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In-Situ Tilling Plow Design Based On TRIZ And Extenics

Lijuan WANG, Yuanyi LIU, Xin'ao LI, Hailong CHE, Xibin LI,
Zhengzhong LI, Xian WANG
School of Agricultural and Food Science, Shandong University of Technology, China

Abstract:
***Background**: Aiming at the limitation problem of the side-turning characteristics of the share plow in facility agriculture, an innovative design method integrating TRIZ and extenics is proposed to design an in-situ tilling plow capable of deep turning with no side-shift of the soil area.*
***Materials and Methods**: In the design process, firstly, the problem is simplified by using extenics to put forward the contradiction; then, the object field analysis method and seventy-six standard solutions are used to find the solution to solve the contradiction; finally, the advantages and disadvantages of the design solutions are comprehensively evaluated by using the extenics superiority evaluation method, and the optimal solution is determined.*
***Results**: On the basis of solving the practical problems, three-dimensional modeling of in-situ tilling plow, prototype and soil trench test are carried out, and the soil falling rate of the original ditch was 87.9%.*
***Conclusion:** Taking the innovative design of in-situ tilling plow as an example, the feasibility and validity of the integration method are tested, and at the same time, the feasibility of the innovative design of in-situ tilling plow is verified.*
***Key Word**: Facility agriculture; In-situ tilling plow; TRIZ theory; Extenics; Innovative design.*

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I. Introduction

Facility agriculture is a modern agricultural mode of production that has emerged in recent years to achieve efficient production[1]. With the continuous development of China's agricultural technology, the scale of facility agriculture has reached the first in the world, accounting for about 80% of the global facility agriculture[2], but there are still many shortcomings. In facility agriculture, the problems of deep ploughing cannot be realized, resulting in the accumulation of pathogens, pests and diseases, and various harmful crop growth materials[3,4], and the limitations of the lateral displacement characteristics of mouldboard plough in facility agriculture[5], make it necessary to design an in-situ tilling plow that can be deeply ploughed and make the soil not move laterally.

In recent years, the design of product innovation methods has developed rapidly, especially the combination of TRIZ theory and other methods has become a topic of concern for many scholars, and many technical problems have been solved6. In this paper, by integrating TRIZ theory and extension theory, the best design scheme of the in-situ tilling plow is given, and the design of the plough body is completed by the comprehensive design method of the surface of the plough body, and very good results are obtained.

II. Research On The Integration Method Of TRIZ And Extenics

Overview of TRIZ theory

TRIZ theory is a creative problem-solving theory proposed by G.S. Altshuller, an expert of the USSR Admiralty Patent Office[7], who led a group of researchers to study and analyze about 2.5 million patents in the world since 1946, and they summarized the laws of the development and evolution of various technical systems, as well as the innovative principles for resolving contradictions, and combined the principles and laws of various fields of knowledge, combined the principles and laws in various fields of knowledge, and created to solve technical contradictions, Realize the TRIZ theoretical system with innovation as the core and a variety of methods and algorithms as the support. The application of this theory can greatly accelerate the process of creation and invention to obtain high-quality innovative products[8], and can be applied in the engineering community, including design, R&D, manufacturing, safety, reliability, and other fields[9,10]. At the same time, it should be noted that as an emerging innovative theory, TRIZ theory also has some shortcomings, such as the need for in-depth understanding of TRIZ theory when solving problems, and the difficulty of applying the object-field model to multifunctional engineering systems. Therefore, it is necessary to further develop the TRIZ theory and combine it with other innovation theories in order to improve the innovation capability of engineering systems.

Overview of Extenics

Extenics is a new discipline founded in 1983 by Chinese scholar Cai Wen. It mainly studies the extensible structure of things, and studies the laws and methods of the development of things through formal models, which are used to solve contradictory problems[11]. After years of development, the theoretical basis of extenics has gradually been formed, and has been applied to many disciplines such as extensible information, extensible control, extensible marketing, extensible design, extensible data mining, extensible management engineering and traditional Chinese medicine research. Compared with the TRIZ theory, the contradictions studied by extenics are universal, and have a broader and more systematic theoretical basis in terms of research objects and objectives[12]. It is of great significance for the development and application of TRIZ theory and extenics to combine the practicability of TRIZ with the generality of extenics, eliminate the defects of TRIZ and extenics, and study the fusion mechanism of TRIZ and extenics[13].

