

Review

A Review of Research Progress on Soil Organic Cover Machinery in China

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Abstract: Soil organic cover technology is an effective way to solve agricultural productivity and agro-environmental issues. However, some factors limit the widespread adoption of its application, including unclear soil organic cover effects and the lack of high-performance soil organic cover machinery. Aiming to solve the existing problems, improve soil organic cover quality, and reduce energy consumption, this article reviewed the common and commercial machines by reviewing the existing literature and company products. The current problems and technical difficulties of the machines were expounded. Simultaneously, the method of design and optimization of the device (chopper, spreader, rotary tiller, and plow) and its key parts (blades, discs, and plows) were reviewed. Furthermore, the features and differences of the devices and their key parts were compared, and their advantages and disadvantages were analyzed. In conclusion, the future directions for soil organic cover technology and machinery development were suggested, including clarifying the soil organic cover effect, selecting the suitable soil organic cover patterns, and developing soil organic cover machinery.

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Keywords: soil organic cover; straw retention machinery; discrete element method; blade

1. Introduction

For centuries, the soil has always been regarded as a significant factor for crop growth. It was considered a valuable agricultural resource that supported sustainable agriculture development [1]. The most suitable soil for growing crops is composed of 50% soil particles of organic matter and 50% pores [2]. Specifically, moisture and air accounted for 25% of pores, respectively. However, with the increased use of inorganic fertilizers, pesticides, and machinery, the quality of soil is declining year by year. Moreover, the soil has been refined due to long-term conventional tillage practices. Consequently, a failure layer has been formed, resulting in the surface soil particles moving easily under external forces, such as wind and rainfall. There is also a common phenomenon in the soil, called wind erosion and water erosion. Once the soil is destroyed, the crop yield will be decreased and the environment will deteriorate. This is not in line with people's vision. People desire that agriculture can produce more yield without environmental harm and contribute positively to natural and social capital [3].

After a long period of using these planting practices, it has been found that soil organic cover is a better method to protect the soil. Soil organic cover, a soil protection method, refers to maintaining crop residues and/or crops on the surface of the soil after harvesting [4]. The use of permanent soil organic cover is the second of the three principles of conservation agriculture (CA). Soil organic cover has been proven to be one of the most appropriate and sustainable options to increase soil productivity, decrease soil erosion (both water erosion and wind erosion), improve the total porosity and water retention ability of the soil, and increase

infiltration [5–7]. Che et al. found that organic material, in various particle sizes, could reduce daily evaporation of soil moisture. The cumulative evaporation capacity of garden wastes (1~3 cm, 0~1 cm, 3~5 cm in size) and CK (control) were 193.0 g, 269.5 g, 304.0 g, and 1037.0 g, respectively, which were 81.4%, 74.0%, and 70.7% lower than those of CK [8]. The soil moisture content of different layers was increased by covering them with different organic materials. Laura et al. found that soil organic cover can increase soil productivity by enhancing the abundance of all microbial groups and their total catabolic activity [9]. As shown in Figure 1, the content of soil organic carbon (SOC) was increased if the surface of the soil was covered with *Vicia faba* straw. Especially in region C, the content of SOC increased most notably. Kaye et al. found that soil organic cover protects the soil from erosion and prevents loss of nutrients in deep layers through leaching and surface runoff [10].

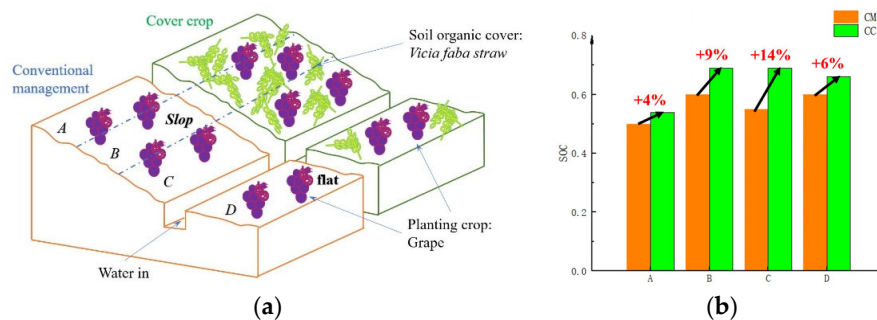


Figure 1. Effect of soil organic cover on SOC content. (a) Test method and material; (b) results of SOC content in different areas.

In the early 1930s, Edward H. Faulkner questioned the conventional tillage in his book called *Plowman’s Folly* [11]. He believed that the reason for the dust bowls that devastated wide areas of the Midwestern USA was conventional tillage [12]. Subsequently, the concept of protecting the soil by keeping it covered gained popularity. In the 1960s, China began to conduct soil organic cover tests. The main materials used for soil organic cover were crop straw and green manure. However, the technologies have only been implemented for small areas due to the limitation of technology and machines and the level of socio-economic development [13]. In the 1990s, with the acceleration of industrialization, the widespread application of chemical fertilizers resulted in the effect that soil organic cover was neglected. In recent years, the quality of the land has been declining year by year. People began to realize the importance of soil protection. To address the issue of land degeneration, a series of associated regulations were promulgated by the Chinese government to promote land quality (Table 1). Currently, according to estimation, the use of soil organic cover is practiced on over 700 Mha. At present, the soil organic mulch mainly includes straw (such as decaying leaves, bark, or compost) and live mulches (such as crops).

Table 1. Relevant development regulations of straw management technology in China.





Department	Regulation/Laws	Related Content
Ministry of Agriculture and Rural Affairs, National Development and Reform Commission, Ministry of Finance et al. [14]	Implementation Plan of the National Black Soil Protection Project (2021–2025) [14]	Promoting the return of crop straw and green manure to the field.
Ministry of Agriculture and Rural Affairs, National Development and Reform Commission, Ministry of Finance et al. [15]	Outline of Northeast Black Soil Protection Plan (2017–2030) [15]	Implementing straw returning to the field to protect the soil.
Ministry of Agriculture and Rural Affairs, Ministry of Finance [16]	Action Plan for Conservation Tillage of Black Soil in Northeast China (2020–2025) [16]	Increasing the application area of soil organic cover (crop straw).

Ministry of Agriculture and Rural Affairs [17]	Technical Guidelines for Green Agricultural Development (2018–2030) [17]	Promoting straw returning and organic matter returning technologies.
Central Document No. 1 [18]	State Council [18]	Promoting comprehensive utilization of straw.

