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RESEARCH ARTICLE

Comprehensive evaluation of multiple cropping systems on upland red soil

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Abstract According to the principles and methods of ecology and system engineering, we set up an evaluation indicator system for multi-component and multiple cropping systems, evaluated the comprehensive benefits of multi-component and multiple cropping systems using grey relation clustering analysis and screened out the optimized model based on research done in the upland red soil in Jiangxi Agricultural University from 1984 to 2004. The results show that the grey relation degree of ''cabbage/potato/maize − sesame'' was the highest among 23 multi-component and multiple cropping systems and was clustered into the optimized system. This indicates that ''cabbage/potato/maize − sesame'' can bring the best social, economic and ecological benefits, increase product yield and farmers' income and promote sustainable development of agricultural production. Therefore, it is suitable for promotion on upland red soil. The grey relation degree of ''canola/Chinese milk vetch/maize/mung bean/maize'' was second, which is suitable for implementation at the city outskirts. In conclusion, these two planting patterns are expected to play important roles in the reconstruction of the planting structure and optimization of the planting patterns on upland red soil.

Keywords upland red soil, multiple cropping systems, grey relation analysis, clustering analysis, comprehensive evaluation

1 Introduction

Upland red soil is an important soil resource in the south of China. Extensive exploration and rational use of the resource is not only strategically important for the sustainable development of agriculture, but also is a major direction for agriculture development in south of China (Xie et al., 1998; Zhao, 2002; Huang, 2002). For a long time, the upland red soil has a low productivity and low economic benefit because of many unfavorable factors and irrational exploration and cultivation of the land. These are disadvantageous to the increase of agricultural production and earnings of farmers.

Climatically, the upland red soil is located in tropical and subtropical temperate areas with sufficient resources of sunlight and water. Thus it is suitable for the cultivation of many kinds of crops. Constructing an effective multiple cropping system can enhance not only the use efficiency of sunlight and water, but can also improve the recycling efficiency of nutrients, thus increasing the ecological and economical benefit of upland red soil (He et al., 2004; Zhao, 2002; Huang, 2002). Until now, although many studies have been conducted to evaluate different cropping systems (Zhang et al., 2003; Song and Cai, 2004; Dai et al., 2004; Xue et al., 2001; Wu et al., 2002; Zhou et al., 2002; Liu and Zhong, 1990; Liu et al., 1996; Xu et al., 1995; Wang et al., 2000; Huang and Shen, 1993; Ye and Huang, 2000; Muza, 1996; Jat et al., 1998; Gollar and Patil, 19 97), their methods are not appropriate due to the lack of qualitative and quantitative analyses between years. In the present study, we introduced a grey relation analysis method, an effective quantitative analysis for different cropping systems. We evaluated comprehensively the benefits of 23 multiple cropping systems on upland red soil from 1984 to 2004. As a result, some optimum systems were suggested. This research not only provides references for practical production but is also helpful for sustainable agricultural development in upland red soil.

2 Study area and materials

The study area is located at the experimental station of the Jiangxi Agricultural University (28°46′04.476″N, 115°50′02.040″E). The annual average temperature was about 17.6°C from 1984 to 2004. The annual ⩾10°C accumulated temperature reached 5600°C, with a sustained

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time of 255 days. The annual mean solar radiation was 114.39 kcal/cm^2. The annual mean sunshine duration was 1820.4 hours. The frost-free period was 272 days and the annual mean precipitation reached 1624.4 mm. The temperature difference between all four seasons was obvious. The illumination was sufficient. Rainfall was abundant. All these were advantageous for the growth of crops. The principal makeup of the soil was Quaternary Period red soil in the study area with the hillock terrain and non-irrigation. The study material and data were derived from the research by Huang (1984), Ye (1998), Zhang (2001) and Su (2004), who investigated comprehensive benefits of multi cropping systems, respectively, in the experimental station of Jiangxi Agricultural University from 1984 to 2004.

