mechanization can easily aggravate the current social situation as it reduces the need for labor. There are five major systems for crust crushing operation as shown in table 1.

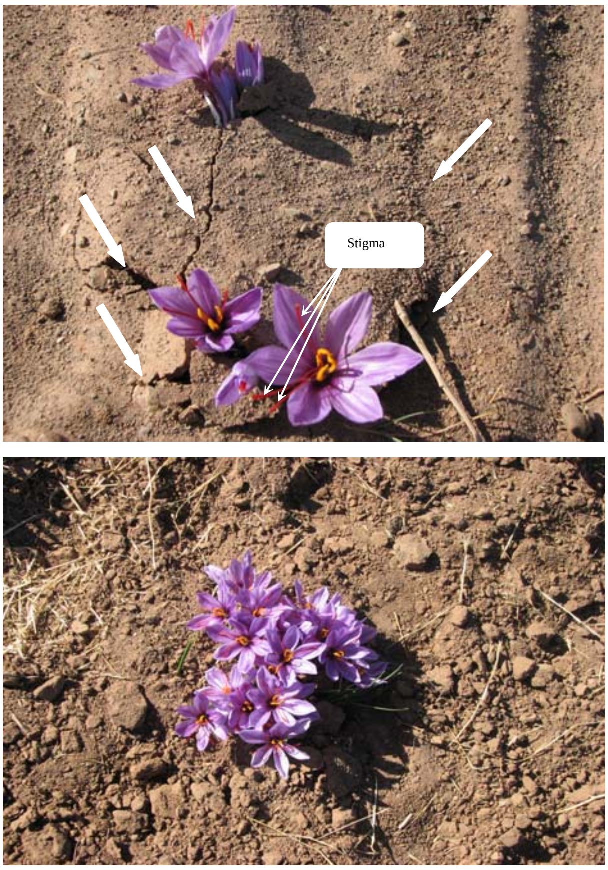

Fig 1. Harrowed land versus non-harrowed. Germination difficulty is apparent in the top image. The thick arrows show how the hard surface of the soil is resisting not in favor of flower germination.

Table 2. Decision making matrix

Alternative \ Attribute	X_1	X_2	...	X_n
A_1	r_{11}	r_{12}	...	r_{1n}
A_2	r_{21}	r_{22}	...	r_{2n}
.	.	.	.	.
.	.	.	.	.
A_m	r_{m1}	r_{m2}	...	r_{mn}

Decision making process

The accessible harrowing systems (table 1) were defined as harrowing candidates. Six key factors (time, cost, energy, availability, quality of work and employment) were considered as technical attributes. Energy as a factor was calculated based on fuel consumption per hectare. Where applicable, animal draft was determined by considering the amount of requisite feed. As a social factor, laborers required for each system were counted. The decision making matrix was formulated as shown in Table 2. Components of the table are defined as the follows: A_i = *i*th alternative X_j = *j*th attribute r_{ij} = the value of *j*th attribute for *i*th alternative.

In this research the number of alternatives (*m*) and attributes (*n*) were 5 and 6 respectively. The observed attributes X_1 through X_6 signify time (T), cost (C), energy consumption (EC), availability (A), quality of work (QW) and employment (E). The selected alternatives A_1 through A_5 are 4WD garden tractor, animal draft, labor, 2WD garden tractor, tiller respectively. The value that decision maker (DM) assigns to a given attribute with respect to a parent attribute is called Weight. This value lies within the range of parent attribute scale. In order to determine the comparative importance of each attribute, the entropy technique was used (Nik et al., 2009) (P_{ij}) is defined as:

$$P_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} ; \forall i, j \quad (1)$$

The uncertainty d_j from data belonging to *i*th attribute can be determined as:

$$d_j = 1 + \frac{1}{Ln(m)} \sum_{i=1}^{m} [P_{ij} . Ln(P_{ij})] \quad (2)$$

Having calculated the above parameters, the weight of four attributes can be calculated as (Asgharpour, 2004; Nik et al., 2009):