“Central Document No. 1” was the name originally given to the first document issued by the central authority, and it focused on the development of agriculture, rural areas, and farmers in 1982.

Currently in China, soil organic mulch is usually divided into two categories (Table 2). The first category is crop straw and crop residues, which remained after crops are harvested. The common crop straw/residues are rice, wheat, corn, cotton, banana, tobacco, and soy beans. For the crop straw/residues, these are chopped and then spread on the field. The second category is live mulch (crops), usually called live cover, intercropped for purposes of providing soil cover. The common crops are *Vicia villosa*, *Vicia sativa*, *Brassica campestris*, *Astragalus sinicus*, *Sesbania cannabina*, *Melilotus suaveolens*, *Astragalus*, *Raphanus sativus*, and *Azolla imbricate* [19]. The live mulch (crops) are chopped and then mixed with soil or buried in the soil directly.

Table 2. Main types of soil organic mulch in China.




Mulch Category	Field Photo		Main Crops
Crop straw and residues			Rice; Wheat; Corn; Cotton; Banana; Tobacco; Soy Beans
Live mulch (crops)			<i>Vicia villosa</i> ; <i>Vicia sativa</i> ; <i>Brassica campestris</i> ; <i>Astragalus sinicus</i> ; <i>Sesbania cannabina</i> ; <i>Melilotus suaveolens</i> ; <i>Astragalus</i> ; <i>Raphanus sativus</i> ; <i>Azolla imbricate</i>

Mechanization is the best way to improve agricultural productivity. Therefore, soil cover machines are indispensable for mechanized soil organic cover. Moreover, the performance of the machines directly affects the cover quality. The quality of the soil would be significantly improved and the yield of the crops would be increased if the cover quality was improved. In contrast, problems such as seeding blockage and low crop emergence rate occur if the cover quality declines. The goal of this paper was to comprehensively review the existing literature related to technologies currently being used in soil organic cover machines for improving soil organic quality and reducing fuel consumption. This article was based on the following aspects and is organized as follows. First, the methods of design and optimization of soil organic cover devices are stated in Section 2. In addition, the differences and features of commercial machines are also expounded in Section 2. Next, in Section 3, the methods of design and optimization of different key parts of the soil organic cover machines are introduced and their advantages and disadvantages are analyzed. Simultaneously, the advanced technology and methods to solve the problems of poor work quality and high energy consumption are concluded and their advantages and applicable scopes are analyzed in Section 4. Moreover, some suggestions are given for future soil organic cover machine development in Section 5. Finally, the main content and aims of this paper are summarized in Section 6.

2. Review of Typical Soil Organic Cover Machinery

According to the working type of the soil organic cover machines, they can be divided into three categories [20]. The first working type is to bury the crop straw or crops in the soil, using the working principle of chopping the materials and then using a plow to bury them. The main working machines are a share plow and a disk plow. The second working type is to mix the crop straw or crops with soil, using the main working principle of chopping the materials and then mixing them evenly. The main working machine is the rotary tiller. The third working type is to cover the soil surface with crop straw or crops, using the working principle of chopping the materials and then spreading them across the soil. The main working machines are a stubble crusher, a straw chopper, and a straw returning machine. The typical machines of the three working types are shown in Table 3. The two main aims of mechanized soil organic cover are chopping finely and spreading/mixing evenly, which can accelerate the rot and decomposition of straw and avoid blockage in the seeding operation [21–23]. Wang et al. proposed that the length of chopped maize straw should be less than 6 cm because the wheat planting row spacing is between 12~14 cm. To avoid blockage, the length of chopped maize straw should be less than half of the wheat planting row spacing [24]. Furthermore, reducing the fuel consumption of the machinery is also a significant goal that cannot only reduce the expenditure of farmers, but also reduce energy consumption and greenhouse gas emissions.

Table 3. Typical machines of soil organic cover in China.

Working Type	Typical Machine	Company	Working Feature
Chopping and mixing machine	 <p>Mixing device Chopping device</p>	Hebei Shuangtian Machinery Manufacturing Co., Ltd. Baoding, Hebei, China [25]	High-speed rotating blades chop the straw, evenly mixing organic mulch and soil.
Chopping and spreading machine	 <p>Spreading device Chopping device</p>	Hebei Lianhang Machinery Co., Ltd. Shijiazhuang, Hebei, China [26]	Moving and fixed knives support chopping; guide vanes adjust spreading parameters.
Chopping and burying machine		YTO group corporation. Luoyang, Henan, China [27]	No need to chop; bury organic mulch directly in the soil; the working depth is over 20 cm. No need to chop; Bury organic mulch directly in the soil; The working depth is between 10 and 20 cm.

2.1. Straw Chopper and Spreader

The straw chopper and spreader are the dominant machines used for handling crop straw and residues. They can work individually, as a single function machine, or with other agricultural implements, as a multiple function machine; they can also be combined with harvesters. When the chopper and spreader work individually or with other agricultural implements, the power is supported by the power take-off of the tractor. When the

chopper and spreader is combined with the harvester, the power is supported by the harvester. The straw chopper and spreader normally included two core devices, which are the chopping device and the spreading device.

2.1.1.1. The Chopping Device

As shown in Table 4, according to the various movements of the chopping blade, the commercial chopping device can be divided into four types: throwing type, chopping and fixed blade, chopping blade, and double rollers. The components of a flapping-type chopping device are the roller, blade, and shell. The blades are installed on the roller, and they are surrounded by the shell. The blades, driven by the roller, chop the straw via high speed-rotation. The blades can rotate around a certain range, instead of being fixed on the roller. The flapping-type chopping device is suitable for wheat straw, rice straw, and crops whose texture is soft.

