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Research on Comprehensive Performance Evaluation of Cultivation Machinery for Tea Garden

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Abstract: Tea garden tiller is one of the most widely used in China, which is indispensable equipment for soil tilling in tea garden. The performance of tea garden tiller is always focused on when being used. Meanwhile, researches on evaluating the performance of tea garden tiller have been rarely reported. So it is of importance to find a methodology to evaluate tiller's performance. In this paper, the important indexes of tiller performances are presented firstly, including fuel consumption, cultivation time, cultivation depth, cultivation width and soil crushing ratio. Then these indexes for eight different types of cultivation machineries from home and abroad are experimented and detected. Thirdly, rough sets and radar chart are utilized for performance evaluation of cultivation machineries, where rough set theory is to determine the weight of performance index and radar chart for performance analysis. Finally, performance of cultivation machinery is analyzed based on radar chart, which can provide the convenience and proof of optimal cultivation machinery selection for farmers. The results of radar chart analysis show that operational performance of KAMA B is the best and Little White Dragon B stand the second place. In addition, from the performance analysis, the deficiencies of service cultivation machinery can be found and the improvements can be suggested.

Keywords: tea garden tiller; performance evaluation; rough set theory; radar chart

1 Introduction

Tea garden cultivation is an important part in tea garden management, which is advantageously functioned by weeds cleaning, soil loosing, soil maturation promotion and so on[1]. Currently, with the increasing of labor transfer and tea garden management costs, tea garden machinery need to conform with tea garden management tendency. There are various cultivation machineries available, some of which have been under research for performance improvement by experts at home and abroad. However, little is about the performance evaluation,[2]. So it is of importance to research the performance evaluation for tea garden tiller. The researches about performance evaluation have been carried out in many fields, such as industry, agriculture, military and so on. The most commonly applied methods for performance evaluation include rough set theory and fuzzy optimization model. Ye wei et al. utilized rough set to reduce the evaluation index for crane performance[3]. Tong Y.F. proposed energy-saving evaluation architecture for lifting machinery from the view of metal structure, transmission mechanism and electronic control[4]. In addition, some intelligent algorithms, such as GA, BP neural network and so on are used to model and solute the performance optimal selection[5]. In this paper, rough set theory and radar chart model will be adopted to research the performance evaluation of tea garden tiller. Radar chart model arises from phylogenetic analysis of TRIZ[6]. Technical evolution model and route is a hot research of TRIZ -technical evolution theory. According to statistics, about 20 kinds of typical evolutionary modes and 350 evolutionary routes have been developed by academic researchers, the most renowned of which are 6 kinds of evolutionary modes proposed by Fey V. and Rivin V, 10 by Zlotin B. and Zusman A, and 11 by Mann D characterized by deep, systematic and structural research. In this paper,a multi-view drawing techniques from a system performance model - the radar map based on technology Evolutionary Potential which is proposed by Mann D is adopted to analyze comprehensive performance of tea garden tiller. The present work was carried out in order to obtain the result of performance of cultivation machinery, which can provide the convenience and proof of optimal cultivation machinery selection for

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farmers. In the next section, the experiment for eight types of tea garden tiller was carried out in Yunnan large leaf tea area and its results were achieved. In Section 3,rough sets and radar chart model are introduced into performance evaluation of cultivation machineries, where rough set theory is utilized to determine the weight of performance index and radar chart is for performance analysis. In Section 4,according to the results of experiment summarized in Section 2, radar charts for eight types of tea garden tiller were drew when the weight of performance index was calculated by means of rough set theory. And the performance of eight machineries was analyzed based on radar charts followed. Finally, research conclusions are summarized.