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} ; \forall j \quad (3)$$

Finally, a hierarchical additive weighting method (HAWM) was applied to generate the ranking of options. Based to this technique, comparative evaluations of tillage operation in saffron fields were specified in Fig 2. Fig 2. Different level of factors relevant to tillage operation in saffron fields. The earliest level from the left is called the goal level and carries a preference value of one. The second level is represents both technical and social factors with the preference of 0.5 for either. The third level of hierarchical decision making contains four attributes which are affected by the goal. Alternatives are placed in the forth level that are influenced by attributes in the third level. Actually the preference matrix in the forth level is the initial decision matrix (Table 3, obtained from region) i.e. all of its elements were normalised through multiplying by C_j , where (Asgharpour, 2004; Nik et al., 2009):

$$C_j = \frac{\frac{1}{r_{ij}}}{\sum_{i=1}^{m} \frac{1}{r_{ij}}} ; J = 1,2,3 \quad (4)$$

and

$$C_j = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} ; J = 4 \quad (5)$$

The ranking of the five systems is the general preference vector.

Results and Discussion

Table 3 presents the initial matrix of decision making for crust crushing of saffron farms. Actually, this table is presenting the crude data. It can be seen from the table that there were significant cost and time variation between systems. It is not surprising that in the traditional systems, there are higher amount of required time and cost than the other systems.

Weight Assessment

The weights of E, QW, A, EC, C and T were calculated as 0.255, 0.016, 0.011, 0.342, 0.098, 0.279, respectively. Therefore the preference vector of third level can be presented as: w_j = {0.255, 0.016, 0.011, 0.342, 0.098, 0.279}. A (availability) has gotten the minimum quantity. It means that this factor has a minimal role in the process of decision making while, in contrast, that of EC (energy consumption) dramatically influences the process. It is worth mentioning that these weights were calculated without including the decision maker's idea. Therefore, manager or decision maker can apply his/her own desired weight to this progress regarding to the probable changes in the conditions.

Table 3. Initial matrix of decision making for Crust crushing of saffron fields

	E	QW	A	EC (Mj)	C (USD)	T (hour)
4WD garden tractor	1	very good	low	334	80	6.45
2WD garden tractor	1	good	low	478	50	8
Tiller	1	middle	relatively low	185	25	10
Animal draft	3	good	relatively low	4646	18	12
Labor	30	bad	high	64560	210	240

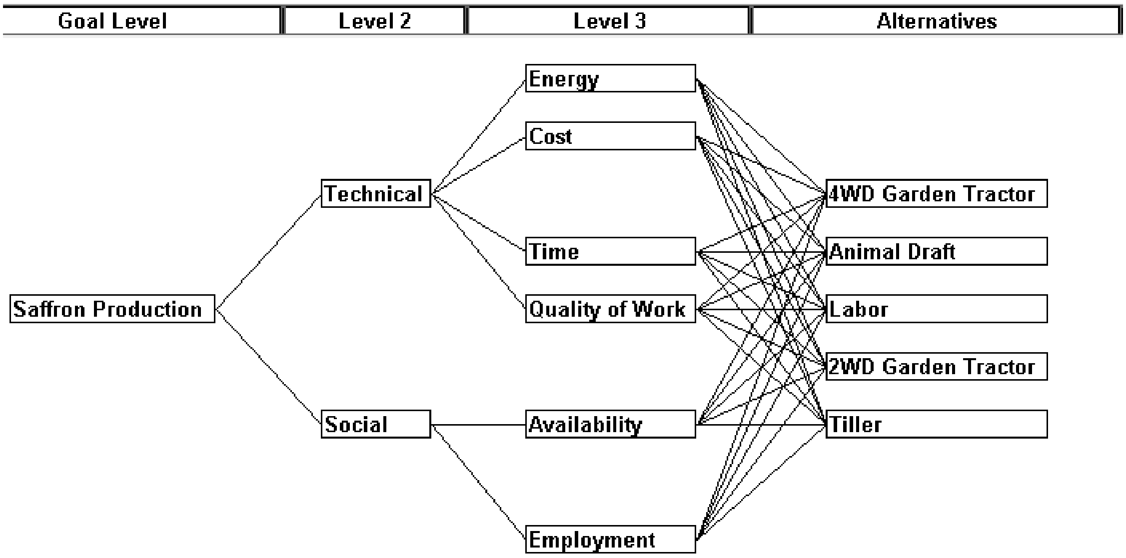

Fig 2. The level of factors engaged in Crust crushing operation in saffron fields.

