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Study on the evaluation of agricultural machinery equipment based on DEA method

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Abstract. The traditional evaluation method for equipment of agricultural machinery is easy to be influenced by subjective factors, and the process of calculation is more complicated. The DEA method can avoid subjective evaluation deviation, and the result of evaluation is objective as well the calculation operation is simple. In view of the problems existing in the traditional evaluation method for equipment of agricultural machinery, this paper uses DEA method to establish a model for the equipment of agricultural machinery in 105 regiment of Xinjiang Construction and Production corps. And using the Lingo software to solve the model, as well analyzing the results with 105 regiment's actual situation. The results show that the method is practical and feasible. It not only has extensive value of popularization, but also can get the defect of the not effective scheme and propose the improvement measures, so as to provide more management information for decision-makers.

Key words. Agricultural machinery, equipment, dea, evaluation.

1. Introduction

The equipment of agricultural machinery is the most basic tasks of agricultural mechanization management, the equipment of agricultural machinery which is reasonable or not is related to mechanization can achieve good economic benefits or not[1].Along with the continuous improvement of the level of agricultural mechanization, the scheme for equipment of agricultural machinery is also constantly updated, and the requirements of users for the efficiency and quality of the scheme for equipment of agricultural machinery are also increasingly high.

In view of the problems of evaluation for the equipment of agricultural machinery, there are few studies at home and abroad. Such as Sha Yourong[2] has used fuzzy comprehensive evaluation combined with analytic hierarchy process to select the optimal scheme for equipment of agricultural machinery, which can fully consider

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all aspects of the factors, so that the equipment of agricultural machinery is more reasonable and more scientific, the results show that the method is feasible, but the process of calculation is more complex. Ma Yuhong[3] has used factor analysis method to construct the index system to evaluate efficiency of the equipment of agricultural machinery from the quantity of agricultural machinery, model, tillage efficiency and agricultural output value, and the result shows that this method can be used to evaluate efficiency for the equipment of agricultural machinery, and it also has guiding significance for the policy measures of the equipment of agricultural machinery. In recent years, Wang Sanxi[4] has applied DEA (Data envelopment Analysis) to the evaluation and optimization of military programming. Chenkui [5] has proposed the method of integrating AHP (Analytic Hierarchy Process) and DEA to be applied in comprehensive decision-making of power network planning. Billei[6] has adopted DEA method to evaluate and optimize the tunnel construction scheme comprehensively. Liu Lifen[7] has used DEA method to establish evaluation index system for underground road traffic engineering design project. Many results show that the index system of multiple scheme evaluation is constructed by using DEA method, this method can achieve better results, and the system structure is simple. As well the evaluation of the object is easy to operatehas and has strong contact and practicability, which can provide the scientific basis for agricultural decision-makers, but this method is seldom studied in the evaluation for the equipment of agricultural machinery.

As at the end of 2016,the total power of agricultural machinery of 105 regiment of Six Division in Xinjiang Construction and Production Corps (refer to 105 regiment) has reached 43,700 kilowatt, with large and medium-sized tractors 714 units, large and medium-sized tractor supporting tools 1143 units. In 2016,the total annual mechanical operation cost of 105 regiment reached 15.2595 million yuan, the agricultural machinery matching ratio is 1:1.6, which can be said that the level of agricultural mechanization development of 105 regiment is better, but if carry on the effective evaluation for the scheme of the equipment of agricultural machinery and choose the best scheme before the agricultural machinery is equipped, it will improve the utilization rate of agricultural machinery and the development level of agricultural mechanization greatly in 105 regiment. To this end, this paper takes 105 regiment as an example, using the DEA method to establish the evaluation model for equipment of agricultural machinery and getting the best equipment scheme which hope to provide decision support for the equipment of agricultural machinery.

2. Introduction of the method

The most basic model of the DEA method is the C^2R model, there are some characteristics of the model are as follows. The abstract concept can be translated into concrete figures vividly and intuitively. It has universal applicability which can be applied to any research institutions and use units for the evaluation of equipment of agricultural machinery. The choice of input or output index which can be chosen by the combination of its own characteristics and the actual situation has strong flexibility. It has time dynamics as well. In the C^2R model, assuming that the

number of decision unit is m, and each decision unit has p kinds of factors devoted and q kinds of output indexes contained. Each factor devoted and output index represents "work effect" and "resource consumption" of each decision unit, which is shown in Table 1.