2 Test & its results

(1)Determination of experiment subjects
Eight different types of cultivation machineries for tea garden from home and abroad are selected for testing, whose technical parameters are as listed in Table 1. After brain storming of field experts, fuel consumption, cultivation efficiency, tillage depth, tillage width and soil crushing rate are selected as performance index of test.
(2)Test[7]
On August 17/2013, field tests of cultivation machineries are carried out in Yunnan large leaf tea area.
1.Brief introduction of test field
The test field covers six acres and relative criteria are listed in Table.2

2.Test means
Aiming at the test index, the test can be carried out as follows: 1) Fuel consumptions detection Get 1L petrol (diesel) by cylinder into cultivation machinery before test and the rest after tillage by cylinder, then petrol (diesel) consumptions of per test can be obtained. 2) Cultivation efficiency detection Record the tillage time and area (unit/acre) and the efficiency (acre/s) can be obtained. 3) Tillage depth detection Three tillage points randomly are selected to measure the tillage depth after each tillage. 3) Tillage width detect Three tillage points randomly are selected to measure tillage width after each tillage. 5) Soil crushing rate detection Three tillage points randomly are selected after each tillage, centering which, clods in whole tillage layer of 0.33m 0.33m area are detected. The soil crushing rate is the percentage the weight of clods, whose longest edge is shorter than 5cm, play of the total mass.
3.The results
The detection results can be shown as in Table .3.

Next, the test results above will be utilized for weights solution of index to optimization based on rough set.

3 Rough set theory and determination of weight method

(1)Rough set[8]
Let U be an uncertain domain associated with a equivalence relation $[x]_R$ is the equivalence relation on the generated-equivalence class and X is a subset of the U . There are:

$$R_{-}(X) = \{x \in U | [x]_R \subseteq X\}$$

$$R^{-}(X) = \{x \in U | [x]_R \subseteq X \neq \varphi\}$$

(2)Information system [3]
Let $S = \{U, A, V, f\}$ be an information system, where U denotes the discussed domain and ($A = C \cup D$)denotes the set properties. Subset of C and D respectively refer to sets of condition attributes and decision attributes sets.$V = \bigcup_{a \in A} V_a$ is the set attribute value and f: $U \times A \to V$ is an information function.Set each attribute subsets as B and define $IND(B)$ as an indiscernibility binary equivalence relation, where $IND(B) = \bigcap_{b \in B} IND(\{b\})$.
(3)Determination of the importance of attributes[9]
Definition 1:Let K= (U, R) be a knowledge base ($r \in R$ as an equivalence relation) and GD(R) is granularity from knowledge $r \in R$:

$$GD(r) = \frac{|r|}{|U^2|} = \frac{|R|}{|U^2|} \quad (1)$$

Definition 2 : Let $K = (U, r)$ be a knowledge base ($r \in R$ as an equivalence relation) and $Dis(r)$ is definition from knowledge $r \in R$:

$$Dis(r) = 1 - GD(r) \quad (2)$$

Set $S = \{U, A, V, f\}$ is an information system, $A = C \cup D$,$X \subseteq C$ is a subset of attributes,$x \in X$ is a attribute,Considering the importance of x to X, that is the improvement degree of definition after adding attribute x to X , the degree of improvement is greater, attribute x is more important for X.
Definition 3 Set as a subset of attributes, as a attribute, if attribute importance degree of x to X is ,its definition:

$$Sig_X(x) = 1 - \frac{|X \cup \{x\}|}{|X|} \quad (3)$$

Among them:$|X|$ is taken as $|IND(X)|$, $Set\,\frac{U}{|IND(X)|} = \frac{U}{X} = \{X_1, X_2, \cdots, X_n\}$,then $|X| = |IND(X)| = \sum_{i=1}^{n} |X_i|^2$
Comparing the method introduced above and the subjectively determined weight, the method is based on test data and scientific calculations, mining the test data to find an intrinsic relation in the importance of index data, therefore, it is more objective and can improve the accuracy of evaluation results.
(4)Synthetic weights method [10]

Table 1: Technical parameters of cultivation machineries

Tiller	Little White Dragon Tiller	KAMA Tiller	Honda Tiller	Capterpillar type plowed Tiller
Brand	Little White Dragon	KAMA	Honda	TKK
Manufacturer	Luoyang Dragon Horse Machinery Co,.LTD	Wuxi worldbest kama power co., LTD	Jialing - Honda Engine Co. Ltd.	Hebei TKK Machinery Manufacturing Co., Ltd.
Type	1WG3.3A,B	KW3CG-50(A,B)	FJ500(A,B)	3ZFL-40(A,B)
Weight (kg)	45	105	60	78
Equipment size (mm)	1200*780*900	1150*600*1050	1395*900*1080	1250*550*800
Standard tillage depth (cm)	10 15	7 15	10	50 100
Standard tillage width (cm)	65	30 50	90	30 50
Maximum output power of the engine (kw)	3.3	2.5	3.05	3.5
Fuel tank capacity (L)	-	2.5	2.4	6
Fuel	gasoline	diesel	gasoline	gasoline

