AgriEngineering

MDPI

Review

Research Progress of Minimal Tillage Method and Machine in China

Dong He, Caiyun Lu *, Zhenwei Tong, Guangyuan Zhong and Xinchun Ma

College of Engineering, China Agricultural University, Beijing 100083, China; hedong@cau.edu.cn (D.H.); B20203070560@cau.edu.cn (Z.T.); zgyuan@cau.edu.cn (G.Z.); 2016307140304@cau.edu.cn (X.M.)
* Correspondence: lucaiyun@cau.edu.cn

Abstract: Minimal tillage methods mainly include subsoiling technology and topsoil tillage technology. Based on the analysis of domestic technical modes and application status of minimal tillage, this paper reviewed the working principle, technical characteristics and research status of subsoiling and topsoil tillage in two key parts. Current technical difficulties were analyzed and generalized, combined with the research progress and application requirements of minimal tillage in China, and future research emphasis and development direction were provided.

Keywords: minimal tillage; subsoiling; topsoil tillage

check for updates

Citation: He, D.; Lu, C.; Tong, Z.; Zhong, G.; Ma, X. Research Progress of Minimal Tillage Method and Machine in China. *AgriEngineering* **2021**, *3*, 633–647. https://doi.org/10.3390/agriengineering3030041

Academic Editor: Chris Cavalaris

Received: 30 June 2021
Accepted: 6 August 2021
Published: 23 August 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Minimal tillage is a tillage method that does not use a plow, reduces the tillage procedure to the necessary for crop production without destroying the soil structure at the proper time, and greatly reducing soil wind and water erosion [1], which mainly includes subsoiling and topsoil tillage and other tillage techniques. China's farmland is facing severe problems of soil compaction and soil and water erosion. The processes of farmland ecosystem are affected by climate change under the mediating effect of soil conditions [2]. As an essential form of conservation tillage, minimal tillage has been highly valued and widely applied.

The technical requirements of subsoiling operation are to break the plow pan layer and obtain good disturbance of the soil. On the other hand, the technical requirements of topsoil cultivation are soil loosening and surface leveling. The upward movement of the plow pan layer was caused by continuous topsoil cultivation [3]. Domestic studies show that a subsoiling operation should be carried out after 2–3 years of topsoil cultivation [4,5]. Currently, the domestic research on the minimal tillage methods includes the research on resistance reduction and abrasion resistance performance of subsoiling shovel, the research on application benefits of tillage technology and the supporting tillage technology system.

Based on the analysis of domestic adaption of minimum tillage, this paper introduced the technology mode and effect of cultivation, expounded the research advances and problems in the subsoiling and topsoil tillage machines; finally, the development trend of minimal tillage in China has prospected, to form the matching technology system of minimum tillage in northern and southern regions, further application and promotion of minimal tillage in China.

2. General Situation of Minimal Tillage

2.1. Technical Mode of Less Tillage

Minimal tillage is mainly based on the principle of reducing soil tillage. A set of a farming system suitable for local conditions is formulated according to the combination of agricultural machinery and agronomy technology in different regions. At present, the research on minimal tillage mainly focuses on subsoiling and topsoil tillage in China.

The implementation of rural land circulation policy, subsoiling subsidy policy and agricultural machinery purchase subsidy policy, and the increase of large and medium-sized tractors, causing severe soil compaction problems by tractor tires and machinery and hindering the sustainable development of agriculture [6,7]. In order to restore the soil bulk density compacted by machine and naturally compacted, break the plow pan layer, ensure proper drainage, improve the soil water retention rate and meet the needs of crop growth, China began to study the technology of subsoiling in the 1960s [8]. Under the condition of straw mulch and uneven land surface, it is challenging to solve low seeding quality only by improving machinery, but topsoil tillage can better solve this problem. Typical technology patterns of minimal tillage are shown in Table 1.

Table 1. Typical technology model of minimal tillage.

