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Selecting a sustainable array of machinery by integrating analytic hierarchy process with gray relational analysis

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Abstract

One of the key factors that contribute to the proper growth and development of agricultural mechanization is the selection of a sustainable combination of agricultural machinery. This study aims to evaluate and select a sustainable combination of agricultural machinery for rice cultivation in a specific region using hybrid decision-making of AHP-fuzzy GRA methods. First, the agricultural operation program and related types of agricultural machinery applied in the region were investigated. Then several sub-criteria were selected for the selection process, in three main criteria (economic, social, and environmental) using literature, chosen by Delphi scores and weighted by pairwise comparison. Finally, available machinery options for each operation were ranked using fuzzy gray relational analysis. Results showed that hybrid methods are powerful tools for solving similar problems confronted with qualitative and quantitative criteria.

Keywords: *agricultural mechanization, sustainable machinery combination, fuzzy MCDM, analytic hierarchy process (AHP), gray relational analysis (GRA)*

1. Introduction

Rice (*Oryza sativa*) is the most important cereal crop in the developing world and is the staple food of over 50% of the world's population, specially in East, South, Southeast Asia, Middle East, Latin America, and West Indies [11]. Iran, with a daily consumption of approximately 100 grams per day each person, is one of the countries in which rice plays a major role in people's food diet [16]. After bread, rice is the most popular food for Iranians and many of their foods are made with rice or rice-based products [19]. Rice farming is known as one of the most important economic activities in the north of Iran.

Having suitable lands and experienced farmers for rice cultivation has caused this region to become a high-potential agricultural hub in Iran. Rice cultivation has different operations and there are multiple activities in each operation. The selection of agricultural machinery for these activities such as tilling, leveling, planting, fertilizing, spraying, and harvesting has always been one of the most important issues in agricultural mechanization.

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2. Literature review

Advances in technology and the entry of new different types of machinery into the markets have left farmers with different choices. Selecting the best combination to perform each step can have a significant impact on the economic efficiency of activity. The difference in the amount of profit in different farms directly depends on the method of selection and management of agricultural machinery [7].

To choose between different options in sustainable development, it is necessary to consider proper economic, social, and environmental criteria. Multi-criteria decision-making (MCDM) tools are generally applied to reach an optimum decision when facing multiple alternatives with multi-conflicting and non-commensurable decision criteria [10]. Almost all the previous studies emphasized that machinery and technology selection in sustainable development is a highly complex decision-making problem as there are many conflicting factors and criteria [26]. Sironen et al. [30] reported a spatially referenced MCDA of policy instrument scenarios for conserving forest biodiversity with ecological, economic, social, and institutional criteria after 20 years in Southwestern Finland. Moreno-Solaz et al. [25] applied MCDM to evaluate different engine technologies of collection trucks (diesel, compressed natural gas (CNG), hybrid CNG-electric, electric, and hydrogen) under sustainability criteria in a Spanish city.

Different MCDM methods have been used in studies. For example, the analytical hierarchy process (AHP) can be very useful in involving several decision-makers with different conflicting objectives to arrive at a consensus decision [5]. Hafezalkotob et al. [15] to select the best olive harvester machines in Iran, designed a decision support system by using different types of MCDM methods such as WASPAS and MULTIMOORA.

Banaeian and Pourhejazy [4] used sustainability criteria in an AHP and fuzzy technique to improve the harvesting machinery selection by using a multi-method decision-making framework. The results of the case study support the idea that considering sustainability criteria can improve machinery selection decisions and address the strategic challenges of agroindustry owners and farmers. Banaeian et al. [3] determined finance, delivery and service, qualitative and environmental management as sustainable criteria and used them in the AHP-Delphi-GRA method to introduce an operational model for supplier selection. Also, AHP plus GRA method is a good combination for sustainability criteria analysis. Requiso et al. [27] used AHP-GRA method for selecting a sustainable protocol for extracting PHA. In another study, Romero-Gelvez et al. [28] used the same method for technology selection in precision agriculture. Monajem et al. [24] selected a sustainable mechanization system as the best-suited method for rice cultivation in Gilan by using AHP. Wei et al. [36] applied GRA with unknown weight information and CRITIC method to site selection for vehicle charging stations and introduced this hybrid approach as simple, effective, and easy to calculate.

