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Selection of Pesticides in Agriculture Using Multi Criteria Decision Making (MCDM) Technique: A Methodology

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SUMMARY

Multiple-criteria decision-making (MCDM) methods are among the analysis techniques in the operational research and management science that have recently been gaining extraordinary popularity and wide applications. Various MCDM methods are available to solve many decision-making problems. There are few research works on agriculture which have come out with the implication of this technique where taking decision is very difficult due to the presence of some conflicting criteria. Selection of pesticide among large number of alternatives is very difficult on the basis of farmers and scientists' point of view keeping environmental safety in mind. The MCDM technique provides enough scope for the selection of pesticides and ranking among several alternatives keeping in view a particular object and on the basis of some selection criteria and their relative weightage. The present paper is an attempt to explore the scope of applying the multiplicative AHP method of multi-criteria decision-making technique to select the most suitable pesticide on the basis of some stated important criteria and ranking them accordingly. The efficacy of the methodology has also been explained using dataset of four pesticides. Selection of most suitable pesticides has been made with the proposed methodology.

Keywords: MCDM, Pesticide, Sensitivity analysis, Toxicity.

1. INTRODUCTION

Multiple criteria decisions making (MCDM) refers to making decisions in the presence of multiple, usually conflicting, criteria. MCDM problems are common in everyday life. In personal context, as for example, to select a car for purchase or to purchase a house, some criteria in terms of price, size, style, safety, comfort, etc. are considered. In business context, MCDM problems are more complicated and deal with many criteria and sub-criteria to arrive at a decision among many alternatives. In research work the Multiple Criteria Decision Making (MCDM) technique is gaining popularity day by day in textiles, agriculture, marketing and even in social sciences. Clear understanding on the subject can explore newer fields of its application in decision making.

In agriculture, the selection of pesticides is very common problem and the farmers are often confused about the selection of proper one under conflicting situation. The selection of a pesticide in the remote village area is generally done by the farmers on the basis of the recommendation made by local dealer, therefore, generating a chance of biasness. In some other situation, this is done on the basis of the recommendations made by scientists considering some important criteria like its effectiveness, toxicity or environmental impact. The poor man's ability to purchase that pesticides or its mode of application remains neglected. Using of MCDM technique can be considered as an effective methodology to select the most suitable one among many available pesticides under some decisive situations that a farmer considers. Thus, the selection can be made without any biasness, entirely scientific and judicious. Sensitivity analysis can also help to manipulate the choices under the desired imposed importance of the criterions.

Generally, the selection a particular pesticide is done on the basis of consideration of mainly the criterions

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like toxicity level, environmental impacts, dosage (amount to be applied) and cost of the pesticide. Among these criteria toxicity level and cost of the pesticides are conflicting in nature with each other. MCDM technique helps selection or priority of selecting the appropriate pesticide among several others base on the weightage given on the criteria by a farmer.

This paper deals with the exploration of possibilities of applying multiplicative AHP method of MCDM technique for ranking of pesticides among finite number of alternatives based on finite number of decision criteria and to analyse the sensitivity of each criterion. The methodology has been explained with an example dataset relating to four pesticides and selecting the most suitable one.

2. OVERVIEW OF MCDM AND AHP

Multiple criteria decisions making (MCDM) is a very popular discipline of Operation Research (OR), having relatively short history of about 40 years. Its development has accelerated with the rapid development of computer technology. Computer programming has helped to handle huge data related to criteria, sub-criteria and alternatives, their systematic analysis to combat MCDM problems which is very much complex in nature.

There are many methods available which have enjoyed a wide acceptance in the academic area and many real-world applications. Each of these methods has its own characteristics and background logic. The Weighted sum model (WSM), Weighted product model (WPM), Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) and Elimination and Choice Translating Reality (ELECTRE) are among the most popular ones. Each has some advantages and disadvantages. User has to choose the suitable method according to complexity of the problems. So, it is very difficult to say which one is the best MCDM method.