To improve the working quality and reduce the energy consumption of the chopping device, many researchers have innovatively designed or optimized the device structure. Sun et al. designed a differential sawing rice straw chopper for use in the field. The machine can improve chopping quality and avoid seeding machine blocking by using a saw disc blade and a crushing knife [28]. Bao et al. established the kinematics model of a single stalk cut by the flapping blade using the D-H method. He found that the impact force of a single weed stem was 74.25 N under the condition of no grass entanglement [29]. The components of the chopping and fixed blade chopping device are a roller, chopping blade, fixed blade, and shell. The chopping blades are installed on the roller, and the fixed blades are installed on the shell. The distance between the chopping blades and the fixed blades is 4–8 cm [30]. Zheng et al. designed a straw chopping device (Table 4) with a chopping and supported fixed knife [31]. The device, which is suitable for maize straw, uses the supported slide cutting force formed by an equal sliding-cutting angle fixed knife and the high-speed spinning chopping knife, along with the shell, to chop straw. The field experiments were conducted, and they showed that the chopping pass rate was 91.5%. The chopping blade chopping device mainly includes a shaft, reciprocating mechanism, chopping blade, and shell. There is a special mechanism that can transform circular motion into linear motion. In the chopping process, the shaft provides power and then transmits the power to the reciprocating mechanism. The reciprocating mechanism drives the blade for chopping. The reciprocating mechanisms usually consist of a four-link mechanism, a cam mechanism, a rack and pinion mechanism, and a worm gear mechanism. A novel chopping device based on a four-link mechanism, which can chop the straw into shorter pieces, was designed by Wang et al. [24]. The experiment results showed that it was superior to the traditional machine. Lin et al. developed a reciprocating intermittent chopping device (Table 4) for maize straw returning, which can improve the chopping pass rate and decrease the soil bulk density at a depth of 0 to 10 cm. [32]. The double rollers chopping device mainly includes a shaft, chopping roller, supporting roller, and shell. There are many blades installed on the double rollers. During the chopping progress, the blades installed on the chopping roller pick up the straw and then drive it to the chopping chamber. Under the interaction of the blades installed on the chopping roller and supporting roller, the straw is chopped completely. In addition, the velocity of the chopping roller is faster than that of the supporting roller. Liu et al. propose a novel chopping method and designed a double roller-type stalk chopping and retention device (Table 4), with different rotation speeds and dynamic double support [33]. The chopping pass rate was 92.58% when the rotation speeds of the chopping roller and the supporting roller were 1700 r/min, and 850 r/min, respectively. Liu et al. installed the disc blade on the supporting roller and the L-type blade on the chopping roller. The performance of the device was improved by analyzing the movement process of the straw during the chopping process [30]. The field validation experiment results showed that the energy consumption was 1150.43 W, and the chopping pass rate was 93.43%.

Table 4. Common forms of the chopper.

Core Device Common Form	Schematic	Features
Flapping type [31]		Suitable for wheat and rice straw; low fuel consumption; simple structure.
Chopping and fixed blade [23]		Suitable for maize, wheat, and rice straw; good chopping quality; wide range of application.
Chopper		
Chopping blade [32]		Suitable for maize and cotton straw; small length of chopped straw.
Double rollers [33]		Suitable for various types of crop straw; high chopping quality.

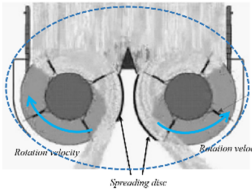

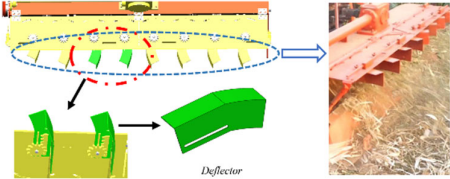
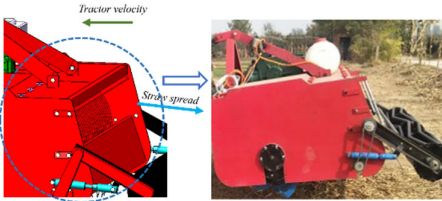
2.1.2. The Spreading Device

As shown in Table 5, according to the different diversion methods, the common spreading device can be divided into two types: active and passive. The active diversion device mainly uses the disc and pipeline to spread the mulch, while the passive device mainly uses the tailboard and shell to spread the mulch. The components of the disc diversion spreading device are the shaft and the disc. The shaft provides power to drive the disc, and by removing the rotation of the disc, the straw could be spread more evenly.

Researchers usually optimize the spreading device structure or change the working speed to improve spreading performance and reduce energy consumption. Liu et al. introduced a spreader that contains two spreading discs and a guide plate (Table 5). The spreader could adjust the throwing width, throwing distance, and throwing uniformity [34]. The pipeline type of spreading device mainly includes a blower and pipeline. When the straw is chopped by chopper, the blower blows it into the pipe and then spreads it on

the field. Humphreys et al. developed the Twynam Happy Seeder (Table 5) for Australian conditions, which consists of a modified Tierri stubble mulcher [35]. The Tierri stubble mulcher has a blower and pipeline which can adjust the spreading distance by changing the blower speed. The components of the tailboard diversion spreading device are the tailboard and guide vane. The guide vane is installed on the tailboard, and it can swing by the driving of the motor. The tailboard diversion spreading device controls the direction of straw throwing through the swing of the guide vane. Ju et al. designed an L-shape blade for spreading and then analyzed its performance [36]. The field experiment results showed that the uniformity rate of straw spreading was 87.63%, indicating that the L-shape blade had the advantage of improving the qualified rate of straw spreading uniformity. The shell diversion spreading device mainly used the shell's shape to change the velocity and direction of straw spreading. Zheng et al. designed baffle plates placed in the back of the shell, which were used to adjust the amount of straw spreading [37]. According to the position of the baffle, the size of the throwing opening can be altered, thus altering the amount and speed of straw spreading.

Table 5. Common types of spreaders.

Core Device	Common Form	Schematic	Features
Spreader	Disc diversion [34]		High spreading quality; real-time adjustment.
	Active Pipeline [35]		Long spreading distance; real-time adjustment.
	Passive Tailboard diversion [22]		Low fuel consumption; adjustable throwing width.
	Shell diversion [23]		Low fuel consumption; adjustable throwing amount.

2.2. Rotary Tiller

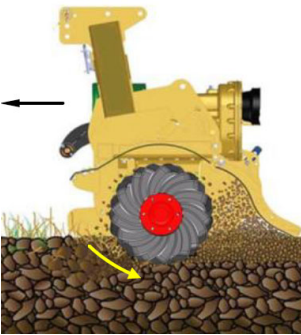
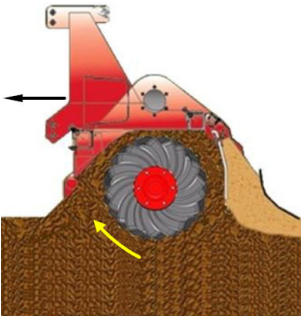
The rotary tiller is the dominant machinery used to mix the mulch (crop straw/residue or crops) with soil. In some areas, where there is a short planting time and a large amount of mulch, spreading mulch on the soil did not allow it to rot and decompose quickly enough. Therefore, mulch was often mixed with soil to improve the decomposition rate and prevent planting blockage. During the rotary tillage operation, the blade was

driven by the shaft, chopping the mulch while mixing it with soil. The working depth of the rotary tiller is normally below 10 cm.