Fusion of TRIZ and extenics solution process

TRIZ's classification of contradictions is specific, which has a strong practical guidance and operability for the resolution of technical and physical contradictions in the design process of products. The classification of contradictions in extenics is abstract, while extenics has a broader and systematic theoretical basis. At the same time, the principle of innovation and the extension of reasoning are similar in the way of solving contradictory problems. It can be seen that there are both differences and intrinsic links between TRIZ and extenics.

Therefore, TRIZ and extenics are organically combined to generalize, complement each other to form a new product innovation method, the specific steps of the whole process are as follows: In the stage of problem description, it mainly aims at the problem to be solved, and uses the extension primitive model to analyze, extract the contradictions, and induce the problem categories[14]. Then, through the extension analysis of the solution to the problem, in the case of difficult to get an effective feasible solution, using the TRIZ innovation principle tools and then according to the hints of the TRIZ principle solution to the feasible solution implementation of primitive transformation[15]. Finally, the final ideal scheme is obtained by the degree of Excellence Evaluation[16]. TRIZ's work on this process is to predict feasible solutions based on extended analysis. The process for resolving the problem is shown in Figure 1.

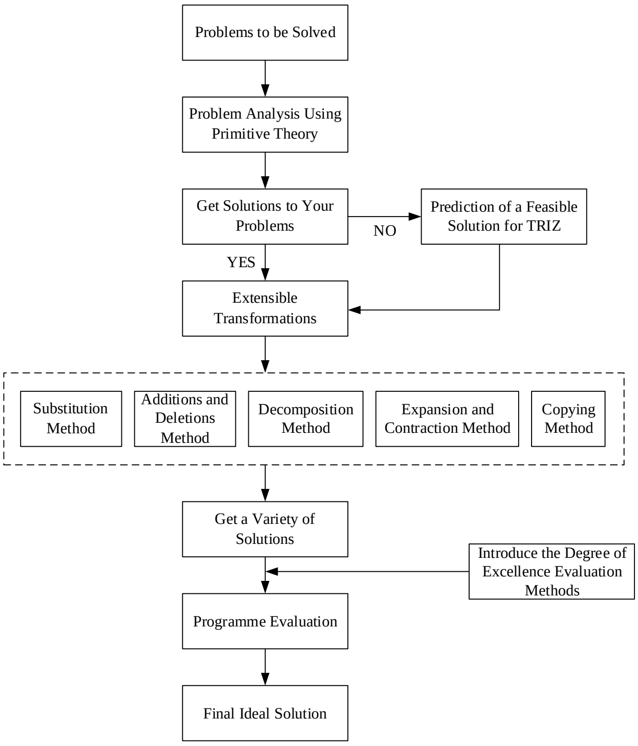


Figure no 1 : The general process of integrating TRIZ and Extenics to solve problems.

III. Design Of In-Situ Plough Based On Fusion Method

Problem description

Facility agriculture needs to be deeply turned, so it is necessary to introduce a mouldboard plough for farming, and the rollover characteristics of the traditional mouldboard plough hinder its wide application in facility farming. Therefore, under the premise of ensuring the deep turning of the mouldboard plough, it is necessary to innovate its design, so that the soil does not move sideways when it is turned.

Contradiction analysis based on primitive model

The principle of soil lifting of the in-situ tilling plow is the three-sided wedge principle, and its ultimate purpose is to make the overturned soil without lateral movement, while the traditional mouldboard plough turns the soil to one side of the furrow in the process of ploughing, which is an incompatible problem.