3 Evaluation object and index system

The 23 multi-component and multiple cropping systems on the upland red soil in Jiangxi Agricultural University from 1984 to 2004 were taken as samples*: (1) soya − maize; (2) mixture green manure − sweet potato; (3) earth pea − mung bean; (4) horse bean − cotton; (5) early maize||mung bean; (6) Chinese milk vetch − maize − sesame; (7) Chinese milk vetch − maize/maize||mung bean; (8) horse bean − maize/sweet potato; (9) canola/soya||maize − sesame; (10) rye grass × Chinese milk/soya − maize; (11) canola||Chinese milk vetch/maize/maize||mung bean; (12) Chinese milk vetch × canola − maize − maize; (13) Chinese milk vetch/soya||maize/maize; (14) horse bean/maize/sweet potato; (15) canola-mung bean||sweet potato; (16) early maize|earthpea; (17) mixture green manure − maize − soya; (18) ryegrass/soya − late maize; (19) maizec||soya; (20) canola − soya + maize − sesame; (21) barley − earthpea − buckwheat; (22) cabbage/potato/maize − sesame; (23) horse bean − watermelon − maize. According to previous reports (Wu and He, 2004; Huang et al., 1995), 20 evaluable factors were included in the evaluation indicators system except the qualitative factors and significantly related factors (Table 1). Those 20 evaluable factors were classified as ecological benefit (I_1–I_{13}), economic benefit (I_{18}–I_{20}) and social benefit. The original data (totalling 2300) of assessment indicators for multiple cropping systems in 1984, 1998, 2001, and 2003 are listed in Table 2.

4 Calculation and results

4.1 Grey relation analysis

We established the optimal value of different indicators, i.e. the reference series $X_0(k)$ ($k = 1, 2,\ldots, n$), based on the actual production and the goal of high yield, great efficiency and high quality; the comparative series (a collection of measurements) $X_i(k)$ ($k = 1, 2,\ldots, n$; $i = 1, 2,\ldots, m$), where i represents different disposal. As general statistical methods, grey analysis first requires the appropriate normalization of raw data to remove anomalies associated with different measurement units and scales. The raw data can be transformed into dimensionless forms by Eq. (1). The processing type used depends upon the nature of data. Generally, the first model of Eq. (1) is applied to data series, in which the larger the value is the better it is. For data series in which the smaller the value is the better

Table 1 Indicators of comprehensive benefits evaluation of multicomponent-multiple cropping systems

the first-class indicator	the second-class indicator	the third-class indicator
Ecological benefits	output energy/GJ·hm^{-2} (I_1)	
	input energy/GJ·hm^{-2} (I_2)	
	energy output/energy input (I_3)	
	solar energy utilizing rate/% (I_4)	
	nutrient input	N/kg·hm^{-2} (I_5)
		P_2O_5/kg·hm^{-2} (I_6)
		K_2O/kg·hm^{-2} (I_7)
	nutrient output	N/kg·hm^{-2} (I_8)
		P_2O_5/kg·hm^{-2} (I_9)
		K_2O/kg·hm^{-2} (I_{10})
	nutrient input/Nutrient output	N (I_{11})
		P_2O_5 (I_{12})
		K_2O (I_{13})
Economic benefits	gross value/yuan·hm^{-2} (I_{14})	
	gross cost/yuan·hm^{-2} (I_{15})	
	net income/yuan·hm^{-2} (I_{16})	
	cost payoff rate/% (I_{17})	
social benefits	labor input number/d (I_{18})	
	gross value/labor input/Yuan·d^{-1} (I_{19})	
	technological progress rate/% (I_{20})	

*− : sequential cropping; ||, +: intercropping; /: relay intercropping; ×: mixed cropping

Table 2 Original data of assessment indicators for 23 multiple cropping systems and indicators of reference cropping system*

