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Multiple attribute decision making for selection of mechanical cotton harvester

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A numerical method called Multiple Attribute Decision Making (MADM) has been used for rational selection of a cotton harvester out of a finite number of cotton harvesters available the world over. In India, efforts are being made to design and develop a commercial cotton harvester to harvest selected cotton varieties sown by adopting common agronomic practices locally for cotton cultivation. The crop parameters for two different planting systems (existing planting system prevalent in India and experimental high density planting system) together with machine performance attributes of mechanical cotton harvesters using different types of mechanisms have been reviewed in this paper. Suitable cotton harvester was selected for both type of planting systems on the basis of attribute coding system. The main crop parameters which affect the performance of a cotton harvester like row spacing, plant height, plant population and crop yield were selected for the study. Machine performance attributes selected were picking efficiency, trash content, gin turnout, field capacity and field losses. Equal weightage was given to all machine attributes like picking efficiency, losses, trash content, gin turnout and field capacity of the cotton harvester. The spindle type cotton picker was best suited to the existing cotton planting system of India. Based upon TOPSIS method, if relative ranking was given to the pertinent attributes then the best mechanical cotton harvester for existing planting system was brush and paddle type cotton stripper. For high density planting system, if equal importance was given to all machine attributes of the cotton harvester, the finger type cotton stripper and spindle type cotton picker were best suited. On the basis of TOPSIS method, if the relative importance of pertinent attributes was considered the best mechanical cotton harvester for high density planting system was finger type cotton stripper.

Key words: Attribute coding, Multiple Attribute Decision Making (MADM), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), cotton harvester, crop attributes, machine performance attributes.

INTRODUCTION

Major production operations for cotton crop include field preparation, planting, weed control, spraying and picking. Amongst all operations, cotton picking is the most difficult, tiresome and tedious job. The average labour requirement in conventional practice of hand picking of cotton in India was reported to be about 517 man h/ha (Prasad et al., 2004). It was not only a tedious job but also ten times costlier than irrigation and twice more costlier than the weeding operation (Prasad and Majumdar, 1999). A person can pick about 15 to 20 kg/day of seed cotton, compared to an average picking of 870 to 2180 kg/day by a single row spindle type cotton

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picker (Sandhar, 1999).

There are various types and designs of cotton harvesting machines available in the world. In advanced countries like USA, Australia, Brazil and Russia etc, cotton picking is carried out mechanically by cotton pickers (most commonly used machines) and cotton strippers. These harvesters are designed for the particular planting system, established in the advanced countries. For Indian researchers and manufacturers, it is a tough task to select and design a cotton harvester due to design constraint and different planting systems in different regions of the country. In order to select and design a cotton harvester, short stature, less symopodial and synchronous matured varieties or hybrids needed to be developed and tested under high density planting system (Singh and Buttar, 2012).

In India, the already existing planting system is to plant the cotton at 67.5 × 67.5 cm (Goyal et al., 2009). Trials of another system, that is, high density planting system are being conducted, has advantages like it has 4 to 5 times more plants (1 to 2 lakhs/ha) results higher yield of cotton, that is, 35 to 40% with net profit ranged between Rs. 20,000 to 54,000/ha (Anonymous, 2013). Same cotton yield could also be obtained by adopting high density planting system with BT cotton hybrids having less symopodial branches as compared to other conventional sown BT cotton hybrids with an additional advantage of suitability for mechanical picking (Singh and Buttar, 2012).

A selection of a mechanical cotton harvester among all the available harvesters for different planting system in local conditions is difficult. Thus, a method called Multiple Attribute Decision Making (MADM) is useful to solve the problems involving selection and design of cotton harvester among a finite number of available cotton harvesters. Agrawal et al. (1991) presented an efficient approach for a computer-based solution to the problem of selection of an optimum robot specifically to aid industry. The selection procedure proceeds to rank the alternatives from the selected harvesters by employing a MADM method termed TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). A methodology was presented by Agrawal et al. (1992) for the evaluation and selection of an optimum gripper, either at the time of changing over from one job to another in the completely automated industry, or at the time of purchase of grippers and robots from the world market.

Singh and Agrawal (2012) also made an attempt to integrate concurrent engineering and multiple attribute decision making approach to design and develop nanoactuators for a number of abilities, for example, actuation, modelization, realization, and performance. This approach ensured that optimally selected nanoactuator elements are closest to the hypothetical best and farthest from the hypothetical worst solution in order to design nanoactuators for the application under consideration.

This paper aims at coding the important attributes of cotton crop planted by two main planting systems, that is, existing planting system prevailing in India and experimental high density planting system as well as machine performance attributes of a cotton harvester. Although the concept of attribute coding has been used extensively in other sectors, in agricultural machinery research and design, no reference is available on attribute coding method called TOPSIS. The crop parameters for both planting systems and machine performance attributes of mechanical cotton harvesters with different mechanisms have been reviewed in this paper. Coding/grading of different attributes of crop parameters and machine performance attributes are given as per their importance. It is hoped that a suitable cotton harvester can be selected for both type of planting systems, that is, existing planting system and experimental high density planting system on the basis of attribute coding system.

IDENTIFICATION OF ATTRIBUTES

Proper identification of attributes is essential for the selection of a cotton harvester. In most of the cases the user needs to be assisted in identifying the crop and machine attributes judiciously for optimum application. If the crop and machine attributes identification is done carefully, the selection of the mechanical cotton harvester for cotton picking/harvesting will be precise and accurate. Different attributes were identified under three categories viz. crop, specific requirement of harvesting aid attributes and machine performance attributes as shown in Table 1.