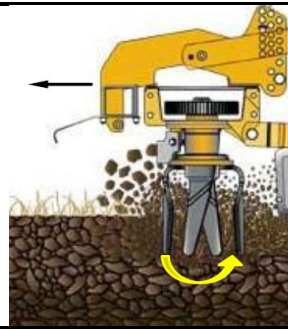
As shown in Table 6, according to the working type of the rotary tillage, the common rotary tiller can be divided into three categories: downcutting horizontal rotary tiller, upcutting horizontal rotary tiller, and vertical rotary tiller. The main components of the three categories of rotary tillers are the blade, shaft, and frame. The rotation direction of the horizontal rotary tiller in downcutting is the same as that of the tractor wheels. During the chopping process, the blades are driven by the shaft, chopping the mulch and soil at a high rotation speed. The shaft will provide a forward force during rotation, driving the machine forward. Therefore, this type of rotary tiller could reduce fuel consumption.

The effect of reducing fuel consumption and improving working quality can be achieved by changing the operating speed direction of the rotary tiller and the shape of the blade. Matin et al. designed a rotary tiller and compared various types of blade working effects [38]. They found that there was no difference in soil infiltration rate among the three types of blades, but the soil disturbance and torque of the straight blade were superior. The rotation direction of the horizontal rotary tiller in upcutting is opposite to that of the tractor wheels. This means that it could provide greater soil disturbance due to the opposite direction of rotation. In addition, the shaft provides a backward force during rotation, which will drive the machine backward. Therefore, this type of rotary tiller will consume more fuel. Sun et al. created a multi-segment composite design for the arrangement of the rotary tiller on the shaft and divided it into segment I and segment II along the axial direction [39]. The optimized rotary tiller can improve the effect of soil chopping. The vertical rotary tiller blade is perpendicular to the ground to mix the mulch and soil. This type of rotary tiller has the advantages of strong soil crushing ability and no disturbance of the soil layer after plowing, but it also exhibits disadvantages, such as poor mulch burial rate and high energy consumption [40].

Table 6. Common types of rotary tillers.

Core Device	Common Form	Schematic	Features
Rotary tiller	Horizontal rotary tiller in downcutting [41]		Low fuel consumption; wide range of application.
	Horizontal rotary tiller in upcutting [41]		High chopping quality; high fuel consumption; suitable for hard soil.

Vertical rotary tiller [41]



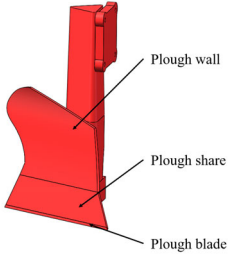
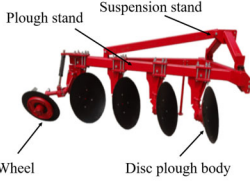
Strong soil crushing ability;
high work quality.

2.3. Plow

The plow is mainly used to bury the mulch (crop straw/residue or crops) in the soil. In some areas of China (Northeast region), the average annual temperature is low, with strong winds during the autumn and winter seasons. If the mulch is simply spread on the ground, it is easily blown away by the wind and is not easily decomposed. Therefore, the best way to solve this problem is to bury the mulch in the soil using a plow. The working depth of the plow is normally 10 cm to 20 cm.

As shown in Table 7, according to the working depth of the plow, the common plow can be divided into two categories: the moldboard plow and disc plow. The moldboard plow has a greater working depth than the disc plow, typically 20 cm, while the disc plow is usually 10 cm deep. The main components of the moldboard plow are the plow body, plow frame, traction device, and hitch device. As the core part of the moldboard plow, the plow body mainly includes a plow blade, plowshare, and plow wall. In the process of plowing, the mulch and soil are chopped by the plow blade and then tumbled up along the plowshare and plow wall. Eventually, the mulch is pressed into the soil. According to the operating speed, the plow can be divided into a high-speed (8–12 km/h) plow and a low-speed (5–7 km/h) plow [42]. According to the different attachment methods, the plow can be divided into traction type, suspension type, and semi-suspension type. Sun et al. developed a duplex straw crushing, spreading, and plowing machine. Through the analysis of the vertical and horizontal forces of the machine and the strength check of ANSYS, the working intensity and operational stability of the whole machine is guaranteed. Simultaneously, the field test showed that the vegetation coverage rate of the duplex operation was 95.7%, which is superior to the requirements of $\geq 80\%$ according to the national standards of China GB/T 14225–2008 [43]. The main components of the disc plow are the disc plow body, wheel, plow stand, and suspension stand. The disc plow body is the core part of the disc plow. There is an angle (generally $10^\circ\text{--}30^\circ$) between the disc plow body rotation plane and the advancing direction (Figure 2a). The special installation angle can play the role of chopping the mulch and enhancing the ability to bury the mulch into the soil. According to the different disc installation forms, the disc plow can be divided into two types: ordinary type and vertical type. Specifically, there is an angle (generally $30^\circ\text{--}45^\circ$) between the disc plow body rotation plane and the ground plumb line in the ordinary type of disc plow (Figure 2b), while the disc plow body rotation plane in the vertical type of disc plow is perpendicular to the ground (meaning that the angle between the disc plow body rotation plane and the ground plumb line is 90°) (Figure 2c). The different driving forms of the disc plow can be divided into the non-driven type and driven type. Liu et al. designed an asymmetrical type of driven disc plow and determined its main structure and technical parameters [44]. The field experiment results showed that the tillage stability coefficients were more than 90%.

Table 7. Common types of plow.

Core Device	Common Form	Schematic	Features
Plow	Moldboard plow		Working depth: 12–20 cm; high fuel consumption.
	Disc plow [45]		Working depth: 8–12 cm; high working speed.