Technical Modes	Characteristics	Advantages	Disadvantages
Subsoiling	Subsoiling refers to a tillage method that uses a matching subsoiler to break the plow pan layer and improve the soil structure of the plough layer without disturbing the original soil structure. It is regarded as an important part of the minimal method [9].	Subsoiling can break the hard bottom plough layer, loosen the soil, deepen the ploughing layer, improve the water permeability and air permeability of the soil and the soil aggregate structure [10], increase the soil water storage, promote the growth of crop roots and increase crop yield [11].	Subsoiling depth is significant, working resistance is considerable, increase in surface unevenness after operation [12], subsoiler is easy to wear, the bottom of subsoiling shovel tip will form the hard base [13]; subsoiling shovel processing is complex and high cost.
Topsoil tillage	As an important form of minimal tillage [14], topsoil tillage refers to the operation of the surface soil within 10 cm below the surface from harvest to planting before, which reduces the depth of soil tillage. It is also a key technology of conservation tillage.	Topsoil tillage can loosen the surface soil, reduce the surface straw coverage rate, level the surface, improve seeding quality, improve soil temperature [15], control weeds, diseases and insects [16,17], reduce soil water and wind erosion [18,19] and reduce operating costs.	Disturbance to the topsoil is significant, destroying the soil aggregate structure [6] and reducing the soil's load-bearing capacity; successive years of topsoil tillage will cause the plow pan layer to move up [20].

The application of minimal tillage methods has been gradually attracted attention which it improved the soil's physical and chemical properties and improved crop yields in China. The model of appropriate technology has been formed in different regions for different ecological environments and crop species. In addition, the typical tillage treatments and the effect of each area in China are shown in Table 2.

In recent years, the research on minimal tillage methods and their matching technology has increased by domestic research institutions, each region matching technology model has been gradually established. Summarize the development trend of minimal tillage methods in recent years in China: (1) Pay attention to the role of subsoiling to break the plow pan layer and topsoil tillage to level the surface and control weeds. (2) Pay attention to the remarkable effect of combining deep pine and topsoil tillage with building a reasonable arable layer. (3) The application scope gradually increases.

2.2. Application Status of Minimal Tillage

The subsoiler is the tool to realize the subsoiling operation, and the rotary tiller is the representative machine for surface soil cultivation.

According to the statistics of the Department of Agricultural Mechanization Management of the Ministry of Agriculture and Rural Affairs, China has organized and completed the subsoiling and land preparation of agricultural machinery 155 million mu, and the quantity of subsoiler is increasing year by year, indicating that China's attention to the subsoiling and land preparation is gradually increasing. The area of subsoiling reached the highest level in 2015 and maintained a relatively stable trend in other years (as shown in Figure 1), which may be because subsoiling occurs every two to three years in China.

Table 2. Typical tillage treatments and the effect of each area in China.

