ISSN 1 746-7233, England, UK
World Journal of Modelling and Simulation
Vol. 5 (2009) No. 2, pp. 144-150

System dynamic simulation of three crops per year in paddy field*

Jing Cui[1], Gang Huang[2†], Yonglu Tang[2]

[1] Uncertainty Decision-Making Laboratory, Sichuan University, Chengdu 610064, China
[2] Sichuan Academy of Agricultural Sciences, Chengdu 610066, China

(*Received January 12 2009, Accepted April 12 2009*)

Abstract. Understanding the effects of three crops per year in paddy field. In this research we use system dynamic based on orthogonal experiment to the value of three crops per year system in paddy field. Through this model and simulation, we get a series of results. At the same time, we use a long-term experiment to verify these programmes. We investigated the impacts of yield, economic benefit, resource utilization and soil fertility. Our results indicate that the development of three crops per year in paddy field may improve long-terms stainability of paddy field ecosystems.

Keywords: system dynamic model, paddy field, orthogonal experiment

1 Introduction

Circular economy is a new economy development mode based on the foundation of incessantly and circularly utilized substances[9]. It requires to that the economy activity be organized as a closed flow with "resource utilization – green industry – resource regeneration"; all of the raw materials and energy resources rationally utilize at incessantly circular system, and the effect of economy activity to nature environment is controlled at the least extent. The main characteristics of cycle economy are low exploitation, high usage and low pollution. All the materials and energy can be utilized reasonably and durably in the cycle economy to reduce the influence to the smallest possible amount. In this paper, we will conduct the research of county cycle economy by the way of system dynamics.

System Dynamics is a simulation technology of studying complex great system based on the foundation of feedback control theory and the measurement of computer imitate technology[4]. System Dynamics combines systems analysis and systems synthesis to study systemic complex questions[1].

Our country has larger population and smaller land. Multi-cropping in paddy field is an important way to increase production[10]. Chengdu plain has adequate labor, it is the main production base of agricultural commodities in Sichuan province. This study from the beginning of cycle economy theory, put forward some new three crops a year system, "wheat – rice – vegetable" pattern, "rape/potato – rice" pattern,, etc. These are only partially operational in current patterns and "are the most important challenge for land use and environmental modelers"[8].

2 Modelling

* This research was supported by the National Science Foundation for Distinguished Young Scholars (Grant No. 70425005) and Integration Research and Demonstration of Key Technology of Cycle Efficient Production Mode in Farmland (Grant No. 2007BAD89B00), P. R. China.
† Corresponding author. Tel.:+86-28-84504080; fax:+86-28-84504198.
E-mail address: huanggangsaas@163.com.

The climate of Chengdu plain are very special. Generally, there are still $60 \sim 80$ days were are not fully utilized between harvesting rice and sowing wheat. In order to development three-harvest cropping system better, advance rice harvesting time or delay wheat sowing date or prolong the time of the growth in autumn from $65 \sim 80$ days to $85 \sim 120$ days[7], realize year – round cycle model of three-harvest cropping system.

According to the the natural climatic conditions and soil characteristics of Chengdu Plain, we can develop three-cropping system appropriately, so that improving farmers' income[3]. According to the actual situation of rice cultivation, following the three cropping systems, higher income, better benefits, "wheat – rice – vegetables" pattern and the "oil/potato – rice" pattern for the specific analysis.

2.1 Cropping systems design

According to the Chengdu Plain of the natural climatic conditions and soil characteristics, you can develop an appropriate three-cropping system, and improving farmers income. According to the actual situation of paddy planting, we will analysis "wheat – rice – vegetable" pattern and "rape/potato – rice" pattern concretely.

"wheat – rice – vegetable" pattern is a multiple cropping models. In Sichuan Basin, Wheat usually sow from late October to early November,harvest from late April to early May. Wheat growth need longer time and efficiency, and there are still about 50 days are not fully utilized between harvesting rice and sowing wheat. In order to increase the effectiveness of the paddy, Before sowing wheat we can plant vegetables[2].

"rape/potato – rice" pattern is another multiple cropping models. In Chengdu Plain, potatoes are generally planted in spring and autumn. Potatoes plant usually in late autumn, potatoes and rapes intercropping format "Rape/potato – rice" pattern.