cropping systems	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}	I_{13}	I_{14}	I_{15}	I_{16}	I_{17}	I_{18}	I_{19}	I_{20}
X_0	236.34	9.38	3.39	1.45	196.90	93.00	103.20	384.90	268.50	312.00	1.13	0.46	1.12	74947.20	1535.05	48202.20	247.50	164.00	164.50	98.99
X_1	19.86	40.17	0.49	0.66	245.20	217.95	103.20	91.80	34.50	22.95	2.67	6.32	4.50	3323.70	1655.50	1668.20	100.77	280.00	55.60	20.60
X_2	19.32	44.60	0.43	0.91	215.20	164.25	229.50	19.35	6.45	32.25	11.12	25.47	7.12	3694.80	1535.05	2159.75	140.70	265.00	69.50	23.20
X_3	15.03	38.10	0.39	0.74	245.20	213.45	103.20	60.00	22.50	15.00	4.09	9.49	6.88	3526.50	1668.10	1858.40	111.41	260.50	62.10	24.40
X_4	32.99	48.08	0.69	0.98	334.90	294.45	112.35	112.35	42.15	28.05	2.98	6.99	4.01	5351.55	1951.30	3400.25	174.26	259.00	58.00	30.40
X_5	26.67	45.08	0.59	0.96	286.45	177.75	163.20	102.75	38.55	25.65	2.79	4.61	6.36	3077.40	1672.90	1404.50	83.96	283.50	41.20	26.20
X_6	34.62	43.87	0.79	0.99	245.20	247.95	255.00	104.85	35.40	50.55	2.34	7.00	5.04	5661.60	1804.75	3856.85	213.71	242.50	65.40	31.20
X_7	230.57	84.97	2.71	1.43	284.40	138.00	254.50	242.30	86.50	178.80	1.17	1.60	1.42	16544.37	6246.00	10298.37	164.88	225.00	73.53	64.20
X_8	236.34	69.67	3.39	1.39	300.40	174.50	300.00	265.80	123.20	246.80	1.13	1.42	1.22	18558.51	6347.90	12210.61	192.36	270.00	68.74	93.20
X_9	154.13	81.38	1.89	0.90	298.20	212.20	298.30	234.20	168.30	263.00	1.27	1.26	1.13	16485.15	5296.00	11189.15	211.28	180.00	91.58	74.30
X_{10}	123.41	130.38	0.95	1.05	310.40	218.30	318.91	221.30	143.20	256.20	1.40	1.52	1.24	11683.70	4998.00	6685.70	133.77	180.00	64.91	45.60
X_{11}	117.39	71.34	1.65	0.75	265.80	187.00	275.00	185.60	89.40	188.00	1.43	2.09	1.46	17135.80	5055.00	12080.80	238.99	164.00	103.85	85.60
X_{12}	125.67	87.65	1.43	0.81	196.90	176.40	245.00	145.30	98.40	190.30	1.36	1.79	1.29	14789.40	4864.40	9925.00	204.03	195.00	75.84	63.40
X_{13}	21.57	53.52	0.40	0.53	259.00	187.00	278.50	189.80	99.80	194.50	1.36	1.87	1.43	8536.80	2475.80	6061.00	244.81	320.00	81.30	44.30
X_{14}	21.11	51.76	0.41	0.46	248.40	189.00	289.00	190.30	100.10	214.30	1.31	1.89	1.35	8888.70	2591.60	6297.10	242.98	312.00	79.00	44.60
X_{15}	20.33	51.30	0.40	0.51	268.00	200.00	256.70	178.40	132.40	210.20	1.50	1.51	1.22	8528.60	2454.30	6074.30	247.50	318.00	81.20	44.50
X_{16}	41.12	103.75	0.40	0.87	276.00	168.00	247.60	212.90	89.40	162.80	1.30	1.88	1.52	17689.50	5946.50	11743.00	197.48	187.50	62.60	97.55
X_{17}	39.59	102.38	0.39	0.83	396.80	168.00	288.80	268.70	120.10	174.70	1.48	1.40	1.65	13973.60	6046.70	7926.90	131.09	180.00	44.00	63.05
X_{18}	36.81	97.82	0.38	0.77	388.70	240.00	330.00	300.40	117.20	166.40	1.29	2.05	1.98	13458.40	5855.70	7602.70	129.83	165.00	46.10	56.86
X_{19}	36.34	97.26	0.37	0.77	483.00	160.00	275.00	384.90	109.70	153.20	1.25	1.46	1.80	16465.20	7133.60	9331.60	130.81	217.50	42.90	30.30
X_{20}	14.57	11.92	1.22	1.34	444.00	126.00	384.00	346.50	268.50	312.00	1.28	0.47	1.23	15240.30	11289.00	3951.30	35.00	243.50	164.50	84.30
X_{21}	10.33	9.38	1.10	0.86	363.00	93.00	295.50	279.00	180.00	264.00	1.30	0.52	1.12	17625.20	9424.50	8200.70	87.01	265.00	128.20	84.60
X_{22}	27.19	24.11	1.13	1.45	424.50	120.00	360.50	324.50	254.50	294.00	1.31	0.47	1.23	74947.20	26745.00	48202.20	180.23	268.00	130.00	98.99
X_{23}	16.57	14.99	1.11	1.37	372.00	103.50	319.50	309.00	225.00	276.00	1.20	0.46	1.16	25612.90	12486.00	13126.90	105.13	254.00	99.50	94.34