BCS and ANP models have been used in a service provider selection framework for the layout of dynamic maintenance network nodes for agricultural machinery clusters and the process capability is the most important determinant for a service network [17]. For solving the problem of multiple attribute group decision-making (MAGDM) problems in new agricultural machinery products supplier selection, Lu et al. [22] developed a TOPSIS and entropy-weighted method and the results showed that the TOPSIS method can be useful for tacking uncertain decision-making problems. In a study to provide a comparison between the performance of three fuzzy MCDM methods in the selection process, fuzzy GRA requires less computational complexity to generate the same results than TOPSIS and VIKOR [2]. Therefore, this study applied a combination of Fuzzy logic with GRA to achieve better results in the selection process.

In a sustainable food system, farmers must improve their management strategies to compete and be flexible against diverse and unpredictable criteria on the farm. Therefore, it is important to understand the decision-making processes for adaptation. There is an empirical gap in the hybrid decision-making method that needs to be applied, evaluated, or empirically verified with real problems, especially in the agri-food industry. The new point of this study is the application of a new hybrid method (Delphi-AHP--fuzzy GRA) to solve a critical local problem. The main contribution of this paper is to choose the best machinery combinations for different operations of rice farming in the Gilan Province. Then one of the motivations is the combination of conventional (economic and technical), social, and environmental criteria from the literature.

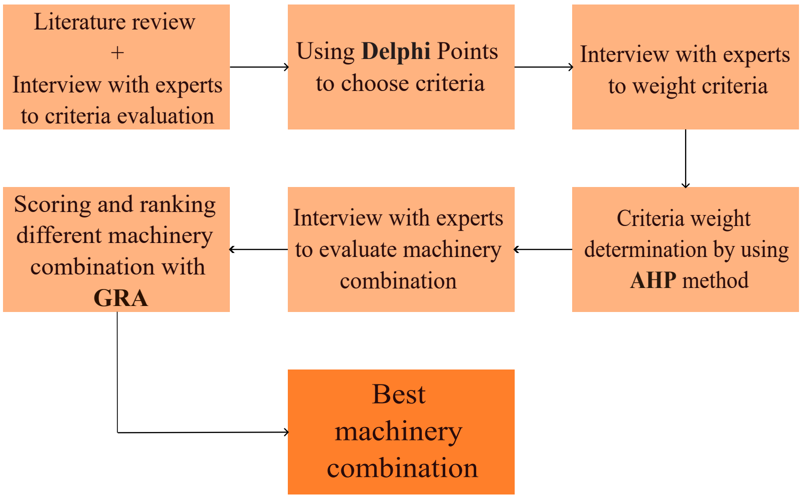

Figure 1. Decision-making multi-step framework

For decision-making about machinery combinations, a multi-step framework has been presented (Figure 1). Delphi points obtained by literature review, two-part interviews with experts, AHP weighting, and GRA methods for ranking the machinery combinations are the steps of the presented decision-making process. At the end, the best machinery combination will be identified and presented.

3. Material and methods

3.1. The region of study

Gilan is a province located in the north of Iran. The Gilan Province has 220,012 hectares of paddy agricultural land that produces 1,095,442 tons of paddy annually [32]. Because of the special climate of Gilan and high average rainfall, the environment of this province is suitable for rice farming. Spring and summer are the seasons when rice farming activities are at their peaks. Economically, rice is the most important agricultural product for the Gilan Province. Many locals' economic situations depend on selling rice or working on rice lands as labor. Gilan by having 8734 tractors, 59,969 tillers, and 5159 rotavators is one of the active markets of rice farming machinery [32].

3.2. Rice farming operations

Land preparation consists of soaking, plowing, and puddling called tillage [6]. Tillage has two primary and secondary types. The most important tools for agricultural operations are engine powers such as tractors and tillers, and agricultural machinery [23]. Today, tillage is mechanized by using agricultural machinery. Different machines with different combinations are used for tillage. Traditionally, the seedbed for rice is prepared by puddling followed by transplanting of rice seedlings [12]. After tilling, it is needed to make the surface of the land suitable for planting by leveling. Planting is done both traditionally and mechanically. Planting machinery is responsible for planting the crop while traditional planting labor is used to place the plant roots in the soil. Restrictions on access to sufficient labor and the low running speed of agricultural operations traditionally are very important issues [38]. The next step in rice planting includes fertilizing, spraying, and weeding. The final operation is harvesting, which has the greatest variety of machines available to do it.