According to the formal description of extenics, its conditional matter element is:

$\boldsymbol{L}=\boldsymbol{M}_1=(O_{m1},c_{m1},v_{m1})=$ (plough wall, rollover characteristics, high)

The target object element is:

$\boldsymbol{G}=\boldsymbol{M}_2=(O_{m2},c_{m2},v_{m2})=$ (turned over mounds, the falling rate of the original ditch, high)

The problem is an incompatible issue and is described as:

$\boldsymbol{P}=\boldsymbol{G}*\boldsymbol{L}=\boldsymbol{M}_2\uparrow\boldsymbol{M}_1=(O_{m2},c_{m2},v_{m2})*(O_{m1},c_{m1},v_{m1})$

The process by which the mound is finally turned over through the plough wall can be represented by a series of event A. It can be seen from the implication rules of the matter:

$\boldsymbol{A}_1\Leftarrow\boldsymbol{A}_2\Leftarrow\boldsymbol{A}_3$

Among them,

$$\boldsymbol{A}_1=\begin{bmatrix}\text{buckle over the mound}, & \text{dominating object}, & \text{mound}\\ & \text{location}, & \text{plough wings}\\ & \text{form of force}, & \text{gravity}\end{bmatrix};$$

$$\boldsymbol{A}_2=\begin{bmatrix}\text{flip over the mound}, & \text{dominating object}, & \text{mound}\\ & \text{location}, & \text{plough chest}\\ & \text{form of force}, & \text{side thrust and gravity}\end{bmatrix};$$

$$\boldsymbol{A}_3=\begin{bmatrix}\text{lift over the mound}, & \text{dominating object}, & \text{mound}\\ & \text{location}, & \text{ploughshare}\end{bmatrix}.$$

It can be seen from the analysis of element A that the reason for the lateral movement and overturning of the soil is that the plough body curves to produce lateral thrust on the soil as the mouldboard plough moves forward during ploughing. And the reason for the side thrust of the plough body surface is the side thrust of the plough chest part and the buckle overturning of the plow wing part.

From the above analysis, it can be seen that the main reasons for the rollover characteristics of the soil are the overturning effect of the plough chest on the soil and the buckle and overturning effect of the plough wing on the soil, both of which will have adverse effects and are harmful effects. The plough chest and plough wings make up the plough wall, so the problem can be summarized as "the plough wall has a harmful effect on the soil". In TRIZ theory, this problem is classified as a detrimental object-field model problem and can therefore be solved with object-field analysis tools.

Feasible solution prediction based on TRIZ innovation principle

The principle of matter-field analysis states that all functions can be decomposed into two substances and one field, i.e., a function consists of three elements of two substances and one field[17]. The object-field analysis model is usually described in terms of triangles, and the hazard object-field model of the mouldboard plough is shown in Figure 2.

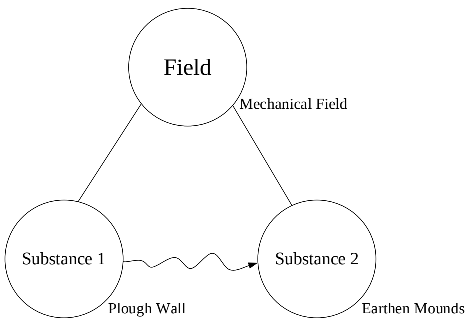


Figure no 2 : The hazard object-field model of the mouldboard plough.

Object-field models are generally divided into four categories: effective models, inadequate models, missing models, and harmful models, and the TRIZ theoretical object-field analysis tool focuses on the latter three models, and proposes six general solutions to solve these three models, as shown in Table 1.

Table no 1 : A general solution to object-field analysis.

General solution number	There are problems	Specific solutions
1	Inadequate models	A second field is introduced to enhance the useful effect
2		A second field and a third substance are introduced to enhance the useful effect
3		Introduce a second field or a second field and a third substance in place of the original field or the original field and matter
4	Missing models	Completes the missing elements (fields, matter) to complete the model
5	Harmful models	A third substance is added to block harmful effects
6		A second field is introduced to counteract the harmful effects

For complex problems, the object-field analysis method also provides 76 standard solutions, which are divided into five categories according to the characteristics of the object-field model[18]. The hazardous sobject-field model analyzed in this paper belongs to the second subcategory of the first type of standard solution among the five types of standard solutions, which are described in Table 2.