Table 2: Relative criteria of test field

Criteria / Location	Tree height (cm)	Tree amplitude (cm)	Tree width (cm)	Soil type	Soil moisture	Breed
Yunnan Pu'er tea garden	82.4	165.6	215.4	Red loam	13.29%	Yunkang No.10

Table 3: Test results for all indexes

Index / Machinery	Fuel consumption (L/acre)	Cultivation efficiency (s/acre)	Tillage depth (cm)	Tillage width (cm)	Soil crushing rate (%)
L.W.D A	0.25	1075.01	12.33	64.78	62.77
L.W.D.B	0.25	986.87	14.11	72.89	82.19
KAMA A	0.16	1264.05	14.11	43.22	57.44
KAMA B	0.16	1220.19	16.11	64.78	82.98
Honda A	0.35	1269.91	9.44	69.67	61.00
Honda B	0.35	1201.94	11.89	73.89	68.17
TKK A	0.31	860.22	9.11	26.44	89.07
TKK B	0.31	982.38	9.89	31.56	82.12

In information system of $S=(U,A,V,f)$, each attribute value of which has different influence on decision attribute in the condition attributes set of $C \in A$. Therefore, their weights should be determined. In this article, the final weight I are composed by subjective and objective components,the objective of which is solved by the above calculation method and denoted by P and the subjective one is based on expert's experience and denoted by Q:

$$I=\alpha Q+(1-\alpha)P \quad (0 \leq \alpha \leq 1) \tag{4}$$

Among them: is called the experience factor ,$0 \leq \alpha \leq 1$, which reflects decision maker's preference degree between objective weight and subjective weight in the decision making process, if is larger,the decision makers pay more attention to the experience of experts; On the contrary, they pay more attention to objective weigh. Two limits in formula 2 are objective weight and subjective weight.

4 Radar chart modeling

According to the test index, the radar chart model is established as shown in Figure1, which can be illustrated as in Table.4. Fig. 1 Radar chart for performance evaluation of tea garden cultivation machinery

According to Table 4, the paper solves five above indexes by the synthetic weights method based on rough set theory, and $\sum_{j=1}^{10} i_j = 1$. The five indexes can be divided into two categories of cost index and effectiveness index. The former value is the lower the better, and the latter is the higher the better; Fuel consumption and cultivation time are cost indexes,the others are effectiveness indexes. As in Figure1, there are five axes representing the five indexes around the circle respectively, and each axis is divided into three parts. Where the index is marked in the axis is determined by its grade, which will be discussed in detail in the next section. The angle between the adjacent axis is $\alpha(\alpha = 360° \times i$, where denotes the index weight).

Table 4: Weight of each index

Number	1	2	3	4	5
Index(i)	Fuel consumption	Cultivation efficiency	Tillage depth	Tillage width	Soil crushing rate
Weights	c_1	c_2	c_3	c_4	c_5

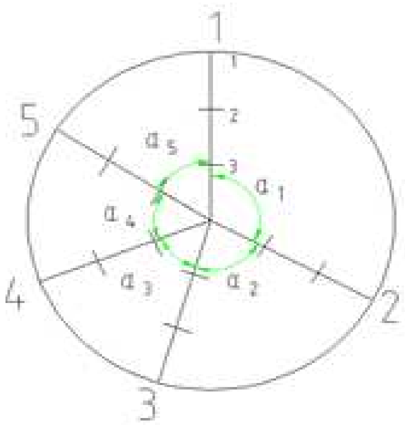

Fig. 1: Radar chart for performance evaluation of tea garden cultivation machinery.