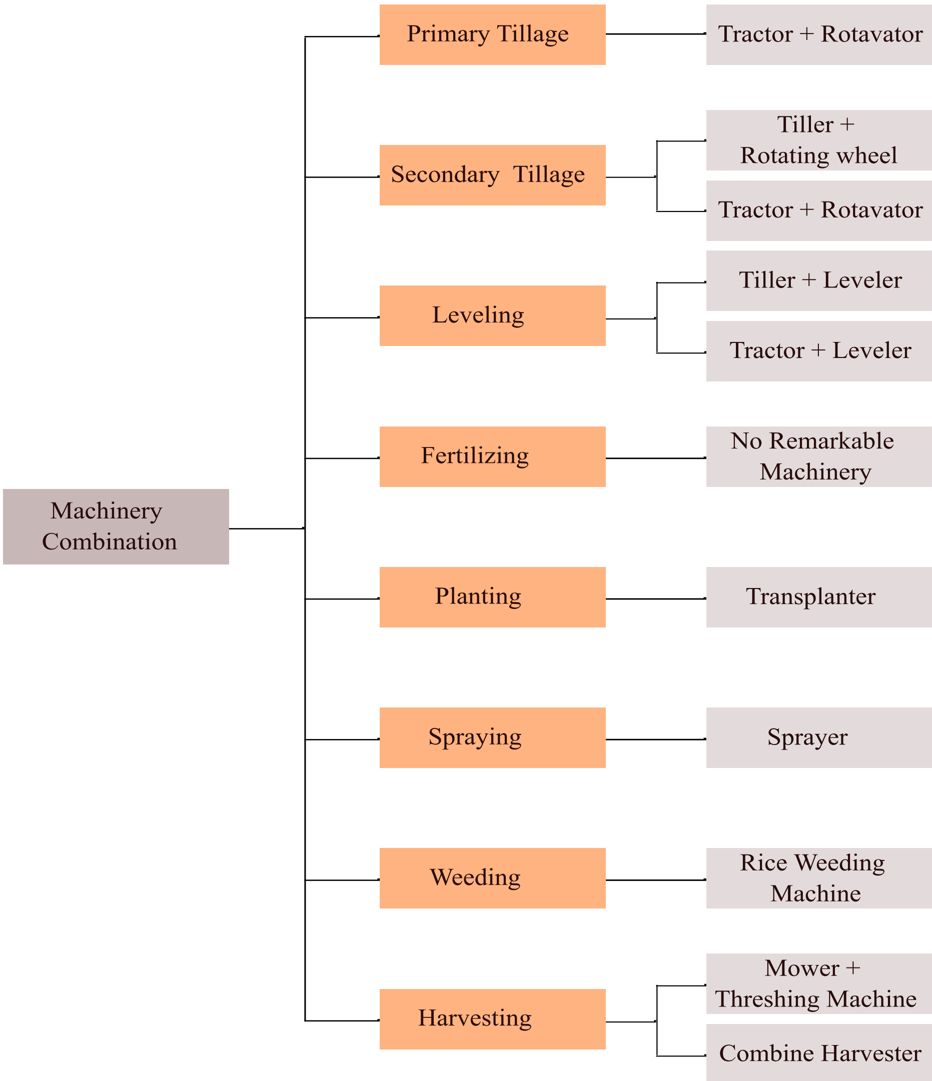

Figure 2. Machinery combinations in the Gilan Province

This study hypothesizes that the considered decision-making framework can provide combinations of different machines that accomplish different agricultural operations while avoiding additional costs. Also, the new decision support system can be a good guide for farmers and companies to receive facilities.

To determine the machinery combination for different operations of rice cultivation, it is first necessary to identify the common combinations and the activities that have more than two combinations, and then select between the identified combinations. Figure 2 shows different machinery combinations that are used in the Gilan Province.

3.3. Delphi method

The Delphi method, introduced in the 1950s, is a systematic and interactive method that relies on a panel of independent experts. Delphi is a very flexible tool that permits reaching a consensus, through the collection of experts' opinions on a given issue during successive stages of questionnaire and feedback (Vidal et al. [35]). The Delphi method aims to structure group opinion and discussion [13]. It was developed to increase the accuracy of forecasts [37]. When there is incomplete knowledge about a problem or phenomenon, Delphi is well suited as a research instrument [31] and can help the researcher to select the best alternatives among others.