*Reference cropping system is represented as X_0.

it is, it can be addressed by the second model of Eq. (1).

$$\begin{cases} X_i'(k) = \frac{X_i(k) - \min(X_1(k), \cdots X_{23}(k))}{\max(X_1(k) \cdots X_{23}(k)) - \min(X_1(k), \cdots X_{23}(k))}, \\ X_i'(k) = \frac{\max(X_1(k), \cdots X_{23}(k) - X_i(k)}{\max(X_1(k), \cdots X_{23}(k)) - \min(X_1(k), \cdots X_{23}(k))}, \end{cases} \quad (1)$$

The grey relational coefficient can be intuitively considered as the point-to-point relation at certain time point effort driver between X_0 and X_i, and at any data point p, the relation coefficient L_i (p) between $\{X_0(p)\}$ and $\{X_i(p)\}$ is defined as:

$$L_i(p) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_i(p) + \rho\Delta_{\max}} \quad (2)$$

Where $\Delta_i(p)$ represents the absolute balance between two series at p point, that is, $\Delta_i(p) = |x_0(p) - x_i(p)| (1 \leqslant i \leqslant m)$. Besides, $\Delta_{\max}$ and $\Delta_{\min}$ in Eq. (2) denote the distance for each time in all compared sequences. We named ρ as the distinguish coefficient. It was used to adjust the difference of relational coefficients, where ρ[0,1], the smaller the value of ρ is, the larger the distinguished ability is. Generally $\rho = 0.5$; and L(0,1].

The weighted grey relation grade (GRG) is computed by summing up the grey relational coefficients corresponding to each effort driver and their respective weights. The selection of the weighting factor for a grey relational coefficient reflects the importance of that datum. The weights (W_k) in the weighted GRG indicate the significance of effort drivers in different planting modes and the more reasonable weights could evaluate more properly. The weighted GRG is shown in Eq (3).

$$r_i = \sum_{k=1}^{n} w_k L_i(k) \quad (3)$$

Where i\{1, 2,…,n\}, $\sum_{k=1}^{n} Wk = 1$.

The weights of economic benefits, social benefits and ecological benefits adopted were 0.2, 0.5, and 0.3, respectively, and the ecological benefits included energy benefits and fertilizer benefits. Both weights adopted was 0.15. On the basis of the weighted GRGs between the project to be estimated and the reference projects, we ranked all the projects according to their weighted GRGs. This procedure is called the grey relational rank which directly reflects what degree of influence the reference project can exert on the project to be estimated. We evaluated the weighted GRGs between the project to be estimated and each of the reference projects.

According to the above methods, we calculated the grey relation degrees of comprehensive benefits of 23 multiple cropping systems.

As shown in Table 3, the order of grey relation degrees above 0.6 in the comprehensive benefits of cropping systems was X_{22} ("cabbage/potato/maize − sesame") > X_{11} ("canola||Chinese milk vetch/maize || mung bean") > X_8 ("horsebean − maize/sweet potato"); and the order of grey relation degrees between 0.5 and 0.6 in comprehensive benefits was X_9 ("canola/soya || maize − sesame") > X_{16} ("horsebean/maize/sweet potato") > X_7 ("Chinese milk vetch − maize/maize + mung bean") > X_{12} ("Chinese milk

Table 3 Grey relation degrees of comprehensive benefits of 23 multiple cropping systems and their taxis