The efficiency evaluation index relation formula of decision unit s is

$$\eta_s = \frac{\sum_{i=1}^{q} u_l y_{ls}}{\sum_{i=1}^{p} v_k x_{ks}} s = 1, 2, \cdots, m, \tag{1}$$

According to the last formula which is within the range of $\eta_s \leq 1$ to determine the selection weight coefficient v_k and u_l.

Taking the decision unit m as an example, the standard formula of C^2R model can be obtained is

$$C^2R \left\{ \begin{array}{cc} \max \eta_{s0} = & \frac{\sum_{l=1}^{q} u_l y_{ls}}{\sum_{k=1}^{p} v_k x_{ks}} \\ s.t & \\ \frac{\sum_{l=1}^{q} u_l y_{ls}}{\sum_{k=1}^{p} v_k x_{ks}} \leq 1 & s = 1, 2, \cdots, m \\ u_l \geq 0 & l = 1, 2, \cdots, q \\ v_k \geq 0 & k = 1, 2, \cdots, p \end{array} \right\}, \tag{2}$$

Table 1. Input/Output indexes of DEA method

Weight Coefficient		Decision Unit			
		1	2	$\cdots$	m
Input index 1	v_1	x_{11}	x_{12}	$\cdots$	x_{1m}
Input index 2	v_2	x_{21}	x_{22}	$\cdots$	x_{2m}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
Input index p	v_p	x_{p1}	x_{p2}	$\cdots$	x_{pm}
Output index l	μ_1	y_{11}	y_{12}	$\cdots$	y_{1m}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
Output index q	u_q	y_{q1}	y_{q2}	$\cdots$	y_{qm}

(1)Construction of evaluation model for equipment of agricultural machinery

This model implements the dual programming for formula (2) and adds variable (s^+ , s^-) and Archimedes infinitesimal (ε) , which carrys out a simple Chains-Cooper transformation, so that the construction of the evaluation model (H_ε) for equipment

of agricultural machinery is realized successfully.

$$E = E_0 \left(1 - \alpha \left(1/2 - \xi\right)\right) , \tag{3}$$

In the last formula, X_s represents a factor that affects the s-th decision unit and is known to have a range of values is$X_s \geq 0$; Y_s represents the output index of the s-th decision unit and is known to have a range of values is $Y_s \geq 0$.What's more, $X_s = [x_{1s}, x_{2s,} \cdots, x_{ps}]^T \in R$,$Y_s = [y_{1s}, y_{2s}, \cdots, y_{qs}]^T \in R$,$e^T = 1, 1 \cdots 1 \in E_m$,$e^T = 1, 1 \cdots 1 \in E_s$,and usually take $\varepsilon = 10^{-6}$.

(2)Analysis and meaning of result

Formula(3)can be understood as a linear programming problem, which is necessary to bring the correct input and output indexes, then the calculation result can be obtained by using computer software. The optimal calculation results obtained by solving H_ε model are as follows: λ^0,s^{+0},s^{-0},θ^0.Based on these data of result can be used to determine whether the decision unit is weak effective, effective or non-effective of DEA. Specific analysis are as follows.

1)If $\theta^0 = 1$,$s^{-0} = 0$,and $s^{+0} = 0$,it represents the decision unit s_0 is effective of DEA. It indicates that the decision unit has high efficiency in the internal operation and all input indexes have played their maximum effectiveness, so as to the production scale is in the relative best condition.

2)If $\theta^0 = 1$,$s^{-0} \neq 0$,and $s^{+0} \neq 0$,it represents the decision unit s_0 is weak effective of DEA. The decision unit could use two methods to be effective of DEA. One is reducing s^- of the input index and maintain the original output volume, another is increasing s^+ of the output index in the case of constant input capacity.

3)If $\theta^0 \neq 1$??and then if $\sum_{s=1}^{m} \lambda_s^0/\theta^0 < 1$ indicating that the decision unit is increasing in scale??if $\sum_{s=1}^{m} \lambda_s^0/\theta^0 = 1$indicating that the decision unit is unchanged for scale??if $\sum_{s=1}^{m} \lambda_s^0/\theta^0 > 1$ indicating that the decision unit is diminishing in scale.