Table 5: The comprehensive performance evaluation parameters

Target layer	Evaluation parameters	Mark
Comprehensive performance evaluation parameters system	Fuel consumption(L/acre)	c_1
	Cultivation efficiency(s/acre)	c_2
	Tillage depth(cm)	c_3
	Tillage width(cm)	c_4
	Soil crushing rate(%)	c_5

Then, the radar chart can be determined and utilized for further performance analysis. In addition, this paper utilizes this method to determine the radar chart model of all tillers and evaluate the tea farm tillers' performance.

5 Performance analysis for tea garden tiller

(1)Determination of index weight [11]
The comprehensive performance evaluation parameters system is established as shown in Table.5.

According to Table 4, 5 and test results, the performance evaluation information system for tea garden tiller is established as in Table.6

In order to evaluate the comprehensive operational performance of tea garden tillers, each index should be divided into three grades, of which 1 denotes "excellent", 2 denotes "good" and 3 denotes "poor." Relevant historical data for literature and indicators premised on the design requirements of tiller are consulted. Besides, expert opinions are also adopted to determine criteria for the classification which can be shown in Table.7.

Table 6: Comprehensive performance evaluation information system

U \ C	c_1	c_2	c_3	c_4	c_5
u_1	0.25	1075.01	12.33	64.78	62.77
u_2	0.25	1086.87	14.11	72.89	82.19
u_3	0.16	1264.05	14.11	43.22	57.44
u_4	0.16	1220.19	16.11	64.78	82.98
u_5	0.35	1269.91	10.44	69.67	61
u_6	0.35	1201.94	11.89	73.89	68.17
u_7	0.31	860.22	9.11	26.44	89.07
u_8	0.31	982.38	9.89	31.56	82.12

Table 8: Comprehensive performance evaluation information system for tiller

U \ C	c_1	c_2	c_3	c_4	c_5
u_1	2	2	2	1	2
u_2	2	2	1	1	1
u_3	1	3	1	2	3
u_4	1	2	1	1	1
u_5	3	3	2	1	2
u_6	3	2	2	1	2
u_7	3	1	3	3	1
u_8	3	1	3	3	1

Comparing Table.6 and Table.7, information system for tiller can be transferred as Table.8.

Index weight is calculated as follows: $X_1 = \{c_2, c_3, c_4, c_5\}$ Within, X1 denotes the importance of attribute c_1;Meanwhile,$card(u_1) = \cdots = card(u_8) = 1$. $U/IND(X_1) = \{\{u_1,u_6\},\{u_2,u_4\},\{u_7,u_8\},\{u_3,u_5\}\}$, so,$|X_1| = 2^2 + 2^2 + 2^2 + 2^2 = 16, AndU/IND(X) = \{\{u_1\},\{u_2\},\{u_3\},\{u_4\},\{u_5\},\{u_6\},\{u_7\},\{u_8\}\}; so, |X_1 \cup \{c_1\}| = 1^2 + 1^2 + 1^2 + 1^2 + 1^2 + 1^2 + 1^2 + 1^2 = 8; so, Sig_{X_1}(c_1) = 1 - \frac{|X_1 \cup \{c_1\}|}{|X_1|} = 1 - \frac{8}{16} = 0.5; Likely, Sig_{X_2}(c_2) = 1/3, Sig_{X_3}(c_3) = 0.2, Sig_{X_4}(c_4) = 0.2, Sig_{X_5}(c_5) = 0.2$ Subjective weights can be determined by experts as: $Q_1 = 0.3, Q_2 = 0.2, Q_3 = 0.15, Q_4 = 0.15, Q_5 = 0.2$ Meanwhile, objective weights are also calculated as follows: $P_{c1} = \frac{0.5}{0.5+1/3+0.2+0.2+0.2} = \frac{15}{43}, P_{c2} = \frac{1/3}{0.5+1/3+0.2+0.2+0.2} = \frac{10}{43}, P_{c3} = P_{c4} = P_{c5} = \frac{0.2}{0.5+1/3+0.2+0.2+0.2} = \frac{6}{43}$ According formula (2), due to that objective weight is of more importance than subjective one, set experience factor $\alpha = 0.4$, and then synthetic weights of each attribute index can be solved as follows: $I(c_1) = 0.4 \times 0.3 + 0.6 \times \frac{15}{43} \approx 0.329, I(c_1) =$