cropping systems	ecological benefits (I_1–I_{13})		economic benefits (I_{14}–I_{17})	social benefits (I_{18}–I_{20})	total weight benefits	taxis
	energy benefits	fertilizer benefits				
X_1	0.5198	0.3681	0.5198	0.3656	0.4748	22
X_2	0.5427	0.3927	0.5427	0.3901	0.4752	21
X_3	0.5246	0.3698	0.5246	0.3891	0.4755	20
X_4	0.5609	0.4131	0.5609	0.3937	0.5010	18
X_5	0.5124	0.4047	0.5124	0.3594	0.4692	23
X_6	0.6062	0.4131	0.6062	0.4161	0.5255	14
X_7	0.5133	0.7929	0.5133	0.4983	0.5772	6
X_8	0.5413	0.8482	0.5413	0.5623	0.6140	3
X_9	0.5710	0.5267	0.5710	0.6338	0.5952	4
X_{10}	0.4975	0.6085	0.4975	0.5452	0.5490	11
X_{11}	0.6210	0.4677	0.6210	0.7498	0.6275	2
X_{12}	0.5635	0.4903	0.5635	0.5500	0.5698	7
X_{13}	0.6535	0.3673	0.6535	0.3921	0.5586	9
X_{14}	0.6481	0.3621	0.6481	0.3943	0.5572	10
X_{15}	0.6601	0.3641	0.6601	0.3933	0.5634	8
X_{16}	0.5493	0.4635	0.5493	0.7033	0.5831	5
X_{17}	0.4880	0.4559	0.4880	0.5633	0.5206	16
X_{18}	0.4884	0.4410	0.4884	0.6039	0.5228	15
X_{19}	0.4814	0.4399	0.4814	0.4310	0.4935	19
X_{20}	0.4047	0.4759	0.4047	0.7409	0.5421	12
X_{21}	0.4419	0.3798	0.4419	0.5989	0.5116	17
X_{22}	0.7364	0.5284	0.7364	0.6899	0.7022	1
X_{23}	0.4460	0.4854	0.4460	0.6150	0.5352	13

vetch × canola − maize − maize") > X_{15} ("rape − mung bean||sweet potato") > X_{13} ("Chinese milk vetch/rape − / soybean + maize/maize") > X_{14} ("horse bean/maize/sweet potato") > X_{10} ("ryegrass × Chinese milk vetch/soybean − maize") > X_{20} ("rape − soybean + maize − sesame") > X_{23} ("horse bean − watermelon − maize") > X_6 ("Chinese milk vetch − maize − sesame") > X_{18} ("ryegrass/soy bean − late maize") > X_{17} ("green manure − maize − soy bean") > X_{21} ("barley − peanut − buckwheat") > X_4 ("horse bean − cotton"). Besides, the grey relation degrees of comprehensive benefits in other cropping systems were less than 0.5.

4.2 Cluster analysis

All the weighted grey relation degrees (r_i, $i = 1,2,3,\ldots 23$) consist of set R. Supposed d_{ij} is the member of set E, named as the set of relation degree diversity, the element of E representing the distance between r_i, r_j, and d_{ij} is expressed as Eq.(4).

$$d_{ij} = |r_i - r_j| \tag{4}$$

On the basis of E, a distance matrix D is calculated in a symmetrical set with zero main diagonal. Then, using the matrix D, we obtain a matrix Rg, named as similar relation set and its members are calculated from Eq.(5).

$$g_{ij} = 1 - \frac{d_{ij}}{\max(D)} \tag{5}$$

Where max (D) represents the maximum element of the matrix D.

According to the above Eqs., we calculated the similar relation matrix Rg about different benefits in different cropping systems and Rg included 23 × 23 elements. The detailed steps were to: assume different cropping systems as X_i ($i = 1,2,3\ldots 23$), find the maximum element from the 22nd rank and 22nd file corresponding to the cropping system X_{22} with the maximum relation degree (0.8195) in the matrix Rg. The cropping system (X_{19}) corresponding to the maximum element has the second best comprehensive benefits index and then the cropping system (X_8) corresponding to the maximum element from the second cropping system has the third comprehensive benefits index. The rest is deduced this way until the cropping system X_6.

The samples were classified by randomly adopting the value of λ ranging between 0 and 1. When $\lambda = 0.93$, the 23 kinds of cropping systems were divided into five ranks, as shown in Table 4.

Combining the results of grey relational clustering analysis and data in Table 2, we drew a conclusion that X_{22}, viz. "cabbage/potato/maize − sesame" was the optimal pattern in triple cropping system. X_{11}, X_8, and X_9 were good and X_{16}, X_7, X_{12}, X_{15}, X_{13}, X_{14}, X_{10}, X_{20}, X_{23}, X_6, X_{18}, X_{17}, X_{21}, and X_4 were moderate. While in the double cropping system, the comprehensive benefits of X_{19}, and X_3 were poor. The clustering results which could objectively reflect the advantage of different cropping systems show that comprehensive benefits of the triple cropping system was significantly better than that of the double cropping system. This is consistent with previous experimental results (Muza, 1996).