TOPSIS METHOD FOR SELECTION OF COTTON HARVESTER

Selection of cotton harvester among the available harvesters is a tough and time consuming task unless some unique method is used for the proper selection process. The main objective of this paper is to develop a selection methodology to enable a user to first narrow down the list of the available alternatives/harvesters to a manageable limit and then apply a method of trade-off between harvesters to make it possible to rank them accordingly.

After the elimination search, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is applied to find the optimum solution which exceeds all the required levels for each attribute. This technique is based on the concept that the selected option must have the shortest distance from the ideal cotton harvester (best solution) as expressed by Figure 1; where the ideal harvester is a hypothetical harvester for which all attribute values correspond to the maximum attribute values in the generated database, and the negative ideal harvester is

Table 1. Crop and machine performance attributes selected for the study.

Crop attributes	Specific aid requirement	Machine performance
Row spacing	Defoliant spray	Picking efficiency
Plant height	-	Trash content
Plant population	-	Gin/Lint turnout
Crop yield	-	Field capacity
		Losses (pre-harvest, ground, stalk etc.)

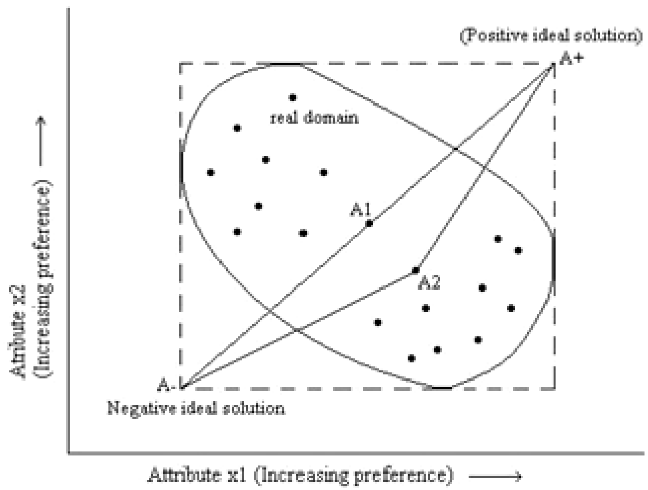

Figure 1. Representation of the selection problem in the case of two attributes.

the hypothetical harvester/solution in which all the attribute values correspond to the minimum attribute values in the generated database for cotton harvesters. This method ensures that the top ranked cotton harvester will be closest to the positive ideal harvester/solution and farthest from the negative ideal harvester/worst solution. Therefore, only a brief step by step procedure is given for the above method.

Algorithm

Stage 1: Elimination search: scan the developed database and obtain a shortlist of cotton harvesters which satisfy the minimum requirement of all the pertinent attributes.

Stage 2: Evaluation and ranking procedure.

Step 1: Generate a work decision matrix (D_{ij}) where row (i) mentioned the attributes of the cotton harvesters and column (j) described the alternatives (type of cotton harvesters).

Step 2: Form a user defined relative importance matrix (A)

Step 3: Find maximum value of λ (Eigen-value) and by using this Eigen-value find vector W, where W represents the weights of each attribute as $(A - \lambda_{max} I).W = 0$

Step 4: Construct a normalised decision matrix (R_{ij}) by using the relation

$$R_{ij} = D_{ij} / \left(\sum_{i=0}^{n} D^2_{ij}\right)^{1/2}$$

Where

R_{ij} = an element of the normalized decision matrix

D_{ij} = numerical outcome of ith option with respect to the jth criterion.

Step 5: Determined weighted normalized decision matrix (V_{ij}) expressed below:

$$V_{ij} = \begin{bmatrix} R_1W_1 & R_1W_2 & R_1W_3 \\ R_2W_1 & R_2W_2 & R_2W_3 \\ R_3W_1 & R_3W_2 & R_3W_3 \\ R_4W_1 & R_4W_2 & R_4W_3 \end{bmatrix}$$

Table 2. Machine performance attributes and their coding.

S. N.	Range and coding of machine performance attributes							
	Picking efficiency		Field losses		Gin/Lint turnout		Trash content	
	Range (%)	Code/Grade	Range (%)	Code/ Grade	Range (%)	Code/Grade	Range (%)	Code/Grade
1	≤ 75	1	≤ 5	5	≤ 25	1	≤ 10	5
2	75-80	2	5-10	4	25-30	2	10-15	4
3	80-85	3	10-15	3	30-35	3	15-20	3
4	85-90	4	15-20	2	35-40	4	20-25	2
5	≥ 90	5	≥ 20	1	≥ 40	5	≥ 25	1
6	Not mentioned	0	Not discussed	0	Not discussed	0	Not discussed	0

Step 6: Find the values of positive and negative ideal solution by using relation

$V^+ = [(\max_j V_{ij}|j\epsilon J), (\min_j V_{ij}|j\epsilon J|i= 1,2...m)]$
$j = \{J=1,2,3...,n\}$
$V^- = [(\min_j V_{ij}|j\epsilon J), (\max_j V_{ij}|j\epsilon J)\ i= 1,2...m)]$

Step 7: Calculate separation measures S_i^+ and S_i^-, where a separation from the positive ideal solution is given by

$$S_i^+ = [\sum_{i=0}^{n}(V_{ij} - V_i^+)^2]^{1/2} \quad (i = 1,2,...,m)$$

And separation from the negative ideal solution is given by

$$S_i^- = [\sum_{i=0}^{n}(V_{ij} - V_i^-)^2]^{1/2} \quad (i = 1,2,...,m)$$

Step 8: Calculate relative closeness to the ideal solution. This index is a measure of the suitability of the cotton harvester for the chosen application on the basis of attributes considered. A harvester with the highest index is optimum

$$C_i^* = S_i^- / (S_i^+ + S_i^-)$$

Step 9: Rank the alternatives in accordance with the decreasing values of indices, C_i^*, indicating the most preferred and the least preferred feasible optional solution.