2.2 The model

Basing on three-harvest cropping system, we choose Several important factors to design orthogonal test. then, we make system dynamics simulation.

(1) Orthogonal experiment

According to the experience of farmers, we analysis "wheat – rice – vegetable" pattern and "rape/potato – rice" pattern to optimize tillage methods, straw returning, and total nitrogen by three factors and three levels orthogonal experiment (Table 1).

Table 1. orthogonal experiment of three crops per year in paddy field

	total Nitrogen(A)	straw returning(B)	tillage methods(C)
level 1	low Nitrogen	straw returning one – season	zero – tillage one – season
level 2	medium Nitrogen	straw returning two – seasons	zero – tillage two – seasons
level 3	high Nitrogen	no straw returning	tillage

According to table 1, we can design orthogonal experiment (Table 2).

(2) Simulation of system dynamic model

Vensim software is used in this article to analysis "wheat – rice – vegetable" pattern and "rape/potato – rice" pattern, then simulate these programs. "wheat – rice – vegetable" pattern is mainly affected by tillage methods, straw returning, and total nitrogen (Fig. 1) "rape/potato – rice" model is mainly affected by tillage methods, straw returning, and total nitrogen (Fig. 2).

(3)Yield analysis

In the "wheat – rice – vegetable" pattern, among the nine programs, the output of program 5 is the largest (Table 3). In the "wheat – rice – vegetable" pattern, according to table 1, we can design orthogonal experiment (Table 4).

In the "wheat – rice – vegetable" pattern, tillage methods, straw returning, and total nitrogen are positive indicators, these indicators are the larger the better. So, we select the largest factors from I_j, II_j and III_j. Among I_1, II_1 and III_1, III_1 is the largest, that is A_1. Among $\mathrm{I}_2\mathrm{II}_2$ and III_2, II_2 is the largest, that is B_2.

Table 2. orthogonal experiment schedule of three crops per year in paddy field

	total Nitrogen(A)	straw returning(B)	tillage methods(C)
experiment 1	low Nitrogen	straw returning one – season	zero – tillage one – season
experiment 2	low Nitrogen	straw returning two – seasons	zero – tillage two – seasons
experiment 3	low Nitrogen	no straw returning	tillage
experiment 4	medium Nitrogen	straw returning one – season	zero – tillage two – seasons
experiment 5	medium Nitrogen	straw returning two – seasons	tillage
experiment 6	medium Nitrogen	no straw returning	zero – tillage one – season
experiment 7	high Nitrogen	straw returning one – season	tillage
experiment 8	high Nitrogen	straw returning two – seasons	zero – tillage one – season
experiment 9	high Nitrogen	no straw returning	zero – tillage two – seasons

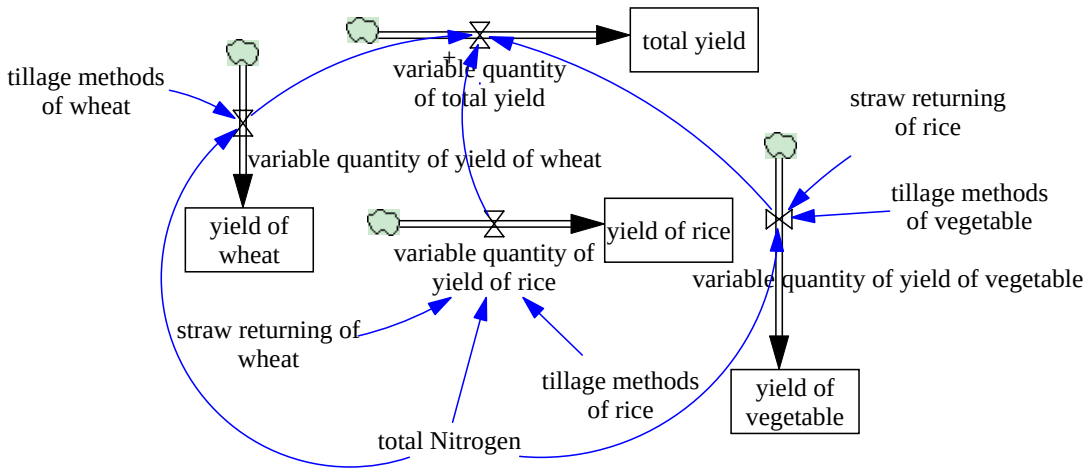

Fig. 1. SD model of "wheat – rice – vegetable"