3.4. The analytic hierarchy process (AHP)

AHP is a multiple criteria decision-making tool that has been used in almost all the applications related to decision-making [34]. In AHP, decision hierarchy is constructed with a goal, criteria, and alternatives [29]. The big advantage of the AHP method is its ability to construct complex, multi-person, multi-attribute, and multi-period problems hierarchically [3]. This model can work with a mixture of quantitative and qualitative criteria [33].

In the AHP method, the decision-maker has been asked to compare different criteria to find out how important a criterion is. AHP method compares each criterion with each other (paired comparison) gives them different weights and turns them to numerical values and the importance of criteria revealed. Consistency ratio (CR) should be calculated to validate the AHP results. Consistency ratios between 0 to 0.10 are acceptable [29].

3.5. Fuzzy set theory

The fuzzy set theory was proposed in 1960 by Zadeh et al. in [40]. A fuzzy set is a class of objects with a continuum of grades of membership [39]. Linguistic terms are used to express the variables using fuzzy sets and membership functions. Triangular fuzzy number (TFN) has been the most popular form to present fuzzy numbers with three points, for example, $\tilde{A} = (l_1, m_1, u_1)$ and $\tilde{B} = (l_2, m_2, u_2)$. The distance between $\tilde{A}$ and $\tilde{B}$ is defined as follows [20, 41]:

$$d(\tilde{A}, \tilde{B}) = \left(\frac{1}{3}\Big((l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2\Big)\right)^{1/2} \tag{1}$$

Defuzzification can convert fuzzy numbers to crisp real numbers [9]:

$$\text{Crisp}(\tilde{A}) = \frac{l + 2m + u}{4} \tag{2}$$

Appropriate linguistic variables for measuring the importance of the criteria and criteria weights are given in Tables 1 and 2 [2].

Table 1. Linguistic variables for importance of criteria

Number	Linguistic variable (importance of criteria)	TFNs
1	very poor (VP)	(0, 1, 2)
2	poor (P)	(1, 2, 3)
3	medium poor (MP)	(2, 3.5, 5)
4	fair (F)	(4, 5, 6)
5	medium good (MG)	(5, 6.5, 8)
6	good (G)	(7, 8, 9)
7	very good (VG)	(8, 9, 10)

Table 2. Linguistic variables for rating the weights of criteria

Number	Linguistic variables (importance of criteria)	TFNs
1	very low (VL)	(0, 0.1, 0.2)
2	low (L)	(0.1, 0.2, 0.3)
3	medium low (ML)	(0.2, 0.35, 0.5)
4	medium (M)	(0.4, 0.5, 0.6)
5	medium high (MH)	(0.5, 0.65, 0.8)
6	high (H)	(0.7, 0.8, 0.9)
7	very high (VH)	(0.8, 0.9, 1)

Potential alternatives will be identified and experts choose the evaluation factors. According to Tables 1 and 2, by considering m options, n criteria, and k decision-makers, the appropriate linguistic variables for weighting criteria ($\tilde{w}_j = \tilde{l}_{ij}, \tilde{m}_{ij}, \tilde{u}_{ij}$) and linguistic ratings for options will be determined with respect to criteria ($\tilde{x}_{ij}$) as TFN.

Decision matrix as aggregated criteria weights and ratings of options are constructed. Alternatives are symbolized by $i = 1, 2 \ldots, m$ and criteria by $j = 1, 2, \ldots, n$. The weights of criteria will be added to aggregated fuzzy weight $\tilde{w}_j$ of criterion C_j and aggregated fuzzy rating $\tilde{r}_{ij}$ of alternative A_i under criterion C_j.

$$\tilde{x}_{ij} = \frac{1}{k}\left(\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \cdots + \tilde{x}_{ij}^k\right) \tag{3}$$

$$\widetilde{w}_j = \frac{1}{k}\left(\widetilde{w}_1, \widetilde{w}_2, \ldots, \widetilde{w}_n\right) \tag{4}$$

The aggregated fuzzy criteria weights and decision matrix will be constructed as follows:

$$\tilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \ldots, \widetilde{w}_n]; \quad \tilde{X} = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \tag{5}$$

3.6. Fuzzy GRA

Dong [8] first introduced the GRA to show the degree of similarity or difference in development trends between an alternative and a reference alternative [21]. The more stable the process of change between the alternative and the reference alternative, the stronger the relationship will be. Otherwise, the degree of the relationship will be smaller [18]. This approach can be the basis for using GRA in measuring the relationship between the reference series and the comparison series.