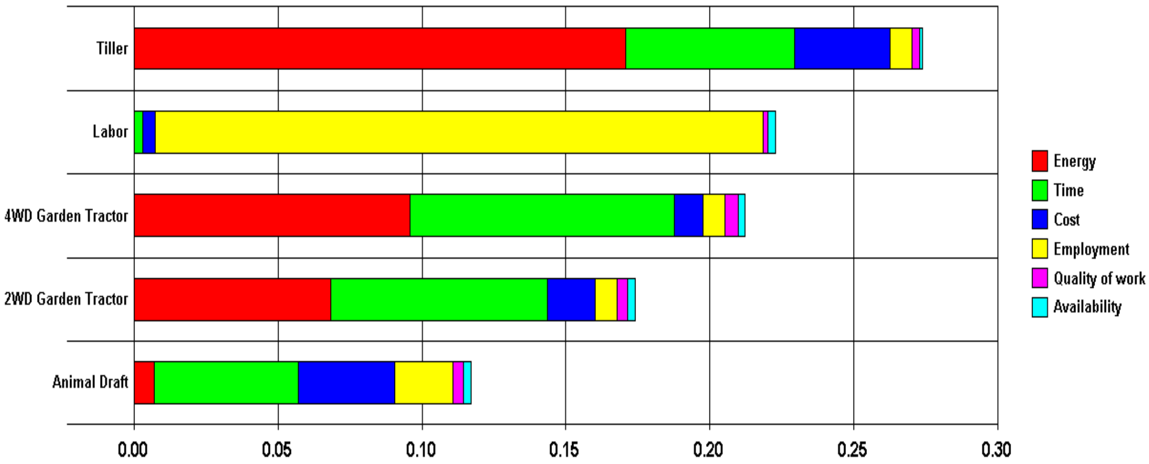

Fig 3. Ranking different alternatives of Crust crushing of saffron fields

Alternative ranking

Ranking of different alternatives of tillage in saffron fields is being showed in Fig 3. This graph is actually the outcome of data analysis in Criterium DecisionPlus (version 3.0.4/S, InfoHarvest Inc., USA) software. The overall score of each alternative (systems) can be seen in the horizontal axis. Fig 3. Ranking of different alternatives of tillage in saffron fields. This approach can be used to predict new concepts here clearly showing the advantages of tiller over the other systems. It means that the decision making system selected this alternative as the most suitable option for this region. This system showed the lowest energy consumption (red colored section) and relatively good scores according to other criteria. It is notable that in every system, each color is related to the amount of the score from the specified criterion. For example, although 4WD tractor has the highest field capacity (the longest length for time) but, it has been

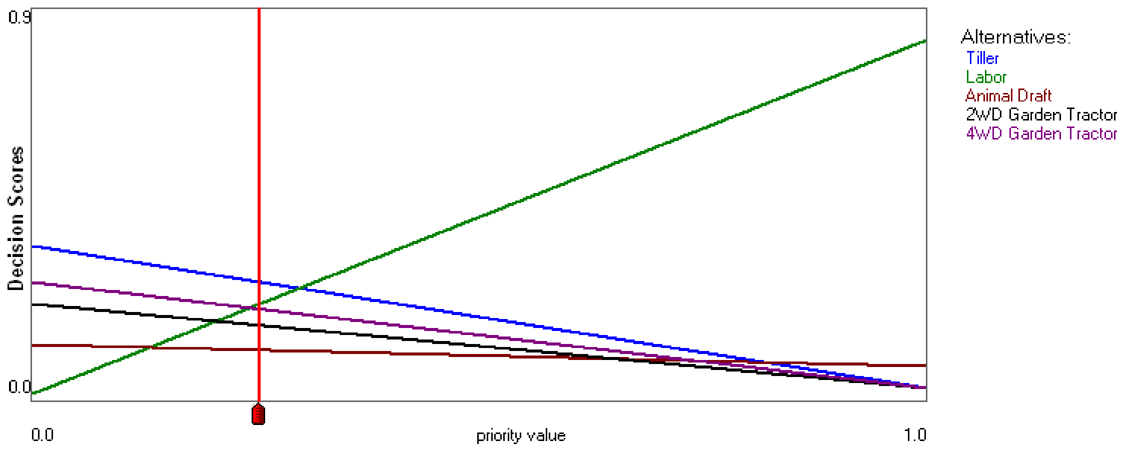

Fig 4. Sensitivity of alternatives to the employment attribute. The current priority (weight) is 0.25