Table no 2 : The first class of standard solutions for the object-field model.

The class to which it belongs	The subclass to which it belongs	Numbering	Standard solution
The first type of standard solution	S1.1 Establish an object-field model	S1.1.1	Establish an object-field model
		…	…
	S1.2 Dismantling the object-field model	S1.2.1	S_3 is introduced to remove harmful effects
		S1.2.2	Introduce improved or mutated S_1 or/and S_2 to eliminate harmful effects
		S1.2.3	Exclusion of harmful effects
		S1.2.4	Use the field F′ to counteract the harmful effects
		S1.2.5	Cut off the magnetic effect

Solutions S1.2.3, S1.2.4, and S1.2.5 have limited solution to the problem. Options S1.2.1 and S1.2.2 are worth considering. According to the solution of S1.2.1 "S_3 removal of harmful effects", the rollover effect can be eliminated by adding a new substance to the side of the plough body, the small rear plow body, to push back the overturned mound, which is now recorded as Scheme 1.

According to solution S1.2.2 "Introduce improved or mutated S_1 or/and S_2", the plough wall is mutated, and this scheme can also eliminate the harmful effect, and this scheme is recorded as Scheme 2.

Primitive transformations for feasible solutions

According to TRIZ's original understanding of the prompt, the mound can be turned over by changing the plough wall. Because the adverse effects of the plough wall on the soil and the positive effect of the requirements are diametrically opposite, the plough wall can be symmetrically varied. As long as the mound can be lifted by the symmetrical mutation of the plough wall, the mound can be turned over to the original ditch.

Do the transformation $\boldsymbol{T_1}$ and make

$$\boldsymbol{T}_1\boldsymbol{M}_0 = \boldsymbol{M}'_0$$

Among them,

$$\boldsymbol{T}_1 = \begin{bmatrix} \text{displacing, dominating objects,} & \boldsymbol{M}_0 \\ \text{transform the result,} & \boldsymbol{M}'_0 \end{bmatrix};$$

$$\boldsymbol{M}_0 = \begin{bmatrix} \text{plough wall, shape,} & \boldsymbol{V}_1 \\ \text{location,} & \text{original plough wall} \end{bmatrix};$$

$$\boldsymbol{M}'_0 = \begin{bmatrix} \text{symmetrically varied plough walls, shape,} & \boldsymbol{V}_{11} \\ \text{location,} & \text{the endpoint of the intersection line away from the plow tip} \end{bmatrix}$$

.

In this scheme, on the main plough body, the mound that passes through the ploughshare is lifted, and then under the action of the lateral thrust of the variable plough wall, it is turned into the furrow to realize the flipping of the original furrow. The complete object-field model of the main plow body is shown in Figure 3 and does not produce harmful effects.

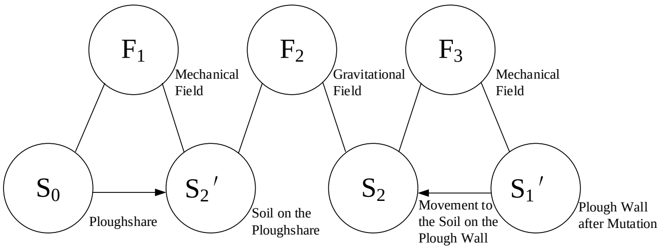


Figure no 3 : Complete object-field model of the main plow body.

When the single plough is cultivated, the soil is formed and piled up on the tip side of the ploughshare by the action of the ploughshare and does not return to the original furrow, and it is necessary to consider eliminating its lateral force, and the two single ploughs can be symmetrically designed to obtain a double plough, and the scheme is recorded as Scheme 3.