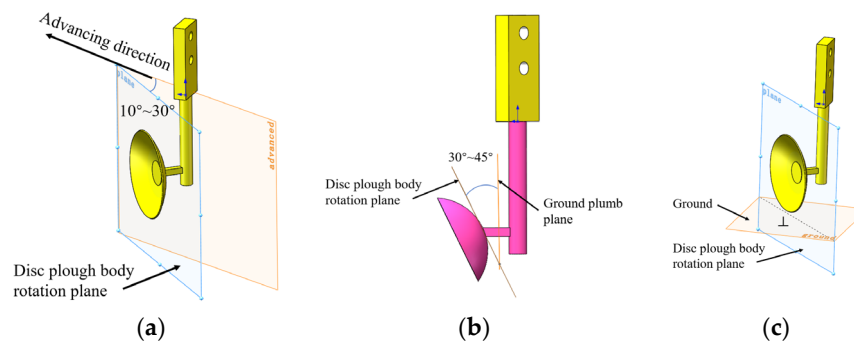


Figure 2. Installation angle of disc plow. (a) Disc plow installation angle; (b) ordinary type of disc plow; (c) vertical type of disc plow.









3. Key Parts of Soil Organic Cover Machinery

The key parts of the soil organic cover machinery are the blades, discs, and moldboards. The quality of these key parts determines the working effect of the machines. Many researchers focused on the design and optimization of the key parts to improve working efficiency and decrease fuel consumption. Therefore, there are many different types of blades, discs, and moldboards. This section introduces the common forms and summarizes their features. The blades are mainly used on straw choppers and spreaders, as well as rotary tillers. The discs and moldboards are mainly used on the plow.

3.1. Blades

The blades and their design have an important effect on working quality, fuel consumption, and extension of the service life. The common commercial blade types are the straight blade, bent blade, and hammer blade. Within the development of the bent blades, there are E-type blades, L-type blades, T-type blades, Y-type blades, and V-L-type blades. The features of these blades are discussed in Table 8.

Table 8. Features of different types of blades.

Type	Schematic	Description	Advantages	Disadvantages	Applicable Machine
Straight [46]		Suitable for soft mulch such as wheat straw, rice straw, and most crops.	Good chopping quality; low fuel consumption.	Easily damaged.	Straw choppers and spreaders
Bent [47]		Suitable for hard mulch and soil chopping.	Good mixing quality.	Easily blocked; high fuel consumption.	Rotary tillers
E [48]		Suitable for hard mulch, such as banana straw.	Good chopping quality; high working efficiency.	Complex structure.	Straw choppers and spreaders
L [49]		Suitable for most mulch and soil chopping.	Good mixing quality; low fuel consumption.	Easily damaged.	Rotary tillers
T [50]		Multi-directional chopping; suitable for soft straw.	Low fuel consumption; simple structure.	Difficult to manufacture.	Rotary tillers
Y [51]		Suitable for hard crop straw (maize, sorghum); similar to Y type blade; barycenter locates on the symmetric line of the blade.	Good symmetry of the shape; large moment of inertia.	Short edge line; a large mass.	Straw choppers and spreaders
V-L [52]		Suitable for maize; a V-bending section is added on L-shaped blade; barycenter located in the same plane with blade handle.	Long operation life; good chopping quality; high work efficiency.	Complex shape; high machining requirements.	Straw choppers and spreaders
Hammer [53]		Suitable for hard crop straw (maize, cotton); usually made of high strength and wear-resistant cast steel.	Good chopping quality; long operating life.	High fuel consumption.	Straw choppers and spreaders

A disc-type of blade was designed by Liu et al., and they found that the fuel consumption was 1150.43 W, which is lower than the typical machine's fuel consumption [30]. Therefore, this novel type of blade could reduce fuel consumption. The maximum chopping force was decreased when the oblique angle of the blade was increased [24]. The different slide-cutting angles of the blade were compared by Liu et al. The maximum peak braking force of the rind and stalk, and the maximum energy transmission efficiency values were obtained under slide-cutting angles of the disc blade tip of 60° [54]. The chopping pass rate could be increased if the shape of the blade was optimized. Jia et al. designed a novel type of blade called the V-L blade, which could improve chopping quality [55]. The only slide-cutting edge blade was designed by Zhao et al., and the different types of blade curves were compared by field experiments. They found that the best overall performance

of the blade curve is obtained from the Archimedes spiral type curve [56]. The different slide-cutting angles of the edge-curve tip were selected by Zhao et al., and they found that the larger the slide-cutting angle, the earlier the soil cutting began and the peak value appeared [57]. Therefore, they suggested that a larger slide-cutting angle is preferred when less soil disturbance is desired.

3.2. Discs

The shape of the disc plow body determines the bury quality of the plow. To improve working quality and efficiency, and reduce fuel consumption, various types of disc plow bodies were designed and developed. The common commercial discs are notched concave discs, wave concave discs, and ordinary concave discs. The comparisons among these discs are shown in Table 9.

Table 9. Features of different types of discs.

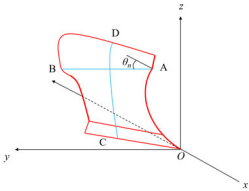
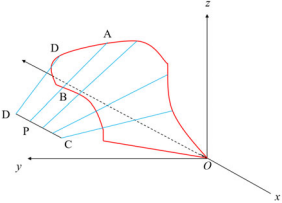
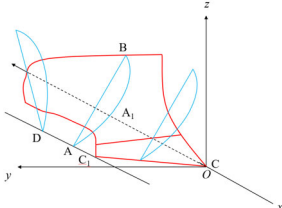
Type	Description	Features	Applicable Machine
Notched concave disc [58]	Suitable for soil and mulch with high moisture content; notches around the disc.	Good buried quality; provide greater force.	High-speed plow
Wave concave disc [59]	Suitable for soil and mulch with low moisture content.	Difficulty in manufacturing.	Low-speed plow
Ordinary concave disc [60]	Strong adaptability	Most commonly used discs; low manufacturing cost.	High or low-speed plow

Li et al. designed a notched disc based on the serrated structure of the mantis fore-foot. The results showed that the chopping resistance of the serrated notch disc is reduced by 1.26%, and the chopping resistance of the mulch is reduced by 4.2% [58]. Wan et al. developed a wave disc and analyzed the motion trajectories under the different values of disc and tractor velocities [59]. Wei et al. optimized the wave disc and found that when the length of the wave was 65 mm, the diameter of the wave was 400 mm, and the number of wave discs was 16, the required counterweight could be reduced by 36.86% and the required traction force could be reduced by 32.86% [61]. An independent drive disc plow was designed by Liu et al., and the key parameters of the disc plow body were determined in order to meet the farmer's requirements [60].