The Analytic Hierarchy Process (or AHP) method has been developed by Saaty (1988). This is one of the frequently discussed methods of decision-making. The reason of its popularity lies in the fact that it can handle the objective as well as subjective factors and the criteria weights and alternative scores are elicited through the formation of a comparison pair-wise matrix which is the heart of the AHP. Since the introduction of AHP, it has evolved into several different variants like revised AHP proposed by Belton and Gear (1983) and multiplicative AHP proposed by Barzilai and Lootsma (1994). These methods have been widely used to solve a broader range of multi-criteria decision problems.

3. AHP METHODOLOGY

AHP decomposes a complex MCDM problem into a system of hierarchy. The final step in AHP deals with the structure of a $m \times n$ matrix. The matrix is constructed by using the relative importance of alternatives in terms of each criterion. The process of working out the problem starts with the formation of a decision hierarchy where the hierarchy of the problem is formed by keeping the overall objective or goal at the top and the alternatives at the bottom. Relevant attributes of the decision problem such as criteria and sub-criteria are placed at the intermediate levels. Next the pair-wise comparison matrix is formed, in this step the relative importance of different criteria with respect to the objective of the problem is determined by using the AHP. For doing this, a pair wise comparison matrix of criteria is constructed using a scale of relative importance proposed by Saaty (1988) which is shown in Table 1. The judgments are entered by using that fundamental scale of AHP. In AHP the number of pair-wise comparisons in a decision problem having m alternatives and n criteria are expressed by the equation;

$$\frac{n(n-1)}{2} + n\frac{m(m-1)}{2}$$

For n criteria, the matrix will be $m \times n$ order. The entry c_{ij} will denote the comparative importance of i criteria with respect to j criteria. In the matrix $c_{ij} = 1$ when $i = j$ and $c_{ji} = \frac{1}{c_{ij}}$.The pair-wise comparison matrix C_1 is shown as: $C_1 =$

The normalized weight of the *i-th* criteria (w_i) is determined by calculating the geometric mean of the *i-th* row (GM_i) of the above matrix and then normalizing the geometric mean of rows. This can be represented as follows:

$$GM_i = \{\prod_{j=1}^{n} c_{ij}\}^{\frac{1}{n}} \text{ and } w_i = \frac{GM_i}{\sum_{i=1}^{n} GM_i}$$

The principal eigen vector (λ_{max}) of the above matrix of the original pair-wise comparison matrix (C_1) is calculated. To check the consistency in pair-wise comparison judgment, consistency index (CI)

and consistency ratio (CR) are calculated by following equations:

$$CI = \frac{\lambda_{max} - n}{n-1} \text{ and, } \quad CR = \frac{CI}{RCI} ,$$

Where, RCI = random consistency index and its value can be obtained from Table 2. If the value of CR is 0.1 or less, then the judgment is considered to be consistent and therefore acceptable. Otherwise, the decision maker has to reconsider the entries in pair-wise comparison matrix.

In order to calculate the relative importance of sub criteria with respect to corresponding criteria, the pair-wise comparison between the attributes of sub-criteria are made in the same way previously discussed. The global weights of sub-criteria are calculated by multiplying the relative weight of sub-criteria with respect to the corresponding criterion and the relative weight of criterion with respect to the objective.

Table 1. The fundamental relational scale for pair-wise comparisons proposed by Saaty (1988)

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance of one over another	Experience and judgment slightly favour one activity over another.
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgment	When compromise is needed.
Reciprocal	If activity p has one of the above numbers assigned to it when compared with activity q, then q has the reciprocal value when compared with p	

After obtaining the global weights of each attributes, the priority index is calculated according to the variant of AHP followed. Finally, the ranking of the alternatives is made on the basis of index obtained

Table 2. RCI values of different number of alternatives

M	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

4. APPLICATION OF MCDM TECHNIQUES IN AGRICULTURAL RESEARCH

In subsistence agriculture two early examples are of interest. Flinn *et al.* (1980) analyse a decision-making problem in the Philippines where six goals are taken into account, for the production of enough rice for family subsistence for the generation of sufficient cash surplus. Barnett *et al.* (1982) use a similar approach to tackle a decision-making problem in Senegal.