Table 4 The ranks of 23 multiple cropping systems

range	Items
excellent	X_{22}
good	X_{11}, X_8, X_9
moderate	X_{16}, X_7, X_{12}, X_{15}, X_{13}, X_{14}, X_{10}, X_{20}, X_{23}, X_6, X_{18}, X_{17}, X_{21}, X_4
poor	X_{19}, X_3
bad	X_2, X_1, X_5

5 Comprehensive evaluation of multiple cropping systems

Comprehensive benefits of multiple cropping systems mainly depend on the unification of ecological, economic and social benefits. In the 23 multiple cropping systems, X_{22}, that is "cabbage/potato/corn − sesame", had (1) significant economic benefits because of reasonable distribution of late convergence and groups space, high use efficiency for solar energy, stable production system, and high crop yield; (2) great social benefits because of the rational arrangement of grain, economic crops and vegetables, which meet different needs; (3)big ecological benefits because of relatively small inorganic fertilizer's inputs, high use efficiency of organic fertilizer which improves the nutrient recycle and the rational ratio of N, P, and K. Thus X_{22} was evaluated as the optimal planting system which is suitable for promotion in the large dry area of red soil.

Besides, in multiple cropping systems, the ecological and economic benefits of X_{11} ("rape || milk vetch/corn/ corn || mung bean"), X_8 ("broad bean − maize/sweet potato") and X_9 ("rape/soybean + maize − sesame") were relatively high. The social benefits, however, was not obvious because of the great manpower investment. Therefore, X_{11} was evaluated as "good", which is suitable for implementation on upland red soil in the outskirts of city.

According to the evaluation of four "superior" or "good" planting patterns, we conclude that the two planting patterns, X_{22} (cabbage/potato/maize − sesame) and X_{11} (rape || Chinese milk vetch/maize/maize || mung bean), have their unique characteristics. They are novel planting patterns. Their ecological benefits, economic benefits and social benefits all exceed that of the present planting patterns. This result is important in readjustment of planting structure and optimization of planting patterns on upland red soil in the future.

The planting patterns of X_{16}, X_7, X_{12}, and X_{15} mostly belong to the triple cropping systems. Their ecological, economic and social benefits were relatively balanced, ranking in the middle or secondary level in 23 planting systems. Thus, their comprehensive benefits were classified as "moderate".

The planting patterns of X_{19}, X_3, X_2, X_1 and X_5 were the main cropping patterns in dry red soil. Because of the unreasonable convergence of crops, the land utilization rate and the multiple cropping index were low and the light energy use was less than three cropping system. In addition, because farmers did not take into account the combination of use and protection, the soil degradation was severe and ecological and social benefits were very poor. Therefore, their comprehensive benefits were rated as "bad" and "poor". Generally speaking, they are not suitable for cultivation and promotion in the dry red large area.

6 Conclusions

The results of localization opposite experiment for 23 multiple cropping systems indicate that the red soil develops gradually from the two cropping pattern to three cropping pattern and the use efficiency of light energy and the land multiple cropping index have been enhanced. Thus, the target of increasing the product yield, farmer's income and production efficiency can be achieved. The increased grain planting pattern belongs to three cropping systems, where "the broad bean − spring corn" are the main planting crops and economic crops such as vegetables and sesame seed are planted in winter and autumn. This is a new planting mode which increases the crop yield and economic benefits.

In short, the cropping system in the study area has gone from the two cropping system in the 1980s, to three cropping system in the 1990s where spring corn is the main crop, to the multiple cropping system with grains, economic crops, feeds and vegetables in the early 21st century. According to 20 indicators, we carried out the gray relation analysis of 23 multiple cropping systems. Deferring to the grey relation degree of the optimized model, we similarly conducted a clustering analysis. The results show that the grey relation degree of "cabbage/potato/maize − sesame" was highest among 23 multicomponent and multiple cropping systems. It can bring the best social, economic and ecological benefits and it was also the optimal mode capable of increasing product yield, farmer's income and production efficiency. The grey relation degree of "canola||Chinese milk vetch/maize || mung bean" follows which is suitable for promotion on upland red soil at the outskirts of the city. The results are valuable in the reconstruction of the planting structure and optimization of the planting patterns on upland red soil in southern China.

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