To use a fuzzy GRA, the decision matrix ($\tilde{X}$) must be converted to a normalized decision matrix $\tilde{R}$. Considering $r_{ij} = (l_{ij}, m_{ij}, u_{ij})$, the normalized performance rating can be calculated as follows [14, 41]:

$$\tilde{r}_{ij} = \left(l_{ij}/u_j^+, m_{ij}/u_j^+, u_{ij}/u_j^+\right), \quad i = 1, \ldots, m, \quad j = 1, \ldots, n \tag{6}$$

where

$$u_j^+ = \max_i \{u_{ij}\} \qquad \forall i \quad i = 1, \ldots, m \tag{7}$$

Reference series determination can be done as (Gumus et al., [14]):

$$\tilde{R}_0 = [\tilde{r}_{01}, \tilde{r}_{02}, \ldots, \tilde{r}_{0n} = \max(\tilde{r}_{ij})] \tag{8}$$

where

$$\tilde{r}_{0j} = \max(\tilde{r}_{ij}), \qquad j = 1, \ldots, n \tag{9}$$

To form the distance matrix, the δ_{ij} distance between the reference value and each comparison value is calculated from equation (1).

The grey relational coefficient ξ_{ij} will be calculated by equation (10) [14]:

$$\xi_{ij} = \frac{\delta_{\min} + \rho\delta_{\max}}{\delta_{ij} + \rho\delta_{\max}} \tag{10}$$

where $\delta_{\max} = \max(\delta_{ij})$, $\delta_{\min} = \min(\delta_{ij})$ and the resolving coefficient $\rho \in [0, 1]$.

To estimate the grey relational grade γ_i, defuzzification formula (equation (2)) is applied to $\tilde{w}_j$:

$$\gamma_i = \sum_{j=1}^{n} w_j \xi_{ij}, \quad i = 1, \ldots, m \tag{11}$$

where $\tilde{w}_j$ is the weight of the jth criterion, and $\sum_{j=1}^{n} w_j = 1$.

Comparing the values of γ_i for each alternative, the final ranking can be determined. The higher value would be the better alternative.

4. Results

Banaeian and Pourhejazy [4] conducted complementary research on rice machinery and defined the most popular sustainable criteria based on Table 3. Based on the Delphi score, sub-criteria are limited to primary cost, payment terms, after-sale services machine capacity, depreciation, yield losses rate for economics, fuel consumption for environmental, and social acceptance for social criteria.

Considering the region of study, different operations of cultivation, and available machinery combinations, it has been revealed that three operations of secondary tillage, leveling, and harvesting are confronted by more than one machinery combination option (Table 4).

Table 3. Criteria of sustainable machinery selection

Criterion	Subcriterion	Current study
Economic and technical	Primary cost	✓
	payment terms	✓
	after-sale services	✓
	product availability	
	service quality	
	manufacturer reputation	
	business background	
	credit and capital of the producer	
	machine capacity	✓
	machine weight	
	maneuverability	
	depreciation	✓
	multi-crop functionality	
	yield losses rate	✓
	reliability	
	technological innovation	
Environmental	supply chain with low carbon technologies	
	eco-labels	
	fuel consumption	✓
	waste generation	
social	social acceptance	✓
	safety	
	socio-economic benefit	

Table 4. Selected operations and available machinery combinations

Operation	Machinery combination
Secondary tillage	tiller + rotating wheel
	tractor + rotavator
Leveling	tiller + leveler
	tractor + leveler
Harvesting	mower + thrashing machine
	combine harvester

GRA combined with fuzzy methodology is applied to evaluate qualitative parameters by expert-panel assessments and make reliable results [1]. A group of 10 selected experts answered the questionnaires in two phases for weight calculation and machine ranking. This group consists of farmers, agricultural machinery sellers, and agricultural ministry experts. A pairwise comparison of criteria determined the importance of each criterion for secondary tillage, leveling, and harvesting machines. Table 5 is the result of the pairwise comparison (weighting based on the AHP method) for sustainability criteria. The sum over criteria weights times grey relational coefficient derives grey relational grade are shown in Table 6.