MCDM model of decision making has been used by Sriswat and Payakpate (2016) in crop management system. In their work they have made comparison of three MCDM methods viz. the analytic hierarchy process (AHP), the technique for order preference by similarity to ideal solution (TOPSIS), and simple additive weighting (SAW) for choosing intercrop plants among rubber trees in plantations. According to their comparison, AHP was found to be most appropriate method among three for intercrop selection in rubber plantation.

Prakash (2003), in his Master's thesis has shown the land suitability analysis for agricultural crops using Fuzzy Multi Criteria Decision Making Approach. Three approaches namely AHP, Ideal Vector Approach (IVA) and Fuzzy AHP were followed to focus on addressing uncertainty in the process of land suitability assessment for agricultural crops. The researcher opined that the hybrid Fuzzy-AHP technique was found to be better than other two. The sensitivity analysis was also performed. The three methodologies were implemented to found the suitable land identification for rice cultivation in Doiwala block of Dehradun district, Uttarakhand.

Selection of an appropriate land evaluation technique in developing countries such as Libya, is very important for current and future land uses planning. Elaalem *et al.* (2010) have compared two land evaluation techniques of MCDM using Fuzzy - AHP and TOPSIS methods for a test area within Jeffara Plain of Libya for barley cultivation considering the need appropriate land evaluation technique in Libya. The results of the Fuzzy AHP and TOPSIS models are based on standardizing land characteristics by using different fuzzy models, applying the pairwise comparisons matrix for criteria weighting and using generalized family of distance metrics functions. Land suitability results for barley from the use the Fuzzy AHP and the TOPSIS methodologies have been derived and compared. Using an overall accuracy and KHAT statistic, it was found that, a good agreement between two methods exists.

Pakpour *et al.* (2013) have used the TOPSIS Multi criteria decision making model to select appropriate method of DNA selection from agricultural soil. An MCDM approach was also applied by Berbel and Rodrignez (1998) to analyse the production in the irrigated farm in Southern Spain.

Pourkhabbaz *et al.* (2014) conducted a case study in the framework of the ecological model and by using multi criteria decision making methods such as Analytic Network Process (ANP), Simple Additive Weighting (SAW) and Vlse Kriterijumska Optimizacija I Kompromisno Resenje - Analytical Hierarchy Process (VIKOR-AHP) in GIS environment with the aim of choosing the suitable locations for agricultural land use in Takestan-Qazvin Plain region of Iran. The study was aimed to determine the ecological capability of agricultural land use by using ANP and SAW methods and ranking the suitable agricultural alternatives in this region using the integrated VIKOR and AHP models. The study was useful in evaluation of environmental capacity of agricultural land use.

Diaz-Balteiro and Romero (2008) had an extensive literature survey on research papers of last 30 years related to application of MCDM on taking forestry decision. More than 250 papers were consulted to arrive at the inference that MCDM is a sound and well-established paradigm for addressing many problems within the broad field of forest management.

Further, Ananda and Herath (2009) in their exhaustive review work, indicated that MCDM is relevant and can contribute to improving forest management decisions. The review identified several trends in the use of MCDM in forestry.

Demirel *et al.* (2018) conducted a study to evaluate suitable methods for preventing soil erosion through fuzzy ANP in Turkey considering the problem as a multi-criteria decision-making problem. In this methodology, the use of optimism index allows to reflect the DM's attitude towards the fuzziness of judgment. The results show that, farming techniques and reforestation are vital methods for the solution of the problem.

Available research papers narrating the use of Multi Criteria Decision Making methodology in Agricultural application are mainly confined to soil suitability assessment in GIS environment for a single or multiple crop cultivation. Some papers deal with forest management and crop management. Not much work is available relating the assessment of suitability of pesticide management. Therefore, in the present study it has been decided to explore the possibilities of application of MCDM methodology for the selection of pesticides for controlling diseases in agriculture.