SELECTION OF PLANTING SYSTEM

Two planting systems were selected by keeping in view the developed cotton harvesters by the researcher. These are

i) Existing Planting System (EPS).
ii) High Density Planting System (HDPS).

Under the Existing Indian Planting System, row to row spacing is kept in the range of 60 to 90 cm and plant to plant distance is kept more than 40 cm. The average plant population of this planting system is in the range of 30,000 to 50,000 plants/ha (Anonymous, 2012). For the second system, that is, high density planting system, the plants are planted at 60 × 15 or 45 × 30 cm spacing having 4 to 5 times more plants (1 to 2 lakhs/ha) and plant height does not exceed 100 cm (Anonymous, 2013).

MACHINE PERFORMANCE ATTRIBUTES FOR COTTON HARVESTERS

Machine performance attributes include picking efficiency, field capacity, field losses, gin or lint turnout and trash content. The coding/grading of machine attributes can be used to select and design cotton harvester from the available harvesters for different planting systems. Table 2 shows the range and coding/grading of machine performance attributes.

Types of harvesting mechanisms

Different types of mechanisms such as rigid and flexible finger type, brush type, spindle type and other mechanisms like pneumatic or chain type are used in the development of cotton harvesters. Figure 2 presents an overview of different types of mechanical cotton harvesters and their harvesting mechanisms which are expressed with the following notations. It also shows the different types of cotton harvesters which are working successfully in advanced countries. These harvesters are developed with different types of mechanisms and used to harvest the cotton crop, cultivated as per their design.

Finger type:	F S
Brush type:	B S
Spindle type:	S P
Other mechanism:	O H

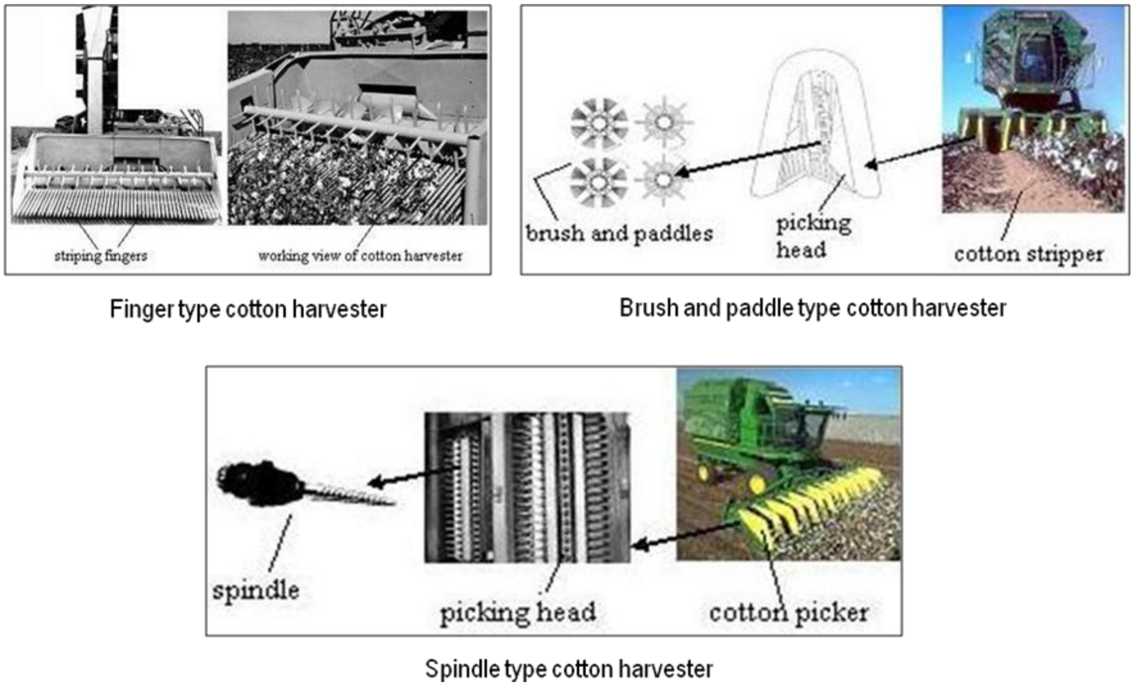

Figure 2. Types of cotton harvesters with different mechanisms. Source: http://www.cottoninc.com/fiber/AgriculturalDisciplines/Engineering/Cotton-Harvest-Systems/Cotton-Strippers/Introduction/.

Picking efficiency

Generally, the picking efficiency of cotton harvesters is in the range of 75 to 90% for different type of picking mechanisms. Most of the authors have discussed this attribute in their research work and as such it has been taken as a pertinent attribute during the selection process.

Field capacity

Most of the researchers have discussed and given due weightage to other attributes like picking efficiency, field loss and trash content, but the field capacity has not been discussed in their research work. Hence, the field capacity discussed by the author has been awarded 1 otherwise 0 coding for the attributes.

Discussed: 1
Not discussed: 0

Field losses

It covers pre-harvest, ground and stalk losses which together comprise total field losses. It was easy to focus on total losses rather than losses discussed separately. For cotton harvester, 5 to 20% range of total loss was observed for field losses during the research work conducted by different authors.

Gin/Lint turnout

Gin turnout is the percentage of cotton fibre obtained after the ginning process. The percentage of gin turnout depends on the crop yield and trash content in the cotton seed harvested by the harvester.

Trash content

Trash content in harvested cotton includes foreign materials like sticks, burs, dust, leaves, shells etc. This was also an important attribute under machine performance and is considered as a pertinent attribute among other attributes. The observed range of trash content was reported to be varying in the range of 10 to 30% with more trash content in the case of cotton stripper because it strips all the plant materials with cotton bolls during harvesting.