According to Table 5, economic criteria have the most effect on the users' decision-making. social and environmental criteria are in the next places in order. Between economic criteria, there are different results in each operation. For example, machine capacity is the most pivotal criterion for users, and depreciation has the least decision-making value in secondary tillage, while leveling primary cost is the most important criterion and depreciation is the least.

Table 5. Criteria weights for secondary tillage, leveling and harvesting

Aspect	Criterion	Weight		
		Secondary tillage	Leveling	Harvesting
Economic	after-sale service	0.0626	0.0607	0.0282
	primary cost	0.1479	0.2135	0.1685
	machine capacity	0.2209	0.1597	0.1078
	payment terms	0.1119	0.1315	0.1036
	depreciation	0.0368	0.0505	0.0501
	losses	–	–	0.1235
Environmental	fuel consumption	0.0628	0.0598	0.0595
Social	social acceptance	0.3571	0.3243	0.3588

Table 6. GRA points for secondary tillage, leveling and harvesting

Operation	Machinery combination	GRA points (γ)
Secondary tillage	tiller + rotating wheel	0.6571
	tractor + rotavator	0.8249
Leveling	tiller + leveler	0.7359
	tractor + leveler	0.7926
Harvesting	mower + thrashing machine	0.5648
	combine harvester	0.9995

Table 7 is the summary of agricultural machinery selection for rice cultivation in different operations.

Table 7. Sustainable machinery for rice cultivation in the Gilan Province

Number	Operation	Sustainable machinery
1	primary tillage	tractor + rotavator
2	secondary tillage	tractor + rotavator
3	leveling	tractor + leveler
4	fertilizing	No. remarkable machinery
5	planting	transplanter
6	spraying	sprayer
7	weeding	rice weeding machine
8	harvesting	combine harvester

5. Conclusions

Although the existence of different options in the selection process is positive, each option has its advantages and disadvantages. Sometimes the process of choosing between options is easy or complicated. Considering different aspects of economic, social, and environmental criteria as main sustainability factors can affect machinery combination selection. One machine or technology may be suitable for one region but not acceptable sustainability in another area or climate.

In the Gilan Province, farmers always have problems choosing between traditional farming and mechanization farming. Hopefully, in recent years, the process of mechanization becomes faster and farmers use more agricultural types of machinery. One of the problems is using different machinery combinations for farming operations. In this study, we tried to find out which machinery combinations are more sustainable in the Gilan Region.

A hybrid AHP-fuzzy GRA method has been applied and results represented three sustainable machinery combinations for three different operations. In secondary tillage operation, the tractor with a rotavator had priority over the tiller with a rotating wheel. The most important reason for this choice is the high capacity and speed of tractors rather than tillers. Due to the same reason mentioned, it is clear why a tractor with a leveler earns more points than a tractor with the tiller.

According to remarkable GRA point differences between machinery in harvesting operation, results showed the superiority of the combined harvesters over the mower with the thrashing machine. Combine harvesters provided faster speed and high capacity with less loss. A tiller with a thrashing machine combination is cheaper than combined harvesters, but this difference between primary prices can not affect the final decision-making.

The mistaken belief among local farmers in this region is that combined harvesters cause more losses and that harvested paddy has a higher moisture content, which reduces the quality of rice. The effect of moisture in post-harvest can be removed by using better drying technologies and it's a subject for further studies but it is clear that combined harvesters have a huge superiority to mowers with thrashing machines in sustainability aspects. AHP plus fuzzy GRA is a powerful method for such studies confronted with qualitative and quantitative criteria. For further studies, it has been recommended to use different hybrid decision-making models in other regions or products to achieve sustainable machinery combinations.

For future research, it is suggested to apply the combined framework of this research or other hybrid MCDMs as a model for better development and orientation of agricultural mechanization in other types of cultivation and regions. Also, complementary analysis like sensitivity analysis or result comparison of different MCDMs is strongly recommended.

References

[1] Arce, M. E., Saavedra, Á., Míguez, J. L., and Granada, E. The use of grey-based methods in multi-criteria decision analysis for the evaluation of sustainable energy systems: A review. *Renewable and Sustainable Energy Reviews 47* (2015), 924–932.

[2] Banaeian, N., Mobli, H., Fahimnia, B., Nielsen, I. E., and Omid, M. Green supplier selection using fuzzy group decision making methods: A case study from the agri-food industry. *Computers and Operations Research 89* (2018), 337–347.