5. APPLICATIONS OF MULTIPLICATIVE AHP IN SELECTION OF PESTICIDES IN AGRICULTURE

5.1 Hierarchy formulation

This is based on the identification of criteria and sub-criteria taken into consideration as per the domain knowledge of the user or field survey. Literature survey reveals that, Safety, Toxicity, Environmental considerations, Cost, Effectiveness, Dose of application, Ease of application, Species specificity are some of the important criteria that are taken into consideration before selecting a pesticide. For the sake of understanding three important criteria; Safety, Ease of application and Economy along with Toxicity, Environmental hazards, Cost, Dose, Waiting period, as few sub-criteria are taken into consideration as shown below. However, the user has the option to include or eliminate other criteria or sub-criteria as per his choice and requirements.

1. Safety
    a. Toxicity (DANGER, WARNING, CAUTION depending upon LD50 number)
    b. Environmental hazards
2. Ease of application
3. Economy
    a. Unit cost
    b. Dose
    c. Waiting period arising out doe to Speed of interaction (quick or slow)

The goal or objective of the present investigation is to determine the quality value of Pesticides based on the certain important criteria like Safety, Ease of application of pesticides and finally the Economy. So, the Pesticide criteria of this problem can be classified under three headings, namely Safety, Ease of application of pesticides and Economy. Safety criteria can be divided into two sub-criteria, Environmental hazards (EH) and Toxicity (TO) whereas, Ease of application (EA) do not have any sub criteria and represented solely by themselves. The economy criterion is also further sub-divided by three sub-criteria like unit cost (UC), Dose (D) and Waiting period (WP)

At the lowest level of the hierarchy, there are four alternatives of Pesticides namely, A, B, C and D (in this case) which should be ranked according to their acceptance value. The alternatives at the bottom can be of any finite number. The schematic representation of the problem is depicted in Fig. 1.

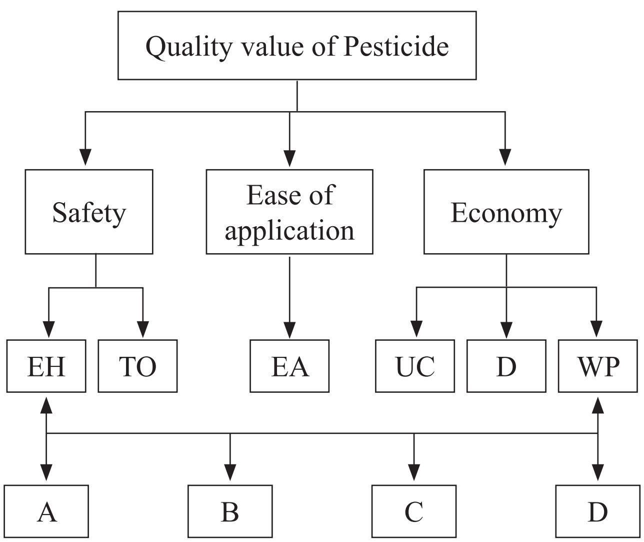

Fig. 1. Hierarchical structure of pesticide properties

5.2 Determination of criteria weights and rankings of alternatives

Table 3. Pair-wise comparison matrix of criteria with respect to objective

Criteria	Safety	Ease of Application	Economy	Geometric mean (GM)	Normalized GM
Safety	1	7	5	3.2672	0.7393
Ease of Application	1/7	1	1/2	0.4153	0.0940
Economy	1/5	2	1	0.7370	0.1668