EXISTING PLANTING SYSTEM (EPS)

The traditional planting system used in India for cotton planting comprises wider row crop with plant height

Table 3. Crop attributes and their coding.

S. N.	Range and coding of crop attributes							
	Row spacing		Plant height		Plant population		Crop yield	
	Range (cm)	Code/Grade	Range (cm)	Code/Grade	Range (plants/ac)	Code/Grade	Range (kg/acre)	Code/Grade
1	100-80	5	≥ 175	5	≤ 40,000	5	≤ 600	5
2	80-60	4	175-150	4	40,000-60,000	4	600-700	4
3	60-40	3	150-125	3	60,000-80,000	3	700-800	3
4	40-20	2	125-100	2	80,000-1,00,000	2	800-900	2
5	≤ 20	1	≤ 100	1	≥ 1,00,000	1	≥ 900	1
6	Not discussed	0	Not discussed	0	Not discussed	0	Not discussed	0

exceeding 100 cm. The plant population under this planting system is lesser than 50,000 plants/acre. Crop attributes which affect the performance of a harvesting machine include crop variety, row spacing, plant height; plant population and crop yield are coded as per their importance in the planting system. Table 3 shows the range and coding/grading of the crop attributes These crop attributes, that is, row spacing, plant height, plant population and crop yield are discussed further in brief.

Row spacing under existing planting system is in the range of 60 and 90 cm. So, the maximum grade 5 was given to the range from 80 to 100 cm spacing. Plant height of cotton plant affects the picking/harvesting performance of cotton harvester. It is difficult to harvest the higher length plants with mechanical type cotton harvester available the world over. The existing cotton varieties having conventional agronomic practices are in the range of having height more than 150 cm. Plant populations represents the number of plants sown per unit area. Generally, plant population is observed up to 50,000 plants per acre under existing planting system, due to which, maximum grade has been given to this range of plant population. Crop yield mostly depends on the spacing pattern or plant populations. Most of the authors have discussed this attribute in their study. The yield corresponding to this planting system was approximately 600 kg/acre. Hence, maximum grading is given to this range of yield.

Row spacing: The range of row to row spacing under existing planting system is between 60 and 90 cm. So, the maximum grade 5 was given to the range from 80 to 100 cm spacing.

Plant height: Height of cotton plant affects the picking/harvesting performance of cotton harvester. It is difficult to harvest the higher length plants with mechanical type cotton harvester available the world over. The existing cotton varieties having conventional agronomic practices are in the range of having height more than 150 cm.

Plant populations: Number of plants sown per unit area represents the plant population. Generally, plant population is observed up to 50,000 plants per acre under existing planting system, due to which, maximum grade has been given to this range of plant population.

Crop yield: Crop yield mostly depends on the spacing pattern or plant populations. Most authors have discussed this attribute in their study. The yield corresponding to this planting system was approximately 600 kg/acre. Hence, maximum grading is given to this range of yield.

Specific requirement of harvesting aid

These include defoliant and desiccants used in crop production to accelerate the preparation of crops for mechanical harvesting. Farmers use desired chemicals to enhance the harvesting efficiency, minimize lodging and reduce trash and lint staining.

If used: 1
If not used: 0

Matrix formation

A matrix of attributes was prepared to describe the importance of each attribute for different cotton harvesters by considering the existing planting system as shown in Table 4. A total of 18 mechanical cotton harvesters including 7 harvesters with finger and brush type mechanisms, 8 cotton picker having spindle type mechanism and 3 harvesters with different mechanism like spirally rounded metal sheets and roller type harvesters reviewed for the selection of suitable cotton harvester during the study. Harvesting aid was used before the operation of 15 cotton harvesters and in 3 cases no aid was used before the operation of cotton harvesting.

In Table 4, notations P1, P2, P3----------P18 represent the research publications and can be mentioned as

P1 - Corley and Stokes (1964)
P2 - Faulkner et al. (2011)

Table 4. Matrix based on coding/grading of machine and crop attributes for existing planting system.

Selected attributes		Coding of Mechanical Cotton Harvester																	
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18
Crop attributes	Row spacing	0	5	5	0	2	1	3	0	0	4	5	3	0	0	5	0	3	0
	Plant height	1	2	0	0	3	0	0	0	1	0	0	0	4	4	2	0	0	0
	Plant population	0	0	5	0	4	1	0	3	0	0	5	0	5	0	0	0	0	0
	Crop yield (kg/acre)	3	4	1	1	1	2	5	5	3	0	1	0	3	5	4	3	1	5
ΣA_x =		4	11	11	1	10	4	8	8	4	4	11	3	12	9	11	3	4	5
Picking-aid attribute (Defoliant spray)		1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Machine performance attributes	Harvesting mechanism	OH	BS	BS	BS	FS	FS	BS	FS	SP	OH	SP	SP	SP	SP	SP	SP	OH	SH
	Picking efficiency	5	0	0	5	0	5	5	5	5	1	0	5	5	2	0	3	2	0
	Field capacity	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0
	Total loss	4	5	0	4	4	5	0	0	4	3	0	0	3	1	4	3	0	4
	Gin or Lint turnout	4	3	3	0	2	3	0	0	4	5	4	3	4	0	4	0	3	5
	Trash content	1	3	4	0	4	1	0	1	5	5	4	0	5	0	5	0	4	5
ΣA_y		14	12	7	9	10	14	5	6	18	15	8	8	17	4	14	6	9	14