[3] Banaeian, N., Mobli, H., Nielsen, I. E., and Omid, M. Criteria definition and approaches in green supplier selection – a case study for raw material and packaging of food industry. *Production and Manufacturing Research 3*, 1 (2015), 149–168.

[4] Banaeian, N., and Pourhejazy, P. Integrating sustainability into the machinery selection decisions in the agriculture sector. *IEEE Engineering Management Review 48*, 4 (2020), 167–173.

[5] Bascetin, A. A decision support system using analytical hierarchy process (AHP) for the optimal environmental reclamation of an open-pit mine. *Environmental Geology 52*, 4 (2007), 663–672.

[6] Bouman, B. A. M., and Tuong, T. P. Field water management to save water and increase its productivity in irrigated lowland rice. *Agricultural Water Management 49*, 1 (2001), 11–30.

[7] Dehpour, M. B., and Bagheri, I. *Management of Agricultural Machinery*. University of Guilan Press, Rasht, Iran, 2010 (in Persian).

[8] Deng, J.-L. Control problems of grey systems. *Systems and Controls Letters 1*, 5 (1982), 288–294.

[9] Eftekhary, M., Gholami, P., Safari, S., and Shojaee, M. Ranking normalization methods for improving the accuracy of SVM algorithm by DEA method. *Modern Applied Science 6*, 10 (2012), 26–36.

[10] Emovon, I., and Oghenenyerovwho, O. S. Application of MCDM method in material selection for optimal design: A review. *Results in Materials 7* (2020), 100115.

[11] FAOStats (21 May 2021). FAO's Sustainable Development Goals (accessed on 15 January 2023).

[12] Farooq, M., Siddique, K. H. M., Rehman, H., Aziz, T., Lee, D.-J., and Wahid, A. Rice direct seeding: experiences, challenges and opportunities. *Soil and Tillage Research 111*, 2 (2011), 87–98.

[13] Goodman, C. M. The Delphi technique: a critique. *Journal of Advanced Nursing 12*, 6 (1987), 729–734.

[14] Gumus, A. T., Yayla, A. Y., Çelik, E., and Yildiz, A. A combined fuzzy-AHP and fuzzy-GRA methodology for hydrogen energy storage method selection in Turkey. *Energies 6*, 6 (2013), 3017–3032.

[15] HAFEZALKOTOB, A., HAMI-DINDAR, A., RABIE, N., AND HAFEZALKOTOB, A. A decision support system for agricultural machines and equipment selection: A case study on olive harvester machines. *Computers and Electronics in Agriculture 148* (2018), 207–216.

[16] HORMOZI, M. A., ASOODAR, M. A., AND ABDESHAHI, A. Impact of mechanization on technical efficiency: A case study of rice farmers in Iran. *Procedia Economics and Finance 1* (2012), 176–185.

[17] HU, Y., XIAO, S., WEN, J., AND LI, J. An anp-multi-criteria-based methodology to construct maintenance networks for agricultural machinery cluster in a balanced scorecard context. *Computers and Electronics in Agriculture 158* (2019), 1–10.

[18] HUI, G., AND BIFENG, S. Study on effectiveness evaluation of weapon systems based on grey relational analysis and TOPSIS. *Journal of Systems Engineering and Electronics 20*, 1 (2009), 106–111.

[19] KARIZAKI, V. M. Ethnic and traditional Iranian rice-based foods. *Journal of Ethnic Foods 3*, 2 (2016), 124–134.

[20] KROHLING, R. A., AND CAMPANHARO, V. C. Fuzzy TOPSIS for group decision making: A case study for accidents with oil spill in the sea. *Expert Systems with Applications 38*, 4 (2011), 4190–4197.

[21] KUO, M.-S., AND LIANG, G.-S. Combining VIKOR with GRA techniques to evaluate service quality of airports under fuzzy environment. *Expert Systems with Applications 38* (2011), 1304–1312.

[22] LU, J., WEI, C., WU, J., AND WEI, G. TOPSIS method for probabilistic linguistic MAGDM with entropy weight and its application to supplier selection of new agricultural machinery products. *Entropy 21*, 10 (2019), 953.

[23] MANSOORI RAD, D. *Tractors and Agricultural Machineries*. Vol. 1. Bu-ali Sina University Press, Hamedan, Iran, 2004 (in Persian).