Its corresponding extension transformation can be expressed as: do an increase transformation $\boldsymbol{T_2}$, so that $\boldsymbol{T}_2\boldsymbol{M}_1 = \boldsymbol{M}_1 \oplus \boldsymbol{M}_{11}$

Among them,

$$\boldsymbol{T}_2 = \begin{bmatrix} \text{increase, action object, } \boldsymbol{M}_1 \\ \text{dominating objects, } \boldsymbol{M}_{11} \\ \text{transform the result, } \boldsymbol{M}_1 \oplus \boldsymbol{M}_{11} \end{bmatrix}$$

$\boldsymbol{M}_{11}$=(symmetry device, function, eliminate side forces).

The whole design process mentioned above is shown in Figure 4.

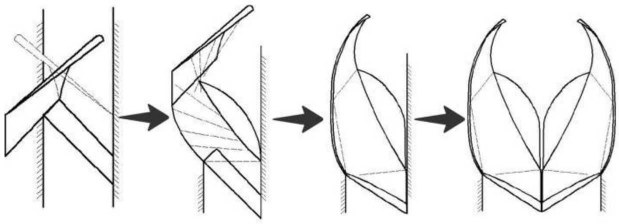


Figure no 4 : Design process of in-situ tilling plow

Excellent degree evaluation

According to the analysis, a total of 3 solutions were obtained. Scheme 1 is to increase the small rear plough body on one side of the plough body, scheme 2 and scheme 3 both use the same plough body surface, scheme 2 is a single ploughshare setting, scheme 3 is a double ploughshare setting. All three schemes can eliminate the rollover characteristics of the mouldboard plow, and the excellent degree evaluation[19] is used to select the best.

1）Determine the measurement criteria

The three factors of plough's simplicity C_1, operation effect C_2 and processing cost C_3 are selected as the measurement conditions, and the measurement condition set is obtained:

$$O = \{(C_1, V_1), (C_2, V_2), (C_3, V_3)\}$$

Among them, V_i is the C_i range.

2）Determine the weight factor

The analytic hierarchy process (AHP) is used to determine the relative ratio between the two factors according to the different importance of each factor to the plough tool, and the 1-9 ratio scale method is used, and the meaning of the scale is shown in Table 3.

Table no 3 : The meaning of the scale.

Scale	Meaning
1	The two factors are equally important
3	Compared to the two factors, the former factor is slightly more important than the other
5	Compared to the two factors, the former factor is obviously more important than the other
7	Compared to the two factors, the former factor is strongly more important than the other
9	Compared to the two factors, the former factor is extremely more important than the other

2、4、6、8	Represents the median of two adjacent judgments

Considering that the importance of the operation effect of the plough tool obviously exceeds the other two factors, and the importance of the processing cost is slightly higher than its simplicity[20], the discriminant matrix *H* established by the AHP method is presented in the following form:

$$\boldsymbol{H} = \begin{array}{c} C_1 \\ C_2 \\ C_3 \end{array} \begin{bmatrix} 1 & 1/5 & 3 \\ 5 & 1 & 5 \\ 1/3 & 1/3 & 1 \end{bmatrix}$$

The weight coefficient obtained by using the sum product method of AHP is α as follows:

α=（0.179，0.573，0.246）

3）Establish an association function and calculate the standard correlation degree

A simple discrete correlation function K_i can be established if the plough's simplicity, operation effect and processing cost are all 1 ~ 5 grades:

$$K_i(x) = \begin{cases} 5, x = \text{extremely simple/ extremely good / extremely low} \\ 4, x = \text{simple/ good / low} \\ 3, x = \text{ordinary} \\ 2, x = \text{complex/ bad/ high} \\ 1, x = \text{extremely complex/ extremely bad / extremely high} \end{cases}$$

The optimum value of the plough's simplicity, operation effect and cost is 5(grade) .