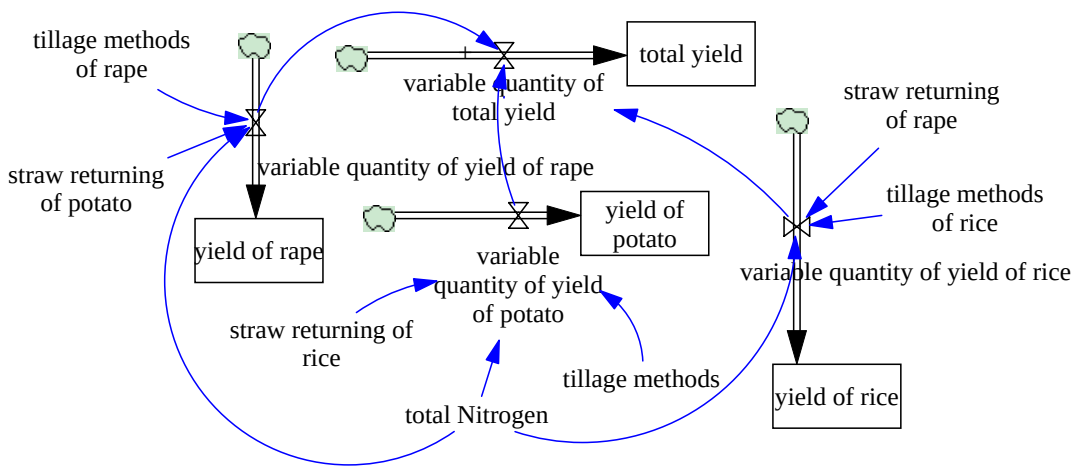

Fig. 2. SD model of "rape/potato – rice"

Among I_3II_3 and III_3, II_3 is the largest, that is C_2. So, the best collocation is $A_1B_2C_2$, that is low Nitrogen, straw returning one – season and zero – tillage one – season.

Because$A_1B_2C_2$ do not appear among the nine programs arranged by orthogonal test, program 5 is closer to the test, that is high Nitrogen, straw returning one – season and zero – tillage one – season. Whether program 5 is the best Program, still need further field to verify. In the"rape/potato – rice" pattern, among the nine programs, the output of program 5 is the largest (Table 3).

In the "rape/potato – rice" pattern, according to table 1, we can design orthogonal experiment (Table 6).

Table 3. "wheat – rice – vegetable" pattern orthogonal experiment yield table (kg/hm)

	wheat yield	rice yield	vegetable yield	total yield
experiment1	6000	7500	15000	28500
experiment2	6600	8100	18000	32700
experiment3	6750	8550	21000	36300
experiment4	6600	7950	18000	32550
experiment5	6900	8475	22500	37875
experiment6	6150	7500	15000	28650
experiment7	6600	8100	19500	34200
experiment8	6300	8400	16500	31200
experiment9	6000	7500	13500	27000

Table 4. "wheat – rice – vegetable" model orthogonal experiment

	total Nitrogen	straw returning	tillage methods	total yield
experiment 1	1	1	1	28500
experiment 2	2	2	1	32700
experiment 3	3	3	1	36300
experiment 4	2	1	2	32550
experiment 5	3	2	2	37875
experiment 6	1	3	2	28650
experiment 7	3	1	3	34200
experiment 8	1	2	3	31200
experiment 9	2	3	3	27000
I_j	29450	31750	32500	
II_j	30750	33925	33025	
III_j	36125	30650	30800	
R_j	6675	3275	2225	