P3 - Faircloth et al. (2004)
P4 - Tupper (1966)a
P5 - Kanpur et al. (1979)
P6 - Tupper (1966)b
P7 - Perish and Shelby (1974)
P8 - Mathews and Tupper (1965)
P9 - Corley and Stokes (1964)
P10 - Oz and Arrayal (2007)
P11 - Faircloth et al. (2004)
P12 - Perish and Shelby (1974)
P13 - Corley (1970)
P14 - Prasad et al. (2007)
P15 - Faulkner et al. (2011)
P16 - Tupper (1966)b
P17 - Sandhar (1999)
P18 - Khalilian et al. (1999)

Table 5 describes the sum of the crop and machine performance attributes obtained from the different cotton harvester which are selected for the study. The sum of crop and machine attributes helps to select the optimum/best cotton harvester among all the selected harvesters. For selection of cotton harvester, the more the value of sum of crop attributes the more the existing cotton planting system will be satisfied and more the sum of machine attributes will give better performance in the existing planting system of India. The coding sum of crop and machine attributes is also plotted in Figure 2.

Figure 3 and Table 5 show those four cotton harvesters, that is, P2, P5, P13 and P15 can be selected having more crop and machine attribute summation values among all the other harvesters. TOPSIS method is used to further help selecting an optimum cotton harvester by finding the relative rank of the machine attribute.

After scanning the generated database of mechanical cotton harvester, the following four combinations were shortlisted for existing planting system. Selected combinations were further ranked relatively to find the optimum solution with the help of TOPSIS method.

P2	P5	P13	P15
11	10	12	11
12	10	17	14

Where,
P2 represents the brush and paddle type cotton stripper (Faulkner et al., 2011);
P5 is Finger and brush type cotton stripper (Kepner et al., 1979);

Table 5. Summation of coding for crop and machine attributes for existing planting system.

Sum of attributes	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18
Crop (ΣA_x)	4	11	11	1	10	4	8	8	4	4	11	3	12	9	11	3	4	5
Machine (ΣA_y)	14	12	7	9	10	14	5	6	18	15	8	8	17	4	14	6	9	14

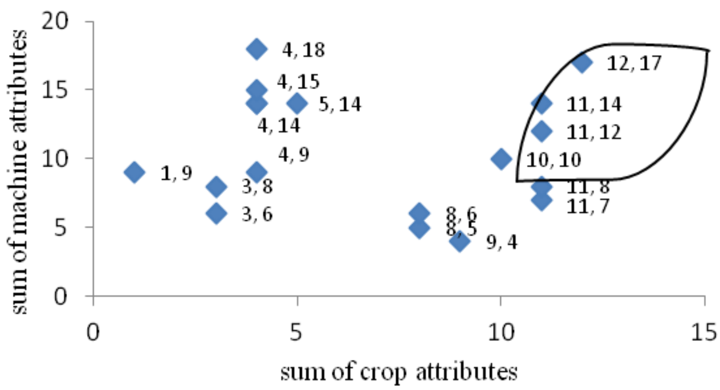

Figure 3. Plotting of coding summation for crop and machine performance attributes for EPS.

P13 is Spindle type cotton picker (Corley, 1970);
P15 is Spindle type cotton picker (Faulkner et al., 2011).

It is clear from the selected four combinations that if equal importance is given to all machine attributes like picking efficiency, losses, trash content, gin turnout and field capacity of the cotton harvester. The spindle type cotton picker (Corlay, 1970) was best suited cotton harvester having maximum sum of crop and machine coding values 12 and 17 respectively, as shown in Table 5, among the selected four combinations for the existing cotton planting system of India.

If the importance of selected machine attributes is not considered to be equal but relative to each other then suitable combination is selected by using TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. To find the optimum solution/best combination the machine attributes like picking efficiency, gin turnout and trash content are considered as pertinent attributes. Other attributes like field capacity and field losses are not considered as pertinent attributes because field capacity of the harvester can be compromised as compared to other pertinent attributes and field losses depends on the picking efficiency. Hence picking efficiency, gin turnout and trash content are considered as pertinent/problem solving attributes.

Therefore, to find the ranks of cotton harvesters for existing planting system, shortlisted cotton harvesters, that is, P2, P5, P13 and P15 were selected by having their picking efficiency, gin turn out and field losses as mentioned in the decision matrix below;

Step 1: Decision matrix (D)

$$D = \begin{bmatrix} 94 & 30 & 19 \\ 95 & 30 & 12 \\ 94 & 39 & 8 \\ 92 & 35 & 5 \end{bmatrix}$$

i_1 = option 1, Brush and paddle type cotton stripper (Faulkner et al., 2011);
i_2 = option 2, Finger and brush type cotton stripper (Kepner et al., 1979);
i_3 = option 3, Spindle type cotton picker (Corley, 1970);
i_4 = option 4, Spindle type cotton picker (Faulkner et al., 2011);
j_1 represents picking/harvesting efficiency;
j_2 represents gin turn out;
j_3 represents trash content.