4)For the non-effective decision unit, it can be adjusted to improve the non-effective of decision unit s_0 by changing the projection on the effective plane of the decision unit. This adjustment can analysis decision units in detail, but also can provide a detailed analysis for researchers and users, so as to turn non feasible to feasible.

Table 2. The process of annual mechanization on main Planting crops of 105 regiment

Serial number	Job projects	Timely working time		Productivity of Working Group class (acre/class)		
1	Chemical weeding of tomato	3.25-4.5	12	——	——	400
2	Primary tillage of tomato	4.1-4.8	8	210	260	——
3	Chemical weeding of cotton	4.2-4.8	7	——	——	400
4	Sowing of tomato	4.5-4.10	6	——	——	120
5	Primary tillage of cotton	4.5-4.10	6	210		
6	Seeding of cotton with film spreading	4.8-4.22	15	——	——	130
7	Secondary leveling of cotton	4.28-5.15	18	——	——	120
8	Secondary leveling of tomato	5.20-5.30	11	——	——	120
9	Chemical regulation of cotton	6.25-7.5	11	——	——	400
10	Harvest of wheat	7.1-7.10	10	200(combine harvester)		
11	Transport of wheat	7.1-7.10	10	each wheat combine harvester equipped with two vehicles		
12	Bundle of straws	7.10-7.20	11	——	——	100
13	Tillage of wheat	7.16-7.25	10	110	160	——
14	Harvest of tomato	7.25-9.15	53	70(tomato harvesting machine)		
15	Transport of tomato	7.25-9.15	53	each tomato harvesting machine equipped with two vehicles		
16	Spraying free and easy leaf agent of cotton	8.26-9.5	11	——	——	400
17	Land leveling of wheat	9.5-9.10	6	210	260	——
18	Sowing of winter wheat	9.10-9.25	16	——	——	150
19	Primary tillage of tomato	9.10-10.30	51	110	160	——
20	Machine mining of cotton	9.20-10.20	31	200(John Deere-CP690 cotton baler)		

Table 3. The fixed cost of agricultural machinery and tools of 105 regiment

Name of agricultural machinery	Price /yuan	Annual fixed fee /yuan
Futon TG1654	390000	63570
Dongfanghong LX2204	517000	84271
John Deere JD5-750	126000	20538
Dongfanghong -LX754	112000	18256
Spray machine	42000	4725
Combined Ground Machine	38000	4275
Cotton Spreading-Film seeder	28000	3150
Tomato seeder	27000	3037.5
Wheat Seeder	21700	2441.3
Secondary tillage Fertilization Machine	15000	562.5
Straw strapping Machine	49800	1687.5
Hydraulic Reverse Four plough	32000	3600
Hydraulic reverse Five plough	9800	5602.5
Straw returned to the field machine	5000	1102.5

Table 4. The Variable cost of agricultural machinery unit of 105 regiment

Job Type	Fuel fee (yuan/mu)	Maintenance fee (yuan/mu)	Wages fee (yuan/mu)	Total fee (yuan/mu)
Primary tillage of Futon TG1654 tractor	11.2	3	12.5	26.7
Land leveling of Futon TG1654 tractor	5.2	2.4	10	17.6
Primary tillage of the Dongfanghong LX2204 tractor	11.4	2.2	12.5	26.1
Land leveling of Dongfanghong LX2204 tractor	5.7	2	10	17.7
field spraying of pesticides of John Deere JD5-750	2.5	2	0.8	5.3
sowing of tomato of John Deere JD5-750	5	3	5	13
sowing of cotton of John Deere JD5-750	5	3	5	13
Secondary tillage of John Deere JD5-750	2	1	1	4
bundle of straws of John Deere JD5-750	5.5	3	3	11.5
sowing of winter wheat of John Deere JD5-750	3	2	3	8
dozen cotton stalks of John Deere JD5-750	6	1.5	1.5	9
full layer fertilization of cotton of John Deere JD5-750	0.6	0.5	1.5	2.6
field spraying of pesticides of Dongfanghong LX754	3	0.8	0.8	4.6
sowing of tomatoes of Dongfanghong LX754	6	2	5	13
sowing of cotton of Dongfanghong LX754	6	2	5	13
Secondary tillage of Dongfanghong LX754	3.5	1	1	5.5
bundle of straws of Dongfanghong LX754	6	3	3	12
sowing of winter wheat of Dongfanghong LX754	5	2.5	3	10.5
dozen cotton stalks of Dongfanghong LX754	6	2	1.5	9.5
full layer fertilization of cotton of Dongfanghong LX754	1	0.5	1.5	3

(1)Choice of decision Unit

According to the local situation, Table 5 is the scheme for equipment of agricultural machinery established. Each scheme is a decision unit, so there are 10 decision units.