Table 5. "rape/potato – rice" model orthogonal experiment yield table (kg/hm)

	rice yield	rape yield	potato yield	total yield
experiment 1	1980	7650	12840	22470
experiment 2	2115	7500	12000	21615
experiment 3	2100	7575	13500	23175
experiment 4	2340	8250	14250	24840
experiment 5	2430	8550	15000	29580
experiment 6	25204	8325	15750	26595
experiment 7	2610	8550	18000	29160
experiment 8	2775	8700	17250	28725
experiment 9	2460	8400	16950	27810

In the "rape/potato – rice" pattern, tillage methods, straw returning, and total nitrogen are positive indicators, these indicators are the larger the better. So, we select the largest factors from I_j, II_j and III_j. Among I_1, II_1 and III_1, III_1 is the largest, that is A_3. Among I_2II_2 and III_2, II_2 is the largest, that is B_2. Among I_3II_3 and III_3, III_3 is the largest, that is C_3. So, the best collocation is $A_3B_2C_3$, that is high nitrogen, straw returning one – season and zero – tillage two – seasons.

Because$A_3B_2C_3$ do no appear among the nine programs arranged by orthogonal test, program 5 is closer to the test, that is high nitrogen, straw returning one – season and zero – tillage one – season. Whether program 5 is the best Program, still need further field to verify.

(4)Effect of the straw returned to field

Crop straw contain mineral nutrients and organic ingredients, straw returning can be used as organic fertilizer, reduce the use of chemical fertilizers. Nitrogen application rate is the same, we can see with the increase of straw returning, crop production are also increased (Program 6).

(5) Sensitivity analysis

Table 6. "rape/potato – rice" pattern orthogonal experiment

	total Nitrogen	straw returning	tillage methods	total yield
experiment 1	1	1	1	22470
experiment 2	2	2	1	21615
experiment 3	3	3	1	23175
experiment 4	2	1	2	24840
experiment 5	3	2	2	29580
experiment 6	1	3	2	26595
experiment 7	3	1	3	29160
experiment 8	1	2	3	28725
experiment 9	2	3	3	27810
I_j	25930	25490	22420	
II_j	24755	26640	27005	
III_j	27305	25860	28565	
R_j	2550	1150	6145	

In the "wheat – rice – vegetable" pattern, R_1=6675, R_2=3275, R_3=2225, $R_1 > R_2 > R_3$ shows factor C's impact is the smallest. factor A and factor B are larger. so the order of the three factors are A > B > C.

In the "rape/potato – rice" pattern, R_1=2550, R_2=1150, R_3=6145, $R_3 > R_1 > R_2$ shows factor B's impact is the smallest. factor A and factor C are larger. so the order of the three factors are C > A > B.

3 Field verified experiment

The field experiment was conducted in Guanghan of the year 1998, area of experimental plot is 333.5 square meters. The fertility of the soil is medium, the soil contains Nitrogen 0.160%, organic matter 3.21%, available Nitrogen 185 mg/kg soil, available Phosphorus 7.0 mg/kg soil, available Potassium 99 mg/kg soil[6].

In the experiment, early rice selected Shanyou 448, late mid-season rice selected Fuyou 802, rape selected Shuza NO.6 (Table 7).

Table 7. sowing(planting) date and harvesting time of different planting patterns (sowing planting/harvestingmonth.day)

	wheat	rice	rape	potato	vegetable
wheat – rice	11.1/5.15	5.25/9.1	–	–	–
rape – rice	–	5.25/9.1	10.20/5.10	–	–
wheat – rice – vegetable	11.8/5.15	5.25/8.25	–	–	8.30/11.5
rape/potato – rice	–	5.25/9.1	10.20/5.10	9.2/12.20	–

(1) Experimental results

Recorded the main growth period of crops and measure the main dry weight during the main growth period. The sample of soil collected from topsoil before the experiment and after 3 years in September after rice harvested. The price of agricultural products are the average of 3 years in this article. Model can be established were Eqs. (1) to (5).

$$\text{net yield of labor} = \frac{\text{gross output-material cost}}{\text{amount of occupide labor}} \tag{1}$$

$$\text{return of material cost} = \frac{\text{gross output-labor cost}}{\text{material cost}} \tag{2}$$

$$\text{solar energy utilization rate} = \text{total dry weight of crops on unit time unit land area} \tag{3}$$

$$\times \frac{\text{dry matter contained energy in per gram}}{\text{total amount of solar radiation the same time on the same land area}} \tag{4}$$

$$\text{return of cost} = \frac{\text{gross output}}{\text{total cost}} \tag{5}$$

(2) Yield comparison

Compared to "wheat – rice" pattern and "rape – rice" pattern, the yield of "wheat – rice – vegetable" pattern increase 37.4%, the yield of "rape/potato – rice" pattern increase 16.9% (Table 8).