Areas	Crop Species	Treatments	The Changes of Soil Physicochemical Properties and Crop Yields
Loess Plateau Dry Crop Zone [21]	Wheat	Deep plough; Subsoiling; No-tillage	Compared with no-tillage, deep plow and subsoiling could decrease soil bulk density by 1.61% and 1.61%, increase soil porosity by 1.41% and 1.41%; The proportion of ≥0.25 mm soil particle size increased by 1.97%, 1.64%, the rainfall utilization efficiency increased significantly by 5.07% and 7.70%, the wheat yield increased considerably by 5.06–7.08%.
Latosol in Hainan Province [22]	Banana	Bulk subsoiling + rotary tillage; Direct seeding; chisel-type subsoiling + rotary tillage; rotary tillage +Compaction	Except for direct seeding, the firmness of 0~30 cm soil was significantly reduced. The "chisel-type subsoiling + rotary tillage" treatment was more effective than the "bulk subsoiling + rotary tillage" treatment in reducing the bulk density of the deep layer (30–45 cm), And the water content of each soil layer is higher than other treatment groups.
Saline alkali soil in northeast China [23]	Maize	Spring subsoiling 30 cm; Spring subsoiling 40 cm; Autumn subsoiling 30 cm; Autumn subsoiling 40 cm; Ridge tillage	The subsoiling treatment can increase the soil moisture content of the arable layer and reduce the soil bulk density. The effect of autumn subsoiling was better than that of spring subsoiling. Compared with conventional ridge planting, the yields of autumn subsoiling 40 cm, autumn subsoiling 30 cm, spring subsoiling 40 cm and spring subsoiling 30 cm increased by 13.72%, 10.50%, 4.72% and 1.53%.
Dry farmland in northern China [24]	Spring maize	Bulk subsoiling + rotary till-age; Chisel-type subsoiling + rotary tillage; No-tillage; Traditional rotary tillage	In 2015 (drought), "chisel-type subsoiling + rotary tillage" and "no-tillage seeding" increased yields by 34.86% and 33.64% compared with "traditional rotary tillage", and in 2016 (abundant water) In 2016, "chisel-type subsoiling + rotary tillage" and "bulk subsoiling + rotary tillage" increased yields by 29.81% and 18.19% compared with "traditional rotary tillage".
Loess Plateau [25]	Spring maize	no-tillage (NT)/conventional tillage (CT)/subsoiling tillage (ST); subsoiling tillage (NT)/conventional tillage (CT); Continuous subsoiling (ST)	In 0–20 cm soil layer, soil bulk density in NT/CT/ST and ST/CT decreased by 7.0% and 11.5%, and soil porosity increased by 8.4% and 13.9%, respectively. In 20–40 cm soil layer, soil bulk density in ST/CT increased by 6.9%, and soil porosity decreased by 5.7%. The multi-year average of maize yield in NT/CT/ST treatment was 4.8% and 10.2% higher than that in NT/CT and ST.
Northern China [26]	Maize/wheat	subsoiling and rotary tillage;subsoiling and no tillage; rotary tillage	Compared with rotary tillage and no-tillage, subsoiling and rotary tillage and subsoiling and no-tillage significantly increased the yield of maize and wheat by 8.62% and 10.17%.
Drip irrigation in south Xinjiang [27]	Cotton	Subsoiling 30 cm (TD1); Subsoiling 40 cm (TD2); Subsoiling 50 cm (TD3); Non-subsoil (CK)	The subsoiling reduced the bulk density of soil; Compared with CK, TD1, TD2 and TD3, the bulk density of 20–30 cm soil was reduced by 1.0%, 1.9% and 3.3%; the yield was 7.0%, 15.5% and 13.0%, respectively.

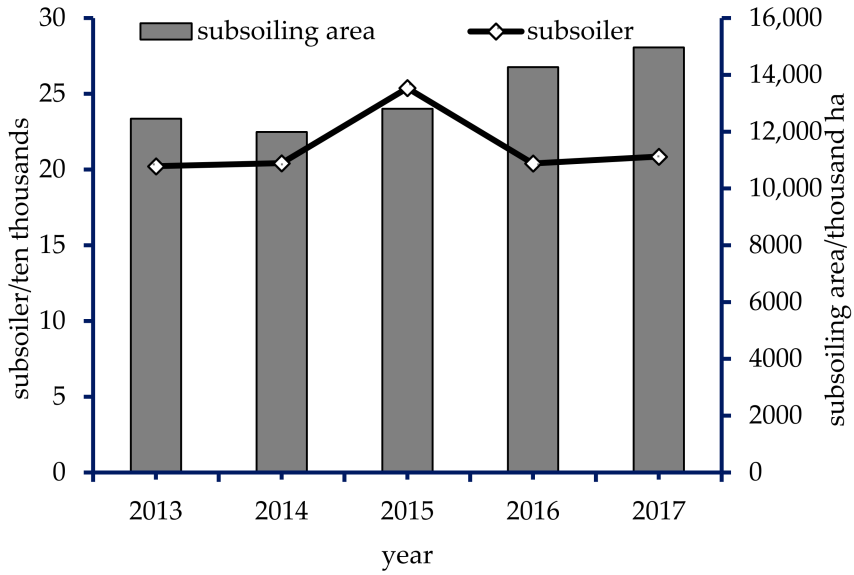


Figure 1. Diagrams of changes of subsoiler ownership and subsoiling area from 2013 to 2017. (Interpretation of national agricultural mechanization statistics annual report in 2013–2017).