Compare the plow body designs of three different schemes. Scheme 1 adds a small rear plough body on one side of the plow body, so as to carry out secondary movement of the soil mound after flipping from the side of the main plow body, and offset the lateral thrust effect of the main plow body, so that the complexity and cost of the structure are inevitably increased, take $K_{C_1}(O_1)=2, K_{C_2}(O_1)=4, K_{C_3}(O_1)=3$; Scheme 2 symmetrically mutates the ploughshare wall part about the forward direction of the plough body, and then connects the connecting surface and the ploughshare according to the movement law of the mouldboard to form the curved surface of the plough body, which can be turned over in situ and the mould has no lateral movement, but the processing cost is high, take $K_{C_1}(O_2)=4, K_{C_2}(O_2)=4, K_{C_3}(O_2)=4$; Scheme 3 is symmetrically designed on the basis of scheme 2 to obtain a double plough, which eliminates the lateral force of the single plough, and makes the original ditch drop rate higher, but the complexity and cost also increase, take $K_{C_1}(O_3)=2, K_{C_2}(O_3)=5$, $K_{C_3}(O_3)=5$.

According to the above analysis, the correlation degree of the three schemes with respect to the measurement indicators: simplicity C_1, operation effect C_2 and processing cost C_3 is as follows:

$K_{C_1}=(K_{C_1}(O_1), K_{C_1}(O_2), K_{C_1}(O_3))=(2, 4, 2)$

$K_{C_2}=(K_{C_2}(O_1), K_{C_2}(O_2), K_{C_2}(O_3))=(4, 4, 5)$

$K_{C_3}=(K_{C_3}(O_1), K_{C_3}(O_2), K_{C_3}(O_3))=(3, 4, 5)$

According to the canonical relevance formula:

$$k_i(Q) = \frac{k_i(Q)}{\max\limits_{x \in X_0} k_i(x)} \quad (1)$$

Then their normative relevance is as follows:

$k_{c_1}=(0.5, 1, 0.5)$

$k_{c_2}=(0.8, 0.8, 1)$

$k_{c_3}=(0.6, 0.8, 1)$

4）Calculate the degree of excellence

The normative relevance of Scheme 1 for measuring condition O is as follows: $K(O_1)=(0.5, 0.8, 0.6)^T$; The normative relevance of Scheme 2 for measuring condition O is: $K(O_2)=(1, 0.8, 0.8)^T$; The normative relevance of Scheme 3 for measuring condition O is: $K(O_3)=(0.5, 1, 1)^T$。

Therefore, the degree of excellence of the three schemes are:

$C(O_1)=\alpha K(O_1)=0.6955$

$C(O_2) = \alpha K(O_2) = 0.8342$
$C(O_3) = \alpha K(O_3) = 0.9085$
Since $C(0_3) > C(0_2) > C(0_1)$, option 3 is considered to be the preferred option.

Final Solution

For the mouldboard plough with simple structure and complex design, the improved design of the traditional mouldboard plough can not realize the goal of turning over the original ditch with only one piece of plough body surface, which requires that the plough body surface changes greatly, and such plough body surface is difficult to use the commonly used plough body design method, such as the horizontal straight line element method, the inclined element line method and the soil turning curve family method.

Therefore, in the design of the surface of the plough body of the in-situ tilling plow, the curved line method should be adopted, and the appropriate restraint surface should be added in combination with the movement law of the soil to form the required plough body surface[21]. Firstly, it is necessary to correct the relative position of the mutated ploughshare and the ploughshare, and at the same time define the ideal trajectory of the moulding, and then adjust the plow share and variation of the plow wall between the transition surface according to the movement of the soil. Finally, in order to ensure that the soil movement is regular, a suitable restraint surface, such as a dump slab, is added. After the design of all components is completed, the overall shape is optimized to achieve a smooth and continuous surface, and finally the surface design of the plow body is completed.

The three-dimensional model of the main plow body is obtained according to the design scheme of the in-situ tilling plow. The three-dimensional model of the main plow body is shown in figure 5.