Table 7: Index evaluation standard

Rank	Fuel consumption (L/acre)	Cultivation time(s/acre)	Cultivation depth(cm)	Cultivation width (cm)	Soil crushing rate(%)
1	[0,0.2]	[0,1000]	>14	(50,80]	>80
2	(0.2,0.3]	(1000,1250]	(10,14]	(35,50]	(60,80]
3	>0.3	>1250	[0,10]	[0,35]	[0,60]

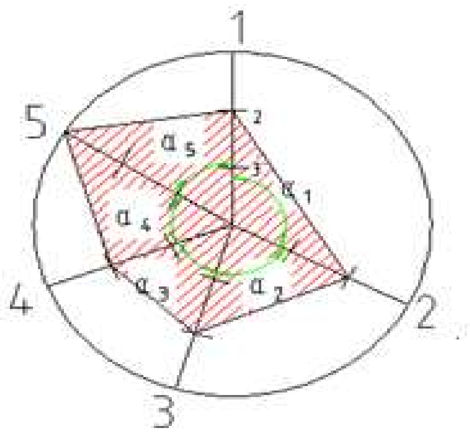

Fig. 2: Performance evaluation radar chart for Little White Dragon A.

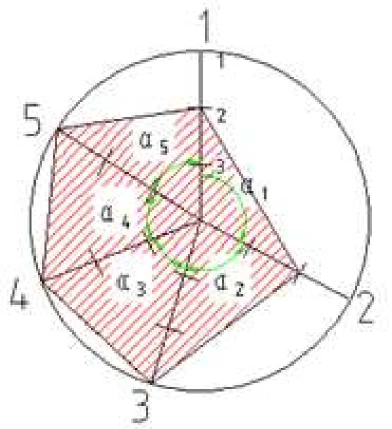

Fig. 3: Performance evaluation radar chart for Little White Dragon model two.

$0.4\times0.2+0.6\times\frac{10}{43}\approx0.219, I(c_3)=I(c_4)=0.4\times0.15+0.6\times\frac{6}{43}\approx0.144, I(c_5)=0.4\times0.2+0.6\times\frac{6}{43}\approx0.164$.
(2)Radar chart modeling According to the above calculation results, the angle between the adjacent axis determined as well as the position where each index is marked in the axis. Therefore, α can be calculated based on the formula of $\alpha=360^\circ\times i$ as follows:

$$\alpha_1=0.329\times360^\circ=118^\circ, \alpha_2=0.219\times360^\circ=79^\circ$$

Likely,$\alpha_3=\alpha_4=52^\circ, \alpha_5=59^\circ$ Therefore, the radar chart for the eight evaluation objects can be obtained as follows.

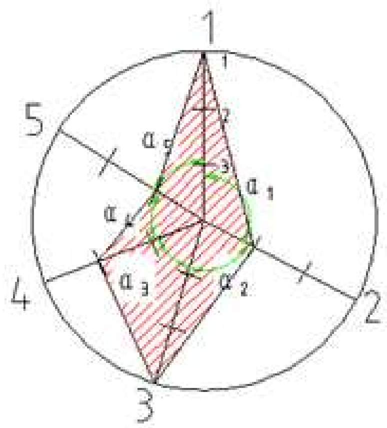

Fig. 4: Performance evaluation radar chart for KAMA A.

6 Conclusions

1) According to the principle, that larger the area marked in red covers, better performance for deep ploughing the machinery has, it can be concluded that, operational performance of KAMA B is the best and then Little White Dragon B stand the second place. The two models for TKK have the same deep plow effect which is worser than others; Two kinds of models for Little White Dragon and Honda have similar cultivating effect and performance. 2) Performance of KAMA B is evaluated as the best. However, its cultivation efficiency is lower than others. Therefore, improvements of machinerys weight and power may contribute to increasing efficiency. 3) Fuel consumption and cultivation depth of KAMA A are good, so its performance improvement should be considered from the comprehensive view of cultivation width, cultivation efficiency and soil crushing rate to enhance the operational performance. 4) Performance of Little White Dragon A and B are good. Subsequent improvements can be obtained by decreasing fuel consumptions and enhancing operation efficiency. 5) The overall performance of Honda A and B are stable. 6) Both A and