As shown in Figure 2, the ownership scale for small tractors (≤14.7 kW) in China decrease constantly, while the ownership scale for large and medium-sized tractors (≥ 14.7 kW) increases year by year, the elimination of small tractors is accelerated and the rapid growth of large and medium-sized tractors shows the trend of large scale gradually. The number of rotary tillers is increasing year by year. In the next few years, the rotary tiller will still be a representative machine for topsoil tillage.

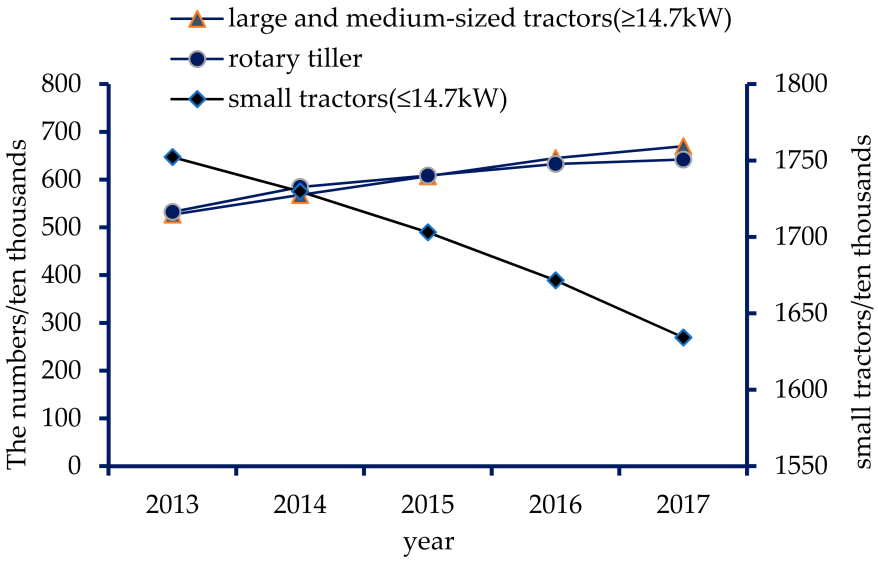


Figure 2. Diagrams of changes in the ownership of small, large and medium-sized tractors and rotary tillers (Interpretation of national agricultural mechanization statistics annual report in 2013–2017).

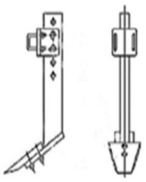
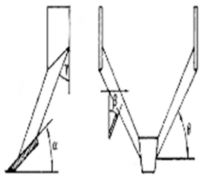
3. Current Status of Key Techniques and Tools for Minimal Tillage

3.1. Research Progress of Subsoiler

To obtain relatively appropriate soil disturbance with relatively small energy consumption demand is an ideal effect to be achieved by subsoiling [28]. The subsoiling shovel is the crucial working part of the subsoiler, deeper into the soil and has high working resistance. The subsoiling operation is based on breaking the plow pan layer, and the operation principle is deep-shovel tip entry at the front end and subsoiling shovel handle

breaking at the rear end [29]. the subsoiler will be divided into chisel-type subsoiler and bulk subsoiler according to the structure and operation principle. At present, the commonly used subsoiler structure is shown in Table 3.

Table 3. The operating principles and characteristics of several typical subsoiling shovel.