Table 5. Schemes for equipment of agricultural machinery in 105 regiment

Scheme Name of agricultural machinery (units)	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6
Futon TG1654	26	27	26	23	26	25
Dongfanghong LX2204	10	9	10	12	10	10
John Deere JD5-750	30	31	30	27	30	30
Dongfanghong LX754	22	22	22	22	21	21
Spray machine	34	34	34	34	33	33
Combined Ground Machine	35	35	35	35	35	35
Cotton Spreading-Film seeder	37	37	37	37	37	37
Tomato seeder	16	17	14	8	17	16
Wheat Seeder	10	9	10	12	10	10
Secondary tillage Fertilization Machine	44	44	44	44	43	43
Straw strapping Machine	21	20	22	26	21	22
Hydraulic Reverse Four plough	7	7	7	4	7	7
Hydraulic reverse Five plough	10	9	10	12	10	10
Straw returned to the field machine	23	23	23	23	23	23
Wheat combine harvester	10	10	10	13	10	11
Tomato harvesting machine	3	3	3	2	3	3
Cotton-Picking Machine	11	11	11	11	11	11

(2)Determination of Evaluation Index

According to the target of the equipment of agricultural machinery, this model starts from the local situation and complys the principle with which the number of decision unit is the twice times of the evaluation index in DEA method is more reliable, the following five criteriaes are selected.The first one is the amount of power

mechanical equipment(u_1), that is the sum of the number of power machines. The second is the power of agricultural machinery(u_2), that is the sum of the power of power mechanines. The third is the amount of agricultural tools' equipment(u_3), that is the sum of the quantity of agricultural tools. The forth is the cost of total annual mechanical operations(u_4),that is the sum of the annual cost of agricultural machinery operation projects, and the cost of agricultural machinery project is the sum of fixed cost and variable cost. The fifth is the matching ratio of agricultural machinery(u_5),that is the ratio of the number of power machines to the number of agricultural tools. In the index, u_1, u_2, u_3 ,u_4 is input index and u_5 is output index. Table 6 is the DEA input/Output index system of the equipment of agricultural machinery.

Table 6. DEA input/Output index system of the equipment of agricultural machinery

index equipment scheme	Input index			
	the amount of power mechanical equipment /units	the power of agricultural machinery /kW	the amount of agricultural tools' equipment /units	the cost of total annual mechanical operations /million yuan
1	88	10390	237	1069.89
2	89	10410	235	1070.98
3	88	10390	236	1068.80
4	84	10110	235	1065.07
5	87	10315	236	1064.28
6	86	10150	236	1063.20
7	85	10075	234	1062.11
8	87	10170	236	1065.37
9	85	10130	234	1061.09
10	86	10150	232	1057.59

(3)Modeling and solving based on the index

According to formula (3)and taking the first decision unit as an example to establish a model and solve, then

θ Other decision units are similarly calculated.

(4)Analysis of calculation results

This model programs which is according to the Lingo software and calculates the results as shown in Table 7.

Table 7. Calculation results

Decision Unit	1	2	3	4	5	6
θ	0.9562	0.9426	0.9537	1	0.9684	0.9802
s_1^-	3.4620	4.7143	3.5346	0	2.9661	2.1052
s_2^-	224.0305	282.8571	233.2940	0	205.8213	56.6126
s_3^-	0.8957	0	0.1688	0	1.1374	
s_4^-	0	5.5723	0	0	0	0
s_1^+	0	0	0	0	0	0
$c = \sum_{s=1}^{m} \lambda_s^0/\theta^0$	c>1	c>1	c>1	c=1	c<1	c<1

From Table 7, the paper makes a judgment on the equipment scheme of agricultural machinery of Table 5,and obtains the advantages and disadvantages of the sort order that is scheme IV, scheme VII, scheme IX, scheme VI, scheme X, scheme V, scheme VIII, scheme I, scheme III and scheme II. Therefore, the scheme IV is the most reasonable choice, which is not only the agricultural machinery resources are fully utilized, but also the input factor scale achieves the best combination and obtains the biggest output benefit in the process of the equipment of agricultural machinery in 105 regiment.