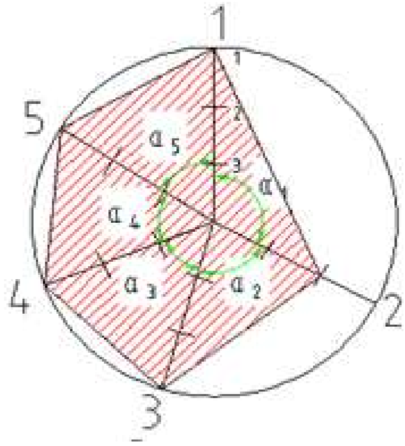

Fig. 5: Performance evaluation radar chart for KAMA model two.

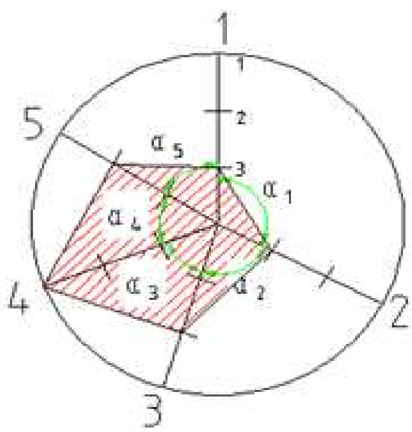

Fig. 6: Performance evaluation radar chart for Honda A.

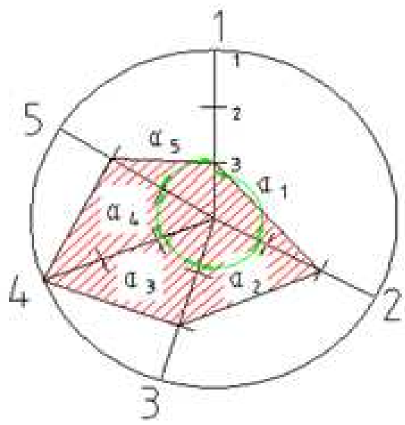

Fig. 7: Performance evaluation radar chart for Honda model two.

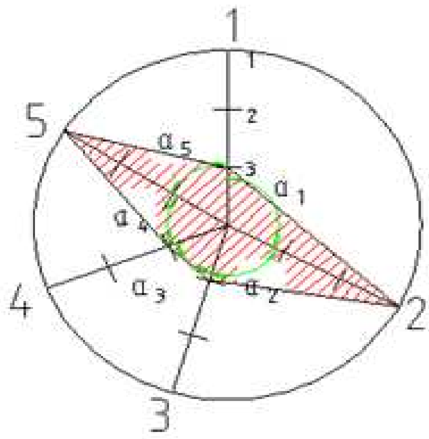

Fig. 8: Performance evaluation radar chart for TKK A.

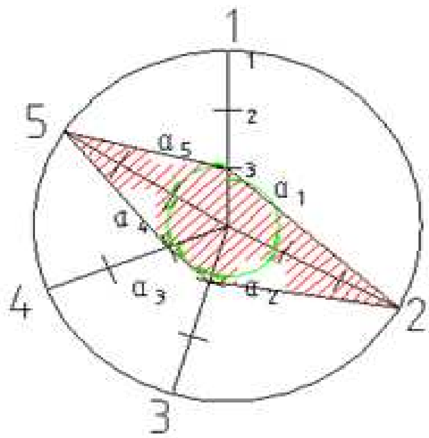

Fig. 9: Performance evaluation radar chart for TKK model two.

B of TKK operate with the same performance. The main problems of operations lie in high fuel consumption and poor cultivation effects. Subsequent improvements can be obtained by bettering their power transmission structure to enhance cultivation performance and diesel utilization.

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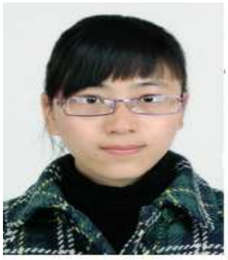

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