Subsoiler Types	Pictures	Principles	Characteristics
Column subsoiler [29]		The subsoiler shanks is vertical column, the installation longitudinal distance is shortened, the subsoiler tine shape is hinged and the replacement is convenient after wear.	Advantages: small partial traction, simple structure, low manufacturing cost. Disadvantages: the depth of cultivation is small, in the depth of the subsoiler tine shape and shank will produce strong compression on both sides of the soil, increasing soil compaction.
Adjustable wing subsoiler [30–32]		By adding adjustable wing plates, the disturbance range of soil can be increased and the conversion between interval subsoiling and all-directional subsoiling can be realized.	Advantages: it increases the width of subsoiling operation, enlarges the area of loosening soil and improves the efficiency of subsoiling. By adjusting the height of the wing plate, the loosening of the bottom or top soil can be achieved. Disadvantages: increased work energy consumption.
Vibration subsoiler [33]		The effect of drag reduction is realized by increasing the excitation source to make the tillage machine vibrate.	Advantages: Significantly reduced traction resistance. Disadvantages: complex structure; Vibration can cause damage to the tractor driver and equipment.
"V" type Subsoiler [34–38]		By the base blade and 2 symmetrical side blades; cut the soil horizontally through the bottom of the left and right blades, and the base blade forms a longitudinal mole at the bottom.	Advantages: small tillage resistance, less oil consumption; loose soil range is large, but can maintain a complete vegetation coverage, avoid moisture; in the bottom of the formation of rainwater storage moles. Disadvantages: large power consumption, easy to block in areas with large amount of straw cover.
Side bending subsoiler [38]		The side bending subsoiler shank cuts the soil, and the shovel tip forms a mole at the bottom of the loose soil layer to increase the rainwater infiltration.	Advantages: The loose soil width is larger by comparing with column deep loose shovel. Disadvantages: a single shank has a large lateral force, need to be installed in pairs.

The energy consumption of deep loosening is usually 3–5 times that of planting or harvesting [39], and reducing tillage resistance during subsoiling is the primary measure to reduce energy consumption. Currently, the domestic research on subsoiling drag reduction includes changing the structural parameters of subsoiler, vibration drag reduction, bionic drag reduction and layered subsoiling drag reduction etc., and has achieved good results.

In terms of drag reduction by changing structural parameters, Zheng et al. [40] designed a polyline soil-breaking blade subsoiler, and Zhao et al. [41] designed a fitting curve subsoiler, in which the soil disturbance and tillage resistance has been reduced effectively. In subsoiling operation, with the increase of tillage depth, the tillage resistance has been increased gradually and the subsoiler shanks are prone to deformation or fracture. Chen et al. [42] designed an extroverted arc subsoiler; the results show that the resistance was the least when the sweep angle is 50°. The shape of the subsoiling ditch has been improved by changing the structural parameters of the subsoiler. Gao et al. [4] found that the wing plate installed at a higher position (about 10 cm away from the surface) can effectively improve the surface hardness of soil and create conditions for subsequent seeding by experiments. Wang et al. [43] found that the disturbance area of the hardpan layer first increased and then decreased by the mounting height of the subsoiler's wing and reached the maximum when the mounting height was 75 mm.

In order to obtain good soil disturbance and reduce the working resistance of the subsoiler, the research of vibration drag reduction is becoming the focal point in China. The vibration subsoiler can reduce drag, save energy and improve working quality by adding an exciting vibration source. The vibration subsoiler can be divided into two types based on exciting vibration source: self-excited vibration subsoiler and the forced vibration subsoiler [44]. The self-excited vibration subsoiler generally adopts elastic components, which vibration was changed according to soil mechanical properties. The impact caused by self-excited vibration mode has little effect on soil compaction, which protects the subsoiler and other components. Currently, the commonly used elastic components are compression spring, plate spring and hydraulic pressure. According to the existing problems of the self-excited vibration subsoiler, such as adaptability weak, relatively high working resistance and easily failed during operation. Cui et al. [45] designed a device with adjustable spring Pre-tightening force to enhance the adaptability of the subsoiler by changing the pre-tightening force of spring. Zhou et al. [46] designed a sliding cutting self-excited vibration subsoiling device based on two principles of sliding cutting and self-excited vibration, and the function of double drag reduction was realized. Wang et al. [47] provided a new method characterized by a hydraulic self-excited source, designed a hydraulic self-excited vibration subsoiler source, and improved the subsoiler's adaptability in different soil textures. The forced vibration subsoiler is driven by a tractor's output shaft to realize the vibration of the subsoiler.