3.3. Moldboards

As for deep burying for the mulch, the shape of the moldboard plow body determined the bury quality. A good plow body is conducive to the tumbling movement of the soil, which could reduce the machine's fuel consumption. The plow body surface is an important indicator for evaluating the quality of the plow body. The common methods used to design the plow body surface are: horizontal straight generatrix, tilt straight generatrix, and twist generatrix [61]. The comparisons among these methods are discussed in Table 10.

Table 10. Features of different types of moldboards.

Type	Scheme	Description	Features
Horizontal straight generatrix [62]		AB: horizontal straight generatrix; CD: directrix; θ_n : straight generatrix angle. The surface is formed by the rotation of AB along CD.	Simple, convenient, and practical; good chopping quality.
Tilt straight generatrix [63]		AB: tilt straight generatrix; CD: directrix.	Good tillage performance; low tillage resistance.
Twist generatrix [63]		AA ₁ B: twist generatrix; CC ₁ : directrix. The surface is formed by the rotation of AA ₁ B along CD.	Suitable for soil with high moisture content, such as a paddy field.

Liu, et al. designed a novel plow used for paddy fields based on the horizontal straight generatrix method [62]. The advantages of the plow are efficient trenching and water drainage. A new design model was developed by Yang et al., and they optimized the design using the 3D drawing software SolidWorks [64]. The optimized software was more concise and intuitive and could improve working efficiency. Ren et al. conducted an applied study on the variation law formula of the element line angle of the plow body surface formed by the horizontal straight generatrix method [65]. The plow body surface composed of an oblique helical surface and a single-leaf hyperboloid surface was introduced by Qian et al. The plow body surface was designed based on the tilt straight generatrix method after the main parameters of the plow body surface were determined [66]. Qian et al. proposed a mathematical model for forming the curved surface of the twisted-column plow body by using the curve as the horizontal straight generatrix method (twist generatrix) [67]. This curve uses an equiaxed hyperbola and an envelope parabola for the guide curve selection.

4. Advanced Computing Methods of Simulating and Predicting Machine Performance

It is not enough to design and optimize the structure of devices and key parts to improve the soil organic cover effect and decrease fuel consumption. Because soil organic cover technology is complicated, it is difficult to observe and judge the influencing factors regarding the effects of soil organic cover. Moreover, mulch is a flexible agricultural material. Therefore, researchers usually use advanced computer simulation technology to simulate the operation process to optimize the performance of the machine. The common simulation technologies used are finite element analysis (FEA), usually used for optimizing key components and evaluating energy consumption; the discrete element method (DEM), usually used for establishing the mulch model and simulating the deformation and failure process of mulch; and the mechanics analysis method (MAM), usually used for optimizing mechanical motion and evaluating the reliability of the machinery [68–70].

4.1. Finite Element Analysis

Currently, FEM is widely used in the agricultural field for high simulation efficiency and accurate simulation results. Qin et al. used FEM to predict mechanical damage and the changes in force and stress [71]. The FEM can be applied to identify the variations in the energy consumption during the soil organic cover process. Liu et al. evaluated the energy consumption and energy transmission efficiency under the various blade velocities and shapes during the maize straw chopping process via FEM [54]. To clarify the relationship between the blades and the energy consumption, and to reduce the computing time, they developed a simplified model (Figure 3). This model exhibits the following characteristics: the leaves (wrapped around the stem) and maize stalk stem sections are ignored, static and dynamic friction coefficients are constants, etc. The difference in the results between the simulation and the field experiment is less than 10%. In addition, the FEM can also be applied to optimize the key parts of the machine. Zhao et al. used FEM to optimize the key parts of a *Lycium barbarum* L. harvester [72]. Specifically, they obtained a better resonance frequency (2 Hz), which can provide the design basis for the harvester. Sun et al. used FEM to conduct static and dynamic analyses of key connecting components via ANSYS Workbench software (ANSYS company, Canonsburg, Pennsylvania, America) [73]. They evaluated the six modes' natural frequencies of the connecting parts (Figure 4). The first-order mode-shaped diagram to the sixth-order mode-shaped diagram showed that the frame worked smoothly under the high rotation speed of the shaft, meeting the work requirements.

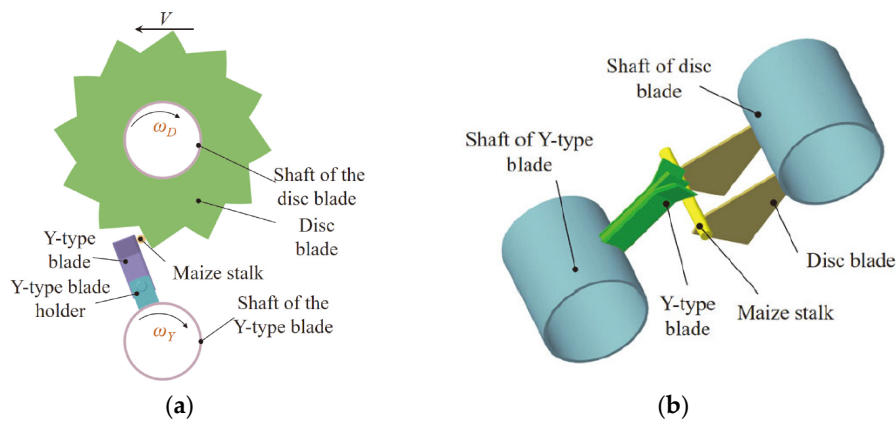


Figure 3. The model of FEA [54]. (a) The chopping device; (b) simplified structure of the model.