It can be inferred from Table 3 that safety criterion is given very strong importance over ease of application parameter, essentially strong importance over economy. Likewise, the other pair wise comparisons have been made. The normalized GM column of Table 3 indicates that the safety parameter of pesticides have the most dominant influence with a relative weight of 0.7393. The relative weights of ease of application and economy criteria are 0.0940 and 0.1668 respectively. For the measurement of consistency of judgment, the original matrix is multiplied by the weight vector to obtain the product as shown below:

$$\begin{bmatrix} 1 & 7 & 5 \\ 1/7 & 1 & 1/2 \\ 1/5 & 2 & 1 \end{bmatrix} \times \begin{bmatrix} 0.7393 \\ 0.0940 \\ 0.1668 \end{bmatrix} = \begin{bmatrix} 2.2313 \\ 0.2830 \\ 0.5026 \end{bmatrix}$$

Now, $\lambda max = \left(\frac{2.2313}{0.7393} + \frac{0.2830}{0.0940} + \frac{0.5026}{0.1668} \right) / 3 = 3.0139$

Therefore,

$$CI = \frac{3.0139 - 3}{3 - 1} = 0.0069 \;\&\; CR = \frac{CI}{RCI} = \frac{0.0069}{0.58} = 0.012040 < 0.1$$

(acceptable)

The consistency in the pair-wise judgment is found to be justified as confirmed from calculating the consistency index (CI) and consistency ratio (CR) putting the value of random consistency index (RCI) against corresponding number of alternatives from Table 2.

Since the safety and economy criteria have sub-criteria as mentioned above therefore pair wise comparison matrix of the respective sub criteria are also need to be made as follows: Consistency ratios are found acceptable, confirms the justification while pairwise comparison is made.

Table 4. Pair-wise comparison of sub-criteria with respect to safety parameter

Appearance	Environmental Hazards (EH)	Toxicity (TO)	GM	Normalised GM	CR
Environmental Hazards (EH)	1	3	1.732	0.750	0
Toxicity (TO)	1/3	1	0.577	0.250	

Hence, from Table 4, the global weight of environmental hazards is 0.75×0.7393=0.5545 and the global weight of toxicity is 0.25×0.7393=0.1848

Table 5. Pair-wise comparison of sub-criteria with respect to economy parameter

Appearance	Unit cost (UC)	Dose (D)	Waiting period (WP)	*GM*	Normalised *GM*	CR
Unit cost (UC)	1	3	2	1.817	0.538	0.012
Dose (D)	1/3	1	1/2	0.550	0.164	
Waiting period (WP)	1/2	2	1	1	0.298	

Hence, from Table 5, the global weight of Unit cost is 0.538×0.1668=0.0897, the global weight of Dose is 0.164×0.1668=0.0274 and the global weight of Waiting period is 0.298×0.1668=0.0497

Since the ease of application does not have any sub-criteria, its global weight is 0.0940.

Therefore, global weights of all the criteria (including sub-criteria) under consideration for selection of pesticides are found out and given in Table 6.

Table 6. Global weight of criteria with respect to quality value of pesticide

Criteria	Global weight	Nature of criteria
Environmental hazards (EH)	0.5545	Benefit criteria
Toxicity (TO)	0.1848	Benefit criteria
Ease of application (EA)	0.0940	Cost criteria
Unit Cost (UC)	0.0897	Cost criteria
Dose (D)	0.0274	Cost criteria
Waiting period (WP)	0.0497	Cost criteria

The toxicity level of a pesticide is determined by LD 50 number. Higher the LD 50 number lower is the toxicity of a pesticide. Therefore, this can be considered as benefit criteria *i.e.*, higher-the-better. Environmental hazards are quantified based on the LD 50 number of the pesticides. LD 50 numbers less than 50 is taken as 1, between 51 to 500 is taken as 2, between 501 to 5000 is taken as 3 and more than 5000 is taken as 4. Higher value indicates lesser hazards which is desirable. Therefore, it is a benefit criterion. Pesticides may be distributed through water, soil and air etc. This is a subjective criterion. In order to express it objectively, the different application methods are assigned with number; 1,2,3. Here in this situation, the process of application of pesticide mixing with water is marked as 1, mixing with soil is marked as 2 and areal application is marked as 3. Therefore, as the number goes from 1 to 3, the ease of application is reduced and hence it can be taken as cost criterion *i.e.* lower-the-better type. Higher dose of application will always incur more cost. So, this can be considered as cost criterion. More waiting period is undesirable after the application of pesticides and hence it can also be taken as cost criterion. Unit cost, dose and waiting period; all are cost criteria *i.e.* lower-the-better type.