At present, the vibration mechanism commonly used in China is the crank-rocker mechanism, CAM, hydraulic vibrator, gear transmission, etc. Aiming at solving the problems, such as given the vibration parts of mechanically forced vibration subsoiler, such problems as complex transmission, poor stability of self-excited vibration subsoiler and not noticeable drag reduction effect, Li et al. [48] designed a hydraulic forced vibration subsoiling unit, which has pronounced drag reduction effect. The above research is mainly based on the design of a chisel-shaped subsoiler. Wei et al. [49] studied the mechanism of winged subsoiler vibrational subsoiling, showing that the traction resistance of winged subsoiler can be reduced by 3.2–27.2% because of vibration. To study the water retention curves of different soil types by vibration-tillage of subsoils, Teng et al. [50] investigated five different soils in Heilongjiang Province, such as black soil and chernozem soil, paddy soil, soda-saline soil and sandy soil. The conclusion was found that the adequate water supply capacity of the soil was significantly improved by vibration subsoiling. Oscillation could reduce the drag resistance, but it also caused unavoidable damage to the tractor and the driver of the tractor, which will restrict its application. Sun et al. [51] analyzed the self-balancing performance of multiple sets of vibration subsoiling shovels, and the

vibration reduction ratio was more than 90%, which realized the self-balancing of the vibrating deep loosening machine during operation. The specific resistance of vibratory shovels in clayey soil is far less than that of rigid shovels, while the specific resistance of two shovels in loam soil is similar. How to carry out deep loosening of vibratory shovels in southern soil with high cohesive soil is an important research direction in the future.

In recent years, more attention has been paid to the application of bionics in agriculture. Zhang et al. [52] designed the multiplex-modality subsoiler based on the combination of claw and toe contour of soil animals and inclined straight line, analyzed its operational performance by using finite element analysis method, and the operating resistance of it was tested in a soil bin, which proved its feasibility. Zhang et al. [53] designed a bionic drag-reducing subsoiling shovel based on the claw toe of Mus musculus, which reduced traction resistance by 8.5–39.5%. However, the processing difficulty and cost of the bionic subsoiler will significantly increase, which the application in practical operations will be restricted. Therefore, relevant research should be carried out in the future.

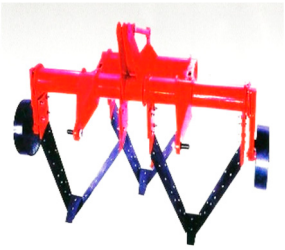
The tillage method of loosening the topsoil with front shoveling and loosening the bottom soil with back shoveling is adopted for subsoiling. After subsoiling, the soil is loosened and broken, and the soil layer does not turn over to promote the ripening of the bottom soil [54]. When the depth of subsoiling is the same, the drag resistance of different shovel types is not consistent, and the larger the area of the front and rear shovel types and the greater the drag resistance [55]. Zhao et al. [56] designed a segmented layered rear subsoiler to reduce the disturbance of the bottom soil and increase the amount of straw disturbance into the furrow. Li et al. [57] found that layered subsoiling improved the stability of subsoiling depth, the surface levelness was better than that of single scoop deep soiling, the soil disturbance coefficient was greater than that of single scoop deep soiling, and the soil ridge height was lower than that of single scoop subsoiling. At present, the selection of the front and back spout and the height of the layered subsoiling shovel depend on experience in our country, and the influence of the shape of the front and back spout, the depth of penetration and the spout drama on the soil disturbance should be further studied.

Based on the above studies, the resistance of subsoiling operation can be reduced by drag-reduction techniques such as changing structural parameters, vibration, bionic drag-reduction and layered subsoiling to a certain extent and save the cost of subsoiling operation. However, the subsoiling needs to be equipped with high-power tractors, which ordinary farmers cannot afford. Moreover, a single operation of machines will lead to repeated soil compaction and lengthen operation time, which is not conducive to agricultural time competition. Under the condition of suitable soil, the combined operation machine can meet the requirements of soil preparation before seed planting with only one operation in the field, which has the advantages of soil protection, efficiency improvement and cost reduction [58], thus becoming an essential direction of the development of tillage machinery. Table 4 shows the typical subsoilers and combined operation machines.