Step 2: Relative important matrix A

Relative importance of picking efficiency over gin turnout [1,2]: 2/1 = 2
Relative importance of picking efficiency over trash content [1,3]: 2/1 = 2
Relative importance of gin turnout over trash content [2,3]: 1/1 = 1

$$A = \begin{bmatrix} 1 & 2 & 2 \\ 0.5 & 1 & 1 \\ 0.5 & 1 & 1 \end{bmatrix}$$

Step 3:

$$(A - \lambda I) = \begin{bmatrix} 1-\lambda & 2 & 2 \\ 0.5 & 1-\lambda & 1 \\ 0.5 & 1 & 1-\lambda \end{bmatrix}$$

After solving the equation for Eigen-value, the maximum value of one root is found to be 3. Therefore

$(A - \lambda I) = 0$
$\lambda_{max} = 3$

$$(A - \lambda_{max} I) = \begin{bmatrix} -2 & 2 & 2 \\ 0.5 & -2 & 1 \\ 0.5 & 1 & -2 \end{bmatrix}$$

Step 4: Calculating weight for each attribute $(A - \lambda_{max} I).W = 0$

$$\begin{bmatrix} -2 & 2 & 2 \\ 0.5 & -2 & 1 \\ 0.5 & 1 & -2 \end{bmatrix} \begin{bmatrix} W1 \\ W2 \\ W3 \end{bmatrix} = 0$$

W1 + W2 + W3 = 1
W1 = 0.50
W2 = 0.25
W3 = 0.25

Step 5: Normalized matrix (R_{ij})

$R_{ij} = D_{ij}/(\sum_{i=0}^{n} D^2_{ij})^{1/2}$

$$R_{ij} = \begin{bmatrix} 0.50 & 0.45 & 0.79 \\ 0.51 & 0.45 & 0.50 \\ 0.50 & 0.58 & 0.33 \\ 0.49 & 0.52 & 0.21 \end{bmatrix}$$

Step 6: Weighted normalized matrix (V_{ij})

$$V_{ij} = \begin{bmatrix} 0.25 & 0.11 & 0.20 \\ 0.26 & 0.11 & 0.13 \\ 0.25 & 0.15 & 0.08 \\ 0.24 & 0.13 & 0.05 \end{bmatrix}$$

- Positive ideal solution

$V^+ = [0.26, 0.15, 0.20]$

- Negative ideal solution

$V^- = [0.24, 0.11, 0.05]$

- Separation from the positive ideal solution and negative ideal solution

$S_1^+ = 0.04$ $S_1^- = 0.15$
$S_2^+ = 0.08$ $S_2^- = 0.08$
$S_3^+ = 0.12$ $S_3^- = 0.05$
$S_4^+ = 0.03$ $S_4^- = 0.02$

Step 7: Relative closeness to the ideal solution

$C_1^* = 0.79$
$C_2^* = 0.50$
$C_3^* = 0.30$
$C_4^* = 0.40$

Step 8: Ranking of the selected cotton harvester

Relative closeness	Rank
$C_1^* = 0.79$	1
$C_2^* = 0.50$	2
$C_3^* = 0.40$	3
$C_4^* = 0.30$	4

From Steps 7 and 8, it is observed that the value of C_1^* is highest and relatively closer to the positive ideal solution than the other relative closeness values calculated to obtained the rank. So, the first rank is given to C_1^* having value 0.79 which is much closer to the ideal solution of value 1. Hence, according to the TOPSIS method, if relative ranking is given to the pertinent attribute then the best mechanical cotton harvester for existing planting system is brush and paddle type cotton stripper (Faulkner et al., 1979). The second best mechanical harvester which may be selected to harvest the cotton is C_2^* having value 0.50 of Finger type cotton stripper (Kepner et al., 1979). There is a need to develop initially a power tiller operated single row cotton stripper for harvesting of suitable local varieties sown in India.

HIGH DENSITY PLANTING SYSTEM (HDPS)

The same attributes selected were row to row spacing, plant height, plant populations and crop yield and coding of these attributes was done as per their importance in high density planting system. Table 6 shows the range and code/grade of the crop attributes.

This crop attributes, that is, row spacing, plant height, plant population and crop yield are discussed further in brief. Different cotton harvesters were reviewed for different cotton varieties planted in different row spacing by the researchers in their studies. Under HDPS system, the row to row spacing is generally provided in the range of 30 to 45 cm. Height of cotton plant affects the picking/harvesting efficiency of cotton harvester. In HDPS

Table 6. Crop attributes and their coding for HDPS.

S. N.	Range and coding of crop attributes							
	Row spacing		Plant height		Plant population		Crop yield	
	Range (cm)	Code/Grade	Range (cm)	Code/Grade	Range (plants/ac)	Code/Grade	Range kg/acre)	Code/Grade
1	≥ 90	1	≥ 175	1	≤ 40,000	1	≤ 600	1
2	90-70	2	175-150	2	40,000-60,000	2	600-700	2
3	70-50	3	150-125	3	60,000-80,000	3	700-800	3
4	50-30	4	125-100	4	80,000-1,00,000	4	800-900	4
5	≤ 30	5	≤ 100	5	≥ 1,00,000	5	≥ 900	5
6	Not discussed	0	Not discussed	0	Not discussed	0	Not discussed	0

system, the height of plant should be less than 100 cm for better performance of cotton harvesters. In High Density Planting System (HDPS), plant populations with more than 1, 00,000 plants per ha is considered to be best suited. Crop yield mostly depends on the row spacing and plant populations. Most of the authors had discussed this attribute in their study.

Row spacing: Different cotton harvesters were reviewed for different cotton varieties planted in different row spacing by the researchers in their studies. Under HDPS system, the row to row spacing is generally provided in the range of 30 to 45 cm.

Plant height: Height of cotton plant affects the picking/harvesting efficiency of cotton harvester. In HDPS system, the height of plant should be less than 100 cm for better performance of cotton harvesters.

Plant populations: In high density planting system (HDPS), plant populations with more than 1, 00,000 plants per ha is considered to be best suited.

Crop yield: Crop yield mostly depends on the row spacing and plant populations. Most of the authors had discussed this attribute in their study.

Matrix formation

A matrix of attributes was developed to describe the importance of each attribute for different cotton harvesters by considering the high density planting system as shown in Table 7.