1. plowshare 2.plough neck 3. dump slab 4.plough chest 5.plough wings

Figure no 5 : Three-dimensional model of in-situ tilling plow

IV. Soil Groove Test

In order to verify the operation effect of the in-situ tilling plow, it was processed and manufactured, and the test was carried out in the indoor soil groove of Shandong University of Technology. The size of the soil groove is 60m (length), ×3m (width) × 0.8 m (depth), and the test power is TCY-23141248 all-electric four-wheel drive soil groove test bench, as shown in Figure 6, the experiment only measures the effect of soil turning.

（a）front （b）back

Figure no 6 : Test site

In the test, according to the predetermined movement law, under the action of gravity, the soil slides down along the surface of the plough body into the original ditch. The final experimental results are shown in Figure 7, and Figure 7(b) shows the soil that has been cultivated, and its soil has been turned over ideally, and is basically in place.

In this paper, the concept of the falling rate of the original ditch is introduced, that is, the amount of falling soil in the original ditch that can be achieved by observing the plough body. The original ditch falling rate is calculated by volume method during the test, after tillage, the soil is turned over by the plough body, the soil is ridged, the cross-section is an isosceles triangle, the ridge volume can be obtained by measuring its bottom edge and height, the total volume of tillage minus the ridge volume is the original ditch falling volume, and the ratio of the original ditch falling volume and the total volume is the original ditch falling rate.

The formula is:

$$D = {}^{V_d}\!/_{V_t} \tag{2}$$

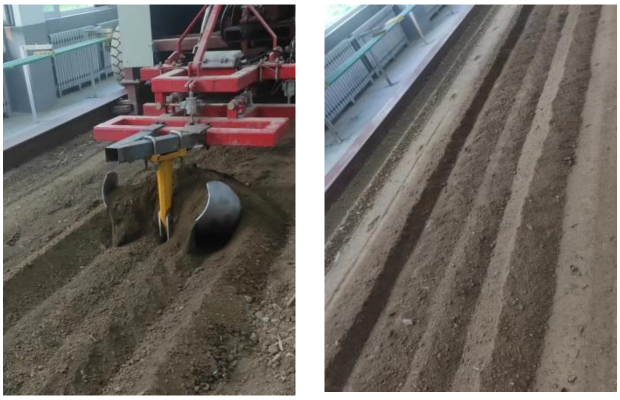
Formula: D is the soil falling rate of the original ditch, and the unit is (%);
V_d is the volume of the original ditch, and the unit is (m^3);
V_t is the total volume of cultivation in (m^3).

The expression for V_d is:

$$V_d = V_t - V_r \tag{3}$$

Formula: V_d is the volume of the original ditch, and the unit is (m^3);
V_t is the total volume of tillage, and the unit is (m^3);
V_r is the volume of the plough body turned into ridges after tillage, and the unit is (m^3).

After calculation, the falling rate of the original ditch was 87.9%.



（a）operation process （b）operation effect

Figure no 7 : In-situ tilling plow test

According to the experimental results, most of the soil tilling after the prototype has been turned over and successfully landed in the original furrow, which further proves that the design scheme of the in-situ tilling plow is feasible.

V. Conclusion

1) Considering the existing problems of the existing mouldboard plough, the method of integration of extenics and TRIZ theory was adopted to improve the design, and the ideal design scheme of the in-situ tilling plow was successfully established through the analysis and solution of contradictions, the transformation of feasible solutions, and the evaluation of schemes, which proved that the integration of TRIZ theory and extenics method has good adaptability and feasibility in practical application, and has certain reference value for related design work.

2) Using the method of degree of superiority evaluation, the degree of superiority of different schemes of in-situ tilling plow was quantitatively evaluated, and the optimal scheme was determined. The results show that scheme 3 has the highest degree of excellence, the best operation effect and the best feasibility.

3) The three-dimensional model is used to process and manufacture the in-situ tilling plow, and the prototype is used to carry out the ploughing test in the soil trough, and the test results show that most of the soil ditch has completed the original ditch overturning, and the soil falling rate of the original ditch is 87.9%, which proves the feasibility of the design scheme of the in-situ tilling plow.