Table 4. Typical subsoilers and combined operation machines.

Models	Key Components	Pictures	Features
1S-250A type Subsoiler [59]	chisel-type subsoiling shovel		This machine is used for subsoiling of land with a hard plow base formed by multi-year rotary tillage and multi-year shallow tilling and no-tillage work. Auxiliary power is above 66.2 KW, the working width is 250 cm, and the subsoiling depth is 30~35 cm.

Table 4. *Cont.*

Models	Key Components	Pictures	Features
1S-250 type Subsoiler [60]	Adjustable wing subsoiling shovel		This machine is an enhanced interval subsoiler, which can form a furrow loose and ridge compaction plough layer. The wing spade is installed in the middle of the spade handle to reduce energy consumption. The working depth is 25~30 cm, and auxiliary power is 66.2~88.2 kW.
1SZL type Vibration Subsoiler [61]	Vibration subsoiling shovel		This machine adopts the new type of subsoiling vibration shovel, which can significantly improve the breaking rate of surface soil, and the width of operation can be adjusted according to the actual needs, so it is suitable for land preparation in spring and autumn dry land. The working depth is 24~40 cm, and the working speed is 4~7 km/h.
1SQ-340 type Bulk Subsoiler [62]	Bulk subsoiling shovel		This machine adopts a frame of the trapezoidal working unit, which is used for subsoiling of the soil with high efficiency and can form rat channels at the bottom of the loose soil layer. Auxiliary power is 58.8~73.6 kW.
1S-310 type Bulk Subsoiler [63]	Bulk subsoiling shovel		This machine's subsoiling shovel head symmetrical, one end of wear can be turned to use, the service life of the subsoiling shovel is prolonged; Deep loosening spade-spacing is 52 cm, the working depth is ≥30 cm, and auxiliary power is ≥99.2 kW.
1SZL-300 type Subsoiling Combined Machine [64]	chisel-type double-wings subsoiling shovel, rotary blades		This machine can complete subsoiling and rotary tillage at one time. It is suitable for cultivation in arid, semiarid and, hilly areas with good soil improvement effect, auxiliary power is 95.6~132.3 kW.
1SZL-300 type Subsoiling Combined Machine [65]	Bulk subsoiling shovel, Heavy-duty press roller		This machine can complete subsoiling, rotary tillage and suppression covering at one time. The suitable depth of subsoiling was 25~50 cm, the depth of land preparation was 8~18 cm, auxiliary power is 106.58~121.3 kW.

3.2. Research Progress of Topsoil Tillage Equipment

Topsoil tillage mainly includes disk harrowing, surface loosing, vertical tillage, etc. The commonly used machines for tillage are disc harrow, tooth harrow, shallow loosening machine, etc. [66]. Some machines for topsoil tillage are discussed in Table 5.

The disc harrow is mainly used for breaking and leveling soil after plowing. It is generally composed of a harrowing group, harrow(rake) frame, suspension frame and adjustable angle mechanism. Disc harrow can cut up the straw on the ground to realize the complete mixing of the surface straw and soil, which is beneficial to the degradation of straw. At the same time, it can also arrange a flat and uniform seedbed. The critical component of the disc harrow is the rake plate, divided into full-edge and notched disks according to the shape of the rake plate, passive and driven disks according to the driving mode. Due to the severe soil hardening, large rice straws and fluctuating soil moisture content in paddy field soil in southern China, Wan et al. [67] designed a hydraulic-driven disc harrow (Figure 3) to enhance the ability to cut straw and soil. Xu et al. [68] developed a new model as-cast bainitic steel, which improved the characteristics of a harrow disk and simplified the process of production. In addition, the wear resistance of the steel is better than that of 65Mn steel after heat treatment.