[24] MONAJEM, S., RANJI, A., KHANI, M., AND DOROSTI, H. Evaluation of rice production systems in Guilan province by using of Analytical Hierarchy Process (AHP). *Cereal Research 3*, 3 (2013), 255–266.

[25] MORENO-SOLAZ, H., ARTACHO-RAMÍREZ, M.-Á., ARAGONÉS-BELTRÁN, P., AND CLOQUELL-BALLESTER, V.-A. Sustainable selection of waste collection trucks considering feasible future scenarios by applying the stratified best and worst method. *Heliyon 9*, 4 (2023), e15481.

[26] PRAKASH GRAG, C., GÖRÇÜN, O. F., KUNDU, P., AND KÜÇÜKÖNDER, H. An integrated fuzzy MCDM approach based on Bonferroni functions for selection and evaluation of industrial robots for the automobile manufacturing industry. *Expert Systems with Applications 213* (2023), 118863.

[27] REQUISO, P. J., NAYVE JR, F. R. P., AND VENTURA, J.-R. S. Sustainable polyhydroxyalkanoates (PHA) extraction protocol selection using AHP-GRA. Preprint version available from: https://www.researchsquare.com/article/rs-518413/v1.

[28] ROMERO-GELVEZ, J. I., BELTRÁN-FERNÁNDEZ, S. V., ARISTIZABAL, A. J., ZAPATA, S., AND CASTAÑEDA, M. Precision agriculture technology evaluation using combined AHP and GRA for data acquisition in apiculture. In *Joint Proceedings of the ICAI 2020 Workshops WAAI 2020, AIESD 2020, WDEA 2020, WSSC 2020 co-located with the Third International Conference on Applied Informatics* (Ota, Nigeria, 2020), H. Florez, I. Galpin and C. Grévisse, Eds., CEUR Workshop Proceedings (CEUR-WS.org), pp. 135-145.

[29] SAATY, T. L. Decision making with the analytic hierarchy process. *Scientia Iranica 9*, 3 (2002), 215–229.

[30] SIRONENT, S., PRIMMER, E., LESKINEN, P., SIMILA, J., AND PUNTTILA, P. Context sensitive policy instruments: A multi-criteria decision analysis for safeguarding forest habitats in Southwestern Finland. *Land Use Policy 92* (2020), 104460.

[31] SKULMOSKI, G. J., HARTMAN, F. T., AND KRAHN, J. The Delphi method for graduate research. *Journal of Information Technology Education: Research 6*, 1 (2007), 1–21.

[32] *Statistical Book of Jihad-e Agriculture Organization (JAO) of Gilan Province*. (18 March 2021), (accessed on 15 January 2023), (in Persian).

[33] TAHERDOOST, H. Decision making using the Analytical Hierarchy Process (AHP); A step by step approach. *International Journal of Economics and Management Systems 2* (2017), 244–246.

[34] VAIDYA, O. S., AND KUMAR, S. Analytic hierarchy process: An overview of applications. *European Journal of Operational Research 169*, 1 (2006), 1–29.

[35] VIDAL, L.-A., MARLE, F., AND BOCQUET, J.-C. Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects. *Expert Systems with Applications 38*, 5 (2011), 5388–5405.

[36] WEI, G., LEI, F., LIN, R., WANG, R., WEI, Y., WU, J., AND WEI, C. Algorithms for probabilistic uncertain linguistic multiple attribute group decision making based on the GRA and CRITIC method: application to location planning of electric vehicle charging stations. *Economic Research. Ekonomska Istraživanja 33*, 1 (2020), 828–846.

[37] WOUDENBERG, F. An evaluation of Delphi. *Technological Forecasting and Social Change 40*, 2 (1991), 131–150.

[38] YOUSEFZADEH, S., AND FIROUZI, S. The study of the factors affecting the development of mechanization of rice cultivation in Guilan province by Delphi technique. *Iranian Journal of Biosystems Engineering 47*, 1 (2016), 83–92.

[39] ZADEH, L. A. Fuzzy sets. *Information and Control 8*, 3 (1965), 338–353.

[40] ZADEH, L. A. *Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems: Selected papers*. vol. 6 of Advances in Fuzzy Systems – Applications and Theory. World Scientific, 1996.

[41] ZHANG, S. F., AND LIU, S. Y. A GRA-based intuitionistic fuzzy multi-criteria group decision making method for personnel selection. *Expert Systems with Applications 38*, 9 (2011), 11401–11405.