Table 8 describes the sum of the crop and machine performance attributes obtained from the different cotton harvester selected for the study. The crop and machine attribute sum helps to select the optimum/best cotton harvester among all the selected harvesters. For the selection of mechanical cotton harvester, the more the value of sum of the crop attributes will be, more it will satisfy the High Density Cotton Planting System, more the sum of machine attributes will be, and better will be its performance in the High Density Planting System of India. The coding sum of crop and machine attributes is also plotted in Figure 4.

Figure 4 and Table 8 show those four cotton harvesters, that is, P5, P6, P9 and P15 can be selected having more crop and machine attribute summation values among all the other harvesters. TOPSIS method was used further to help in selecting an optimum cotton harvester by finding the relative rank of the machine attribute.

After scanning the generated database of mechanical cotton harvester, the following four combinations, that is, P5, P6, P9 and P15 were shortlisted for high density planting system. Selected combinations/best harvesters were further ranked relatively to find the optimum solution with the help of TOPSIS method.

P5	P6	P9	P15
13	14	9	8
10	14	18	14

Where
P5 is Finger and brush type cotton stripper (Kepner et al., 1979);
P6 is finger type cotton stripper (Tupper, 1966);
P9 is spindle type cotton picker (Corley and Stokes, 1964);
P15 is Spindle type cotton picker (Faulkner et al., 2011).

It is clear from the selected four combinations that if equal importance is given to all machine attributes like picking efficiency, losses, trash content, gin turnout and field capacity of the cotton harvester. The finger type cotton stripper (Tupper, 1966) and spindle type cotton picker (Corley and Stokes, 1964) were best suited having acceptable sum of crop and machine coding values 14, 9 and 14, 18 respectively, as shown in Table 8, among the selected four combinations for the high density cotton planting system of India.

If the importance of selected machine attributes is not considered to be equal but relative to each other then suitable combination is selected by using TOPSIS method. To find the optimum solution/best combination, the machine attributes like picking efficiency, gin turnout

Table 7. Matrix based on coding/grading of crop and machine performance attributes for high density planting system.

Selected attributes		Coding of mechanical cotton harvesters																	
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18
Crop attributes	Row spacing	0	2	1	0	4	5	3	0	0	2	1	3	0	0	2	0	3	0
	Plant height	5	4	0	0	3	0	0	0	5	0	0	0	2	2	4	0	0	0
	Plant population	0	0	2	0	2	5	0	3	0	0	2	0	1	0	0	0	0	0
	Crop yield (kg/acre)	2	2	5	5	4	4	5	5	4	0	5	0	3	1	2	3	5	1
ΣA_x =		7	8	8	5	13	14	8	8	9	2	8	3	6	3	8	3	8	1
Picking-aid attribute (Defoliant spray)		1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Machine performance attributes	Harvesting mechanism	BS	BS	BS	BS	FS	FS	BS	FS	SP	OH	SP	SP	SP	SP	SP	SP	OH	SH
	Picking efficiency	5	0	0	5	0	5	5	5	5	1	0	5	5	2	0	3	2	0
	Field capacity	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0
	Total loss	4	5	0	4	4	5	0	0	4	3	0	0	3	1	4	3	0	4
	Gin or Lint turnout	4	3	3	0	2	3	0	0	4	5	4	3	4	0	4	0	3	5
	Trash content	1	3	4	0	4	1	0	1	5	5	4	0	5	0	5	0	4	5
ΣA_y		14	12	7	9	10	14	5	6	18	15	8	8	17	4	14	6	9	14

Table 8. Summation of coding for crop and machine attributes for high density planting system.

Sum of attributes	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18
Crop (ΣA_x)	7	8	8	5	13	14	8	8	9	2	8	3	6	3	8	3	8	1
Machine (ΣA_y)	14	12	7	9	10	14	5	6	18	15	8	8	17	4	14	6	9	14

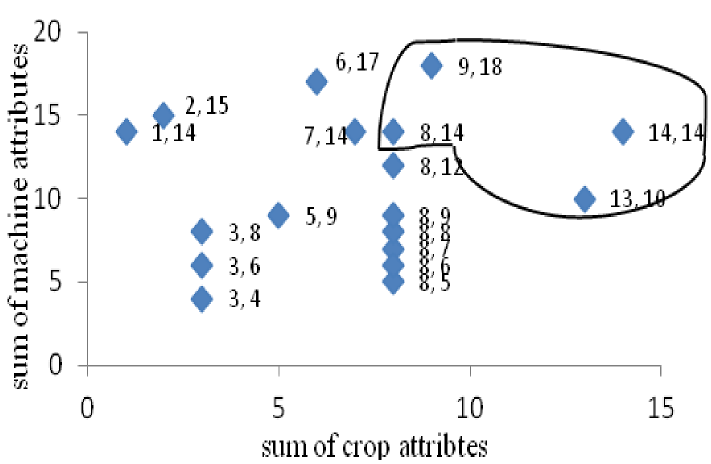

Figure 4. Plotting of coding summation for crop and machine performance attributes for HDPS.

and trash content are considered as pertinent attributes. Other attributes like field capacity and field losses are not considered as pertinent attributes because field capacity of the harvester can be compromised as compared to other pertinent attributes and field losses depends on the picking efficiency. Hence picking efficiency, gin turnout and trash content are considered as pertinent/problem solving attributes.

Therefore, to find the ranks of cotton harvesters for high density planting system, shortlisted cotton harvesters, that is, P5, P6, P9 and P15 were selected by having their picking efficiency, gin turn out and field losses as mentioned in the decision matrix below;

Step 1: Decision matrix (D)

$$D = \begin{bmatrix} 95 & 30 & 10 \\ 94 & 32 & 12 \\ 92 & 38 & 7 \\ 90 & 35 & 5 \end{bmatrix}$$

i_1 = option 1, Finger and brush type cotton stripper (Kepner et al., 1979);
i_2 = option 2, Finger type cotton stripper (Tupper, 1966);
i_3 = option 3, Spindle type cotton picker (Corley and Stokes, 1964);
i_4 = option 4, Spindle type cotton picker (Faulkner et al., 2011);
j_1 = represents picking/harvesting efficiency;
j_2 = represents gin turnout;
j_3 = represents trash content.