In addition, one of the advantages of DEA is that it can effectively improve the decision unit from non-effective to effective of DEA, so as to provide useful management information for decision-makers. For example, in the case of scheme I, the adjusted values of the indicators are as follows.

The adjustment quantity of the amount of power mechanical equipment is

$$(1 - 0.9562) \times 88 + 3.4620 = 7.3164 units$$

The adjustment quantity of the power of agricultural machinery is

$$(1 - 0.9562) \times 10390 + 224.0305 = 679.1125 kw$$

The adjustment quantity of the amount of agricultural tools' equipment is

$$(1 - 0.9562) \times 237 + 0.8957 = 11.2763 units$$

The adjustment quantity of the amount of power mechanical equipment, the power of agricultural machinery and the amount of agricultural tools' equipment are all reduced on the basis of the original input, so that the adjusted scheme becomes DEA effective.

3. Evaluation index and analysis of agricultural machinery system

The indexs used to evaluate the scheme vary from objectives of the scheme to different, but it can be divided into two types of indexs,which is technical and economic effect indexs. The technical effect index for the equipment of agricultural machinery mainly includes the total investment of agricultural machinery, the investment of agricultural machinery per unit area and the amount of power equipment per unit area, etc. While the economic effect index mainly includes the operation cost of the machine work unit, the improvement of agricultural labor productivity and the total income benefit of the agricultural mechanization. In order to evaluate the superiority of the best agricultural equipment scheme, the following six aspects are compared with the actual agricultural machinery system, and the results are shown in Table 8.

Table 8. Comparison the indexs of actual and the best equipment

Index	Actual equipment	the best equipment	growth rate /%
the amount of power mechanical equipment	714units	84 units	-88.24
the power of agricultural machinery	43700kW	10110kW	-76.86
the amount of agricultural tools' equipment	1143 units	235 units	-79.44
the cost of total annual mechanical operations	1525.95 Million	1065.07 Million	-30.20
operating cost per unit area	124.26yuan/acre	86.73yuan/acre	-30.20
the matching ratio of agricultural machinery	1:1.6	1:2.80	75

According to the data in Table 8, the following conclusions can be obtained.

At present, there is a serious wastage of power in 105 regiment. In the best equipped scheme, the power machinery in 105 regiment equipped with 84 units, compared to the actual amount of equipment reduced by 88.24%, and the optimization result of agricultural machinery power is 10110kW, compared to the actual reduced by 76.86%. In addition, the annual cost of mechanical operating which is in the best equipped scheme is 10.6507 million yuan, which is reduced by 30.2% compared to the actual. It can be concluded that the best equipped scheme has achieved better results, which is not only reducing the amount of agricultural machinery equipment effectively, but also improving the matching ratio of agricultural machinery.

4. Conclusion

The work for equipment of agricultural machinery is more complicated. This paper uses the method of DEA to evaluate the relative effectiveness of the equipment of agricultural machinery in 105 regiment, in which the amount of power mechanical equipment, the power of agricultural machinery, the amount of agricultural tools' equipment and the cost of total annual mechanical operations are the input indexs, and the matching ratio of agricultural machinery is output index. This method that has intrinsic objectivity can fully consider all aspects of the factors, so that the equipment of agricultural machinery is more accurate, reasonable and effective. The application of this method to the optimum scheme of agricultural machinery can not only provide scientific and accurate basis of the decision for agricultural machinery workers, but also easy to realize computer processing, convenient and fast, and improve the efficiency of decision-making. At the same time, the optimal result of DEA method is relatively effective, so that the optimal solution is not unique, which is more accord with the reality compared with the unique solution of multi-objective programming. And in this method, the non-effective of DEA can be improved into effective of DEA, that is it can turn what is not feasible into feasible, which provides more decision information for decision-makers.

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