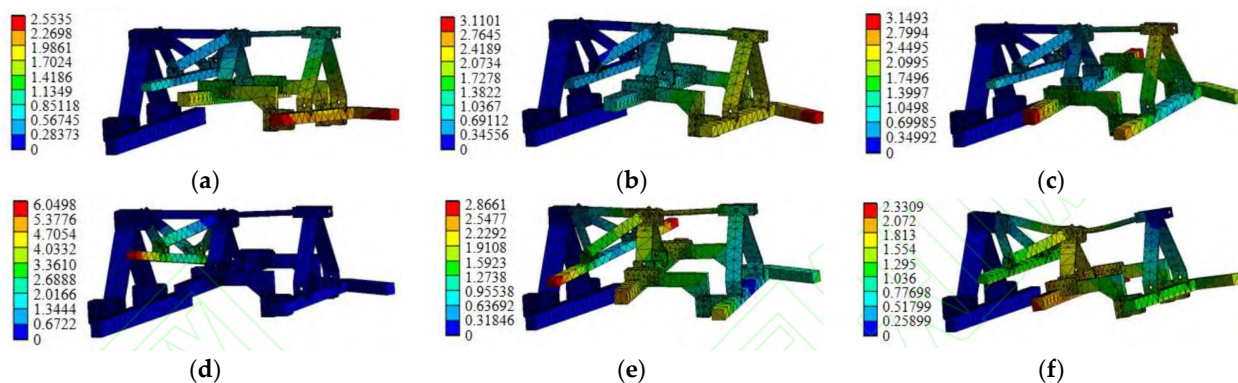


Figure 4. Connection parts 6 order mode shape diagram [73] (a) 1-order mode shape diagram; (b) 2-order mode shape diagram; (c) 3-order mode shape diagram; (d) 4-order mode shape diagram; (e) 5-order mode shape diagram; (f) 6-order mode shape diagram.

4.2. Discrete Element Method

In recent years, experimental, analytical, and numerical methods have become the common approaches to researching the interactions among soils, machines, and crops. Numerical methods have been proven superior to the other two methods, as they are less time-consuming and have a strong capability to investigate complex geometry. Therefore, researchers prefer to select the DEM to explore the interaction among soils, machines, and crops. Zhao et al. used DEM to evaluate the effect of different edge-curve types of blades on the soil chopping and throwing process using EDEM software (DEM-Solutions company, Edinburgh, Scotland, Britain) (Figure 5) [57]. Specifically, he established a model that can simulate the field working situation. By comparing the results of field experiments and simulation experiments, the relative error is 2.5%, indicating that the DEM is a helpful tool. Li et al. developed a numerical model by using DEM to simulate the interaction between bear claws and soil [74]. Then, they designed a subsoiling tool, which could minimize power requirements and optimize soil conditions for crop growth. Fang et al. found the regular pattern of soil particle displacement by researching the effects of soil, straw movement, and blade resistance on soil–blade interactions using DEM [75]. The effects of surcharge accumulation between blades and soil interaction during tillage operation on terrestrial and planetary conditions were clarified by Krzysztof Skonieczny [76]. Liu et al. established an EDEM model to analyze the effect of rotation velocity on chopping force and energy consumption [77]. The difference between field test and simulation results was less than 10%, which proved the accuracy of DEM.

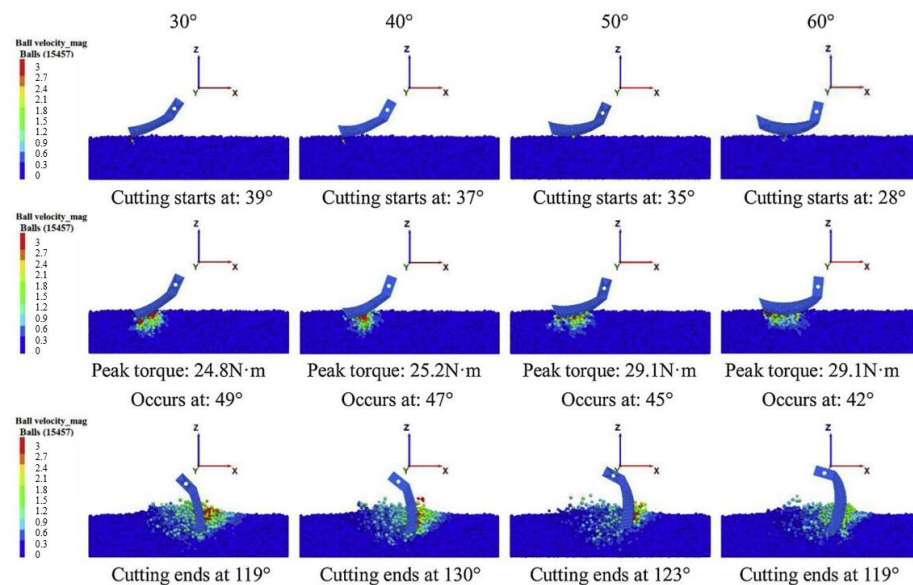


Figure 5. Variation in torque and blade position of the Archimedean spiral blade [57].

4.3. Mechanics Analysis Method

Mechanics analysis, which is mainly used to evaluate mechanical properties, plays a significant role in mechanical design. The velocity and acceleration are often tested to evaluate the force of the key components, while the frequency is tested to evaluate the stability of the machine. Zhong et al. developed the rotary cultivator-soil model based on the smoothed-particle hydrodynamics method, simulated by ANSYS/LS-DYNA software (ANSYS company, Canonsburg, Pennsylvania, America). The effect of the blade speed, the machine's forward speed, and the working depth on torque was analyzed. The results showed that the error between simulation and theoretical calculation is 8.98% [78]. Lin et

al. optimized the reciprocating intermittent chopping device using ADAMS software (MSC. Software company, Los Angeles, California, America.) via the mechanical analysis method [32]. Zhang, et al. established a CFD-DEM (computational fluid dynamics–discrete element method) coupling model of straw particle swarm motion to analyze the variation of force (Figure 6) [79]. There were three types of forces exerted on the straw: straw to straw, frame to straw, and air to straw. The results showed that the forces between straw and straw, and frame and straw were much larger than that that between straw and air. Wang et al. used the kinematic analysis method via Pro/E software (PTC company, Los Angeles, Massachusetts, Boston, America.) to evaluate the performance of the four-link mechanism, and obtained the best value of the key parameters [24].

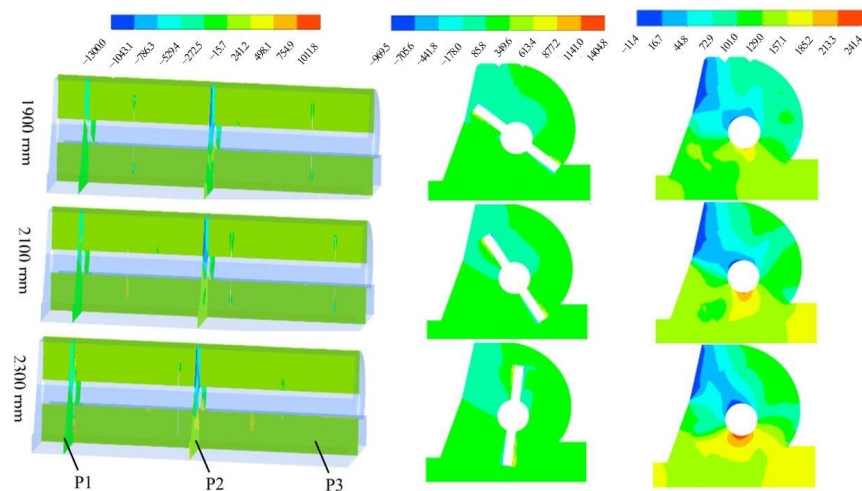


Figure 6. The pressure of the chopping chamber section under different rotating velocities of the chopping blade shaft ($t = 2$ s) [79].