References

[1]. YIN Y, XI F M, BING L F, et al. Accounting and red uction path of carbon emission firom facility agriculture in China [J]. Ying Yong Sheng Tai Xue Bao, 2021(11): 3856-3864.

[2]. LUO F, XU H B, ZUO Z Y, et al. Current situation, deficiency and countermeasures of China's facility agriculture [J]. Jiangsu Agricultural Sciences, 2020, 48(10): 57-62.

[3]. MA J C, DU K M, ZHANG L X, et al. A segmentation method for greenhouse vegetable foliar disease spots images using color information and region growing [J], Computers and Electronics in Agriculture, 2017, 142: 110-117.

[4]. Ghani S, Bakochristou F,ElBialy E M A A, et al. Design challenges of agricultural greenhouses in hot and arid environments – A review[J], Engineering in Agriculture, Environment and Food, 2019, 12(1): 48-70.

[5]. LIU Y Y, YU S J, XU B, et al. Experimental study on in-situ tilling plow in facility agriculture based on discrete element method [J]. Journal of Jilin University (Engineering and Technology Edition): 1-11.

[6]. LIU Z F, GAO Y, HU D, et al. Green Innovation Design Method Based on TRIZ and CBR Principles [J]. China Mechanical Engineering, 2012, 23(9): 1105-1111, 1116.

[7]. Savransky S D .Engineering of Creativity [J].Crc Press, 2002.DOI:10.1201/9781420038958.

[8]. WANG N W, WANG J. Innovative Design of Hot Moxibustion Therapy Apparatus Based on QFD/TRIZ [J]. Packaging engineering, 2018, 39(22): 218-224.

[9]. Caligiana G , Liverani A , Francia D ,et al. Integrating QFD and TRIZ for innovative design[J].Journal of Advanced Mechanical Design Systems & Manufacturing, 2017, 11(2):15.

[10]. Bai Z H , Zhang S , Ding M ,et al. Research on product innovation design of modularization based on theory of TRIZ and axiomatic design[J].Advances in Mechanical Engineering, 2018, 10(12):84-87.

[11]. ZENG P P, TAO T, CHEN X Y, et al. Research on the Application of TRIZ and Extension Theory in Office Chair Design [J]. Furniture & Interior Design, 2022, 29(2): 36-40.

[12]. JIANG F, YANG P H. Study of the combined method based on TRIZ and Extenics [J]. Journal of Guangzhou University (Natural Science Edition), 2014, 13(6): 59-64.

[13]. CAI W, YANG C Y, HE B. Several Problems on the Research of Extenics [J]. ournal of Guangdong University of Technology, 2001, (1): 1-5.

[14]. LI Y W, WANG L, WANG F. E-Surf Image Recognition Algorithm Based On Extenics [J]. Computer Applications and Software, 2014, 31(7): 221-225.

[15]. YANG C Y, CAI W. Recent Research Progress in Dependent Functions in Extension Sets [J]. Journal of Guangdong University of Technology, 2012, 29(2): 7-14.

[16]. WANG J, SUN S. Design of folding mechanism of camping stroller based on extension innovationmethod and TRIZ theory [J]. Journal of Engineering Graphics, 2021, 42(5): 866-872.

[17]. ZHANG J H, TAN R H, CHEN Z S. Study on the Method of Function Analysis Based on Su-field Analysis [J]. Machine Design & Research, 2009, 25(1): 19-23.

[18]. TAN R H. TRIZ and its applications [M]. Beijing: Higher Education Press, 2010.

[19]. CAI W, YANG C Y. Basic theory and methodology on Extenics [J]. Chinese Science Bulletin, 2013, 58(13): 1190-1199.

[20]. ZHANG L, PENG H W, LIU Z F, et al. Knowledge Reuse in Green Product Concept Design Process [J]. Journal of Mechanical Engineering, 2013, 49(7): 72-79

[21]. SHENG J H, LI Z Y. Design of Plow Bottom Surface by Turning over Method [J]. Transactions of the Chinese Society for Agricultural Machinery, 2000, (1): 38-41. [21].