Step 2: Relative important matrix A

Relative importance of picking efficiency over gin turnout [1,2]: 2/1= 2;
Relative importance of picking efficiency over trash content [1,3]: 2/1 = 2;
Relative importance of gin turnout over trash content [2,3]: 1/1 = 1.

$$A = \begin{bmatrix} 1 & 2 & 2 \\ 0.5 & 1 & 1 \\ 0.5 & 1 & 1 \end{bmatrix}$$

Step 3:

$$(A - \lambda I) = \begin{bmatrix} 1-\lambda & 2 & 2 \\ 0.5 & 1-\lambda & 1 \\ 0.5 & 1 & 1-\lambda \end{bmatrix}$$

After solving the equation for Eigen-value, the maximum value of λ was found to be 3.

$(A - \lambda I) = 0$
$\lambda_{max} = 3$

$$(A - \lambda_{max} I) = \begin{bmatrix} -2 & 2 & 2 \\ 0.5 & -2 & 1 \\ 0.5 & 1 & -2 \end{bmatrix}$$

Step 4: Calculating weight for each attribute $(A - \lambda_{max} I).W = 0$

$$\begin{bmatrix} -2 & 2 & 2 \\ 0.5 & -2 & 1 \\ 0.5 & 1 & -2 \end{bmatrix} \begin{bmatrix} W1 \\ W2 \\ W3 \end{bmatrix} = 0$$

W1 + W2 + W3 = 1
W1 = 0.50
W2 = 0.25
W3 = 0.25

Step 5. Normalized matrix (R_{ij})

$$R_{ij} = D_{ij} / (\sum_{i=1}^{n} D^2_{ij})^{1/2}$$

$$R_{ij} = \begin{bmatrix} 0.51 & 0.44 & 0.56 \\ 0.50 & 0.47 & 0.67 \\ 0.49 & 0.56 & 0.39 \\ 0.48 & 0.51 & 0.28 \end{bmatrix}$$

Step 6: Weighted normalized matrix (V_{ij})

$$V_{ij} = \begin{bmatrix} 0.255 & 0.11 & 0.14 \\ 0.25 & 0.12 & 0.17 \\ 0.245 & 0.14 & 0.04 \\ 0.24 & 0.13 & 0.03 \end{bmatrix}$$

- Positive ideal solution

$V^+ = [0.255, 0.14, 0.17]$

- Negative ideal solution

$V^- = [0.24, 0.11, 0.03]$

- Separation from the positive ideal solution and negative ideal solution

$S_1^+ = 0.04$ $S_1^- = 0.11$
$S_2^+ = 0.02$ $S_2^- = 0.14$
$S_3^+ = 0.13$ $S_3^- = 0.03$
$S_4^+ = 0.14$ $S_4^- = 0.02$

Step 7: Relative closeness to the ideal solution

$C_1^* = 0.73$
$C_2^* = 0.87$
$C_3^* = 0.19$

$C_4^* = 0.13$

Step 8: Ranking of the selected cotton harvester

Relative closeness	Rank
$C_2^* = 0.87$	1
$C_1^* = 0.73$	2
$C_3^* = 0.19$	3
$C_4^* = 0.13$	4

From Steps 7 and 8, it is observed that the value of C_2^* is the highest and relatively closer to the positive ideal solution than the other relative closeness values calculated to obtained the rank. So, the first rank is given to the C_2^* having value 0.87 much closer to the ideal solution of value 1. Hence on the basis of TOPSIS method if the relative importance of pertinent attributes is considered, the best mechanical cotton harvester for High Density Planting System is finger type cotton stripper (Tupper, 1969). The second best mechanical harvester which may be selected to harvest the cotton is C_1^* of brush type cotton stripper (Kepner et al., 1979). From the results, it is clear that the cotton stripper is best suited for the HDPS as compared to the cotton picker used in the advanced countries. In countries like Brazil and Argentina, cotton strippers are already popular in HDPS, in which cotton plant population is about 2 lakhs/ha. They are using stripper with on-board trash cleaning systems to overcome the trash content in the seed-cotton. But, trash content in cotton harvested by stripper is the major issue. In India, alternate design of cotton stripper can be done by incorporating the cleaners developed locally.

Conclusions

This research on attribute based coding system for the selection of suitable cotton harvester for the two planting systems reveals:

1) Numerical method called Multiple Attribute Decision Making (MADM) was useful to solve the complex problem for the selection of suitable cotton harvester.
2) If equal weightage (importance) was given to all machine attributes like picking efficiency, losses, trash content, gin turnout and field capacity of the cotton harvester, the spindle type cotton picker (Corlay, 1970) was best suited for the existing cotton planting system of India.
3) Based on the TOPSIS method, if relative ranking is done for the pertinent attributes then the best mechanical cotton harvester for existing planting system was brush and paddle type cotton stripper (Faulkner et al., 1979).
4) For high density planting system, if equal importance is given to all machine attributes of the cotton harvester, the finger type cotton stripper (Tupper, 1966) and spindle type cotton picker (Corley and Stokes, 1964) were best suited.
5) Based on the TOPSIS method, if the relative importance of pertinent attributes was considered, the best mechanical cotton harvester for High Density Planting System was finger type cotton stripper (Tupper, 1969). The second best mechanical harvester which may be selected to harvest the cotton was brush type cotton stripper (Kepner et al., 1979).

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