5. Discussion and Future Work

Numerous studies have proved the potential benefits of soil organic mulch for sustainable agricultural development. Moreover, there is a significant amount of research on the relevant technologies and machines. Zhang et al. reviewed the development of crop residue management machinery and suggested future directions [80]. The blade design, blade arrangement, and power consumption were summarized. However, the machinery for handling live mulch (crops) was not addressed [80]. Wang et al. reviewed the development of straw chopping devices and methods [81]. The main technical modes and characteristics of straw chopping and spreading were summarized; however, the summary of related technical modes and the machines' applicable scopes were not comprehensive. Liu, et al. generalized the primary application of the discrete element method (DEM) for crop straw. Nevertheless, a single method does not fully solve the problem [82]. Therefore, this paper reviewed the development of soil organic cover (including crop residue and live mulch) machinery, summarized the suitable machines for crops (maize, wheat, rice, cotton, etc.) and green manure (*Vicia villosa*, *Vicia sativa*, *Brassica campestris*, etc.), and comprehensively reviewed the advanced computing methods. Nevertheless, there are still some aspects that need further research, such as the effects on agricultural production and the environment, the selection of technical patterns, and the performance of the machines.

5.1. The Effects of Soil Organic Cover Should Be Further Clarified

The field tests of soil organic cover technology have been widely conducted to explore the potential advantages of soil organic mulch for soil and crops in China. For instance, in the Loess region of China, Zhang et al. monitored the impacts of soil organic cover (straw) on erosion and showed that annual loss rates were reduced, while Li et al.

demonstrated that wind erosion from plots using soil organic cover (straw) was about half that from plots using no mulch [83,84]. High levels of surface residue also reduce runoff and water erosion by >90%, thereby reducing sediment and sediment-bound chemicals, which will, in turn, enhance and protect water quality and biotic communities that depend on clean water, particularly in slope farming areas. However, many studies were based on short-term experiments or focused on single or two effective factors. The long-term effects of soil organic cover on crop yield, soil organic matter, soil carbon sequestration, and population structure of soil biodiversity in different regions, different environments, and different cropping systems are still not clear. There remains a lack of studies regarding the integrated effects of soil organic cover on crop yield and environmental ecology. Therefore, the effects of multiple factors need to be further studied in soil organic cover fields.

5.2. The Selection of Technical Patterns Should Be More Suitable

The adoption of soil organic cover in suitable conditions can increase crop yield, alleviate soil-related constraints, and slightly decrease greenhouse gas emissions. A two-year field experiment was conducted in a paddy field in northeast China by Sun et al. [23]. They found that returning treatment 3 (straw returning, autumn rotation burial, and spring leveling) showed better performance, which meant that it could achieve better surface flatness, slurry degree, and vegetation coverage. In the North China Plain, four treatments were investigated by Zhao et al., including straw mixture (SM), half straw mixture (HSM), straw cover (SC), and a controlled check with no straw returning (CK) [85]. The results showed that the SC treatment showed significant advantages in improving soil structure and increasing crop yields. China has developed and formed several technical patterns for soil organic cover that are suitable for different agricultural regions. However, because of the dynamic climate and environmental conditions, soil types, cropping systems, machinery levels, and economic development levels in the regions, one or two soil organic cover technical patterns cannot meet the various needs. It is necessary to refine and improve technical patterns for regional soil organic cover and to establish norms and standards for soil organic cover operations based on further field experiments and demonstrations to guide the extension and adoption of soil organic cover.

5.3. The Performance of the Machines Should Be Further Improved

While clarifying the benefits of soil organic cover and selecting the appropriate soil organic cover patterns, it is also essential to improve the performance of the relevant machines. The methods of theoretical analysis, computer simulation, and field experiments could be applied to develop and optimize the machines' performance. Firstly, the theoretical analysis can help in understanding the chopping mechanism. The main key to soil organic cover technology is to analyze the interaction between the mulch, soil, and machine. It is necessary to explore the conditions of different mulches in different operating processes and clarify the movement laws and characteristics of the mulch during the process. Secondly, more efforts are needed to study the physical and mechanical properties of mulch by carrying out a large number of experiments to acquire simulation parameters. The theoretical design often has a certain deviation from the actual experiment. Only through simulation or actual experiments can the structural design be effectively carried out. Thirdly, it is significant to clarify the effect of the core parts of the machine before designing the machinery. The laboratory experiments could be conducted by using various sensors to measure essential data of core parts, including chopping force, power consumption, and mechanical vibration, which can provide significant guidance for developing soil organic cover machines. In addition, using advanced manufacturing technology and surface heat treatment to improve material processing accuracy and performance are also helpful in improving the machines' performance.

6. Conclusions

Soil organic cover has many potential advantages, including protecting the soil from erosion by water or wind, suppressing weed germination and growth, improving the recycling of nutrients, and improving organic matter accumulation and carbon sequestration. However, due to the poor effects of mechanized operation, its wide application in China is limited. This paper discussed the current soil organic cover technology and machinery. The main conclusions were:

- (a) Choosing different types of machinery according to different crops and planting patterns could improve working quality and efficacy.
- (b) Redesigning or optimizing the key parts of soil organic cover machinery could improve machinery performance and reduce fuel consumption. The machinery could be redesigned or optimized in regards to shape, working velocity, and installation location.
- (c) Selecting advanced computing methods could help us simulate and predict machine performance. In addition, choosing a proper computing method could tremendously reduce computing time.

The use of soil organic cover is a complex process. The use of soil organic cover technology is necessary for solving the agro-environmental issues (soil erosion, degradation, and greenhouse gas emission) involved. The most important issue is to increase the area of soil organic cover technology promotion and application. Prior to this, we should clarify the soil organic cover effect, select the suitable soil organic cover patterns, and develop the soil organic cover machinery to allow farmers to obtain real benefits.

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