Now, according to the multiplicative AHP model, the equation to calculate the quality value of pesticide (MI_{AHP}) becomes;

$$\mathrm{MI_{AHP}} = \frac{\mathrm{EH^{0.5545}TO^{0.1848}}}{\mathrm{EA^{0.0940}UC^{0.0897}D^{0.0274}WP^{0.0497}}} \quad (1)$$

The values of MI_{AHP} for A, B, C, and D pesticide can be calculated on the basis of actual values of parameters against corresponding pesticide. The pesticide having highest MI_{AHP} value will rank top and is most acceptable under the situation taken into consideration. The descending order inthe values will be the ranking on priority.

To understand the whole method a sample dataset is used. This dataset contains information regarding four pesticides *i.e.* Thiamethoxam 25 WG, Lamda cyhalothrin 5 EC, Pymetrozine 50 WG and Buprofezin 25 SC for controlling brown plant hopper in rice field during kharif season. The values of criteria and sub-criteria of four pesticides are obtained from different sources (also referred) and presented in Table 7. The quality value of pesticides ($\mathrm{MI_{AHP}}$) is calculated using equation no. 1 and also shown in Table 7. From the $\mathrm{MI_{AHP}}$ values in the table, it is clear that, Pymetrozine 50 WG possess highest value of 3.6158 followed by Thiamethoxam 25 WG, Buprofezin 25 SC and Lamda cyhalothrin 5 EC. Therefore, Pymetrozine 50 WG is the most suitable one among the four pesticides when all the criteria; safety, ease of application and economy are taken altogether into consideration. This is free from any biasness in choice and not on the basis of a single criteria.

6. SENSITIVITY ANALYSIS

The robustness or stability of the ranking of the pesticides with respect to the criteria weights can be judged by sensitivity analysis. If the weight of any one of criteria under consideration is increased and decreased in steps like ± 10% and ± 20% or by any other quantity adjusting the weights of remaining other criteria proportionately, so that the sum of all the weights remains 1, the priority of acceptance of

Table 7. Criteria values of Pesticides and ranking

Pesticide	Environmental hazards (EH)	Toxicity (TO) (Oral toxicity LD50 mg/kg)	Ease of application (EA)	Unit cost (Rs./Kg)	Dose (ml/ha) #	Waiting period (day) $	MI_{AHP}	Rank
Thiamethoxam 25 WG	3	1563	1	350*	37.5	14	3.3613	2
Lamda cyhalothrin 5 EC	2	171	1	700*	30.0	15	1.6805	4
Pymetrozine 50 WG	4	5820	1	7620*	150.0	19	3.6158	1
Buprofezin 25 SC	3	2741	1	801**	250.0	24	3.1998	3

*Source: *Website of Syngenta*, ** Source: *Website of Dhanuk,*#Source:*Int. j. of Bio-resource and Stress Management 2017, (2),268-27,*$ Source: *Central Insecticide Board and Registration Committee, Ministry of Agriculture and Farmers Welfare, GOI*

alternatives may change. This will certainly help to select the appropriate pesticide in the new situation or governed by necessity of stake holders.

7. CONCLUSIONS

Hence, it can be concluded that the multiplicative AHP technique in the way as shown may find its application for making selection of pesticides effectively. The proposed technique has enough potentiality to be explored to prove its efficacy over the existing system. The selection is based on scientific reasoning, free from biasness and judicious. The selection is never intended to be made on the basis of sole criteria of safety or any other alone but on the basis of considering other several important criteria altogether.

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