Table 8. yield comparison of different planting patterns (kg/hm)

	rice	wheat	rape	potato	vegetable	traditional grain	total grain
wheat – rice	8250.0	2150.0	–	–	–	16828.5	16828.5
rape – rice	8250.0	–	2400.0	–	–	8250.0	15618.0
wheat – rice – vegetable	7800.0	6450.0	–	–	15000.0	16378.5	23128.5
rape/potato – rice	8250.0	–	15000.0	2400.0	–	15618.0	19668.0

noticedtraditional grain include rice, wheat and potato; total grain include rice, wheat, potato and vegetable coefficient: 1.001.333.070.270.15;lettuce represents vegetable

(3) Economic benefits

The net income and gross output of three crops per year in paddy field increased about 1 percent than two crop a year system, in which "wheat – rice – vegetable" pattern increased 233.2% than "wheat – rice", "rape/potato – rice" pattern increased 231.0% than "rape – rice" pattern (Table 9).

Table 9. economic benefit analysis of different planting patterns

	wheat – rice	rape – rice	wheat – rice – vegetable	rape/potato – rice
labor cost(hm)	3750	4350	6000	6150
material cost(hm)	4455	3345	6600	6525
gross output(hm)	14700	13050	27750	25050
net output value(hm)	10245	9705	21150	18525
net income(hm)	6495	5355	15150	12375
net yield of labor((%)	27.3	22.3	35.3	30.1
return of material cost(%)	2.5	2.6	3.3	2.9
return of cost(%)	1.8	1.7	2.2	2.0
net return of newly added(%)	–	–	1.3	0.9
return of marginal cost(%)	–	–	3.0	2.3

(4) Resource utilization

a Three crop a year system improve the utilization of labor capacity, improved the utilization of land significantly, "rape/potato – rice" pattern improve the Utilization of light energy more than other patterns (Table 10).

Table 10. Utilization of production factors of different planting patterns

	wheat – rice	rape – rice	wheat – rice – vegetable	rape/potato – rice
labor utilization(hm)	375	435	600	615
land cropping index(%)	200	200	300	300
solar energy utilization rate(%)	1.17	1.16	1.41	1.49

(5) Soil fertility

Several reports have provided insights into fertilization practices by supplementing chemical fertilizer to alleviate nutrient limitation[5]. The total Nitrogen content and organic matter content of three crops per year improved significantly than two crops per year. (table 11).

Table 11. soil nutrient content of different planting patterns

	wheat – rice	rape – rice	wheat – rice – vegetable	rape/potato – rice
total nitrogen content(%)	0.156	0.168	0.212	0.224
organic matter(%)	3.190	3.210	3.580	4.010
available Nitrogen(mg/kg soil)	181	190	209	187
available Phosphorus(mg/kg soil)	7.1	7.0	6.8	6.5
available Potassium((mg/kg soil)	98.0	96.0	89.1	68.0

(6) derivative pattern

Because different climatic conditions, planting status in all regions are different. People not only can plant efficient vegetables, such as lettuce, cucumber, eggplant, cauliflower, cabbage, etc. People can also plant storage vegetables, such as soybean, corn, potatoes and so on. As long as the climate, fertilizer, water temperature, light conditions are suitable, "rice – rice – vegetable" pattern and "rape/potato – rice" pattern can derivative "vegetable – rice – vegetable" pattern and "potato – rice – potato" pattern[7], etc.

4 Conclusion

Although System Dynamic pattern in this paper should be helpful for solving some problems, more further research still need to do. At the same time, this paper can also analysis from the view of Leaf Area Index, Plant Height,Depth of Root, Biomass of Grain, Plant Usable Nitrogen, Total Crop Above ground, Total Crop Below ground, Total In Crop Grain, etc.

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