hindered from the first ranking by the low score from employment. As regards the large variation of other crops cultivated in this region (e.g. water melon, sugar beet, pistachio, alfalfa) this system can be applied effectively for other small scale purposes as well. Although manual farm operations are costly, the advantages from a social point of view (employment) has promoted this system above more mechanized systems. Clearly, farmers cannot undergo the labor costs thus, it is necessary to make a strategy through which the optimum situation would be created for both farmers and workers. The authors believe that some kind of subsidies can be effective in combating this problem. Otherwise, unemployment will result in more poverty and migration to surrounding cities, creating further social discord. It is worthwhile to say that in studies related to mechanization, MCDM is a dynamic and flexible system with a flexible framework, which assists the decision maker (DM) to enhance his/her profit while maximizing a weighted balance of other attributes. In other word, based on any change in the conditions and the importance of attributes, the DM may use this framework as a guide to choose the best alternative from top scoring alternatives, (Nik et al., 2009).

Sensitivity Analysis

Sensitivity analysis is the study of how the variation (uncertainty) in the output of a mathematical model can be apportioned, qualitatively or quantitatively, to different sources of variation in the input of a model (Saltelli et al., 2008). Calculations of this sort are particularly critical in relation to processes dealing with factors of high variability (e.g. environmental and social factors). Fig 4. Sensitivity of systems to employment. The existing weight is 0.25. Fig 4 presents the sensitivity of systems to employment. In this figure, if a vertical line is traced from the value of 0.25 (the rounded weight of employment) to intersect the tending lines, and then from this conjunction point is drawn horizontally to cross the vertical axis, a score for each system can be graphically demonstrated. From this it is apparent how, if one changes the horizontal position of this vertical line (as can be done with the software), the precedence of this attribute changes. Since the inclined lines (various systems) have difference slopes, the received score of the alternatives (on the vertical axis) may be altered and therefore the order of their preference will be changed as well. For example, if the weight of employment was more than 0.31, the priority of tiller would be exchanged with that of labor. It shows the flexibility of this technique for mechanization planning where depending on the situations, the importance of a factor may be modified. It is worth noting that it is possible to form such graph for other attributes to explore the sensitivity of alternatives to those interested attribute. However it is beyond the scope of this article to introduce all of them.

Conclusions

Saffron production and its related marketplace are strategically important for Iran. Beyond the macro-economics, the labor involved in saffron farming results in broad social impact on many Iranian villages. Recent increases in price for this spice, on world markets threaten the sustainability of worldwide demand, while emphasizing the necessity of more research into this crop. This study focused on soil tillage in saffron fields as it remains a problematical operation. Employing innovative management method for sustainable saffron production and market demand is inevitable. In this research, a Multi-criteria decision making (MCDM) technique was employed to determine the most suitable strategy for mechanization of saffron farms. Planning a policy for one product without considering the other common products is not ideal. In order to optimize both social and mechanization factors, it is inevitable that all alternatives and agricultural potentials will be considered. And while the greater mechanization of saffron production is a fixed and important goal, it is vital also to prepare work opportunities for that part of the labor pool released as a consequence of improved efficiencies. Installing saffron processing factories in rural areas might prove effective. The result of sensitivity analysis showed that if the problem of unemployment somehow might be solved, by extending the area under saffron cultivation, the weight of time would improve to more than 0.53 thus, the garden tractor would become a preferred alternative. Although animal draft has earned the lowest score, there is no reason to abandon this system completely. Finally, modified small animal draft machines can improve the efficiency and robustness of this system.

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