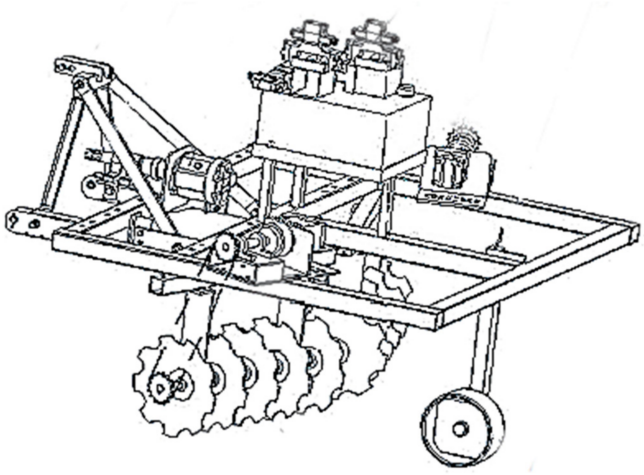


Figure 3. Hydraulic-driven disc harrow structure drawing.

The operation mode of the vertical shaft driving is adopted for the vertical driving-type tillage machine. The power is transferred to the shallow-rotation driving blade by the tractor, which drives the shallow-rotation driving blade group to rotate at high speed to disturb and break the soil to soil preparation. Thus, good transmission performance, suitable for high-power wide-width operation, good consistency of operation depth, the upper and lower soil cannot be disturbed, good moisture retention. Aiming at the characteristics of less tillage in conservation tillage, high quality of surface flatness and high requirements on surface soil erosion during tillage in the Huang-Huai-Hai area of China, Wang et al. [69] designed a vertical drive-type surface tillage machine (Figure 4), which met the requirements of soil crushing and straw mulching [70].

A surface cultivator is a loosening machine whose depth of soil is not more than the ploughing layer. It is generally composed of a surface shovel, rotary blade and surface tillage blade. The rotary blade has the best effect on soil leveling, but the soil disturbance is significant. The chemical and mechanical combined treatment had been used, Hu et al. [71] designed a sprayer-cultivator-combined weeder for permanent raised bed system, the weeding rate was 97.3%. In order to achieve surface tillage and weeding under a large amount of straw mulching, Wang et al. [72] designed a double-vane symmetrical rotary blade with the functions of chopping and sliding cutting. The results showed that the crumbling and weeding ability had an advantage over the topsoil shovel and the condition of soil disturbance, and straw mulching is better than that of the rotary

blade. Yang et al. [73] designed a surface tillage blade with the reciprocating plug of soil (Figure 5). When the cut soil distance of the cutting tool is less than 30 mm, the broken soil coefficient of soil is more than 90% after topsoil cultivation, and soil bulk density is less than 1.22 g/cm^3.

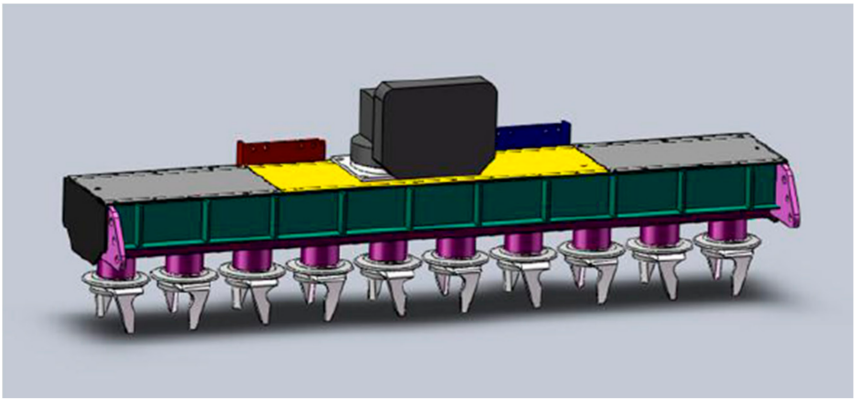


Figure 4. Vertical drive-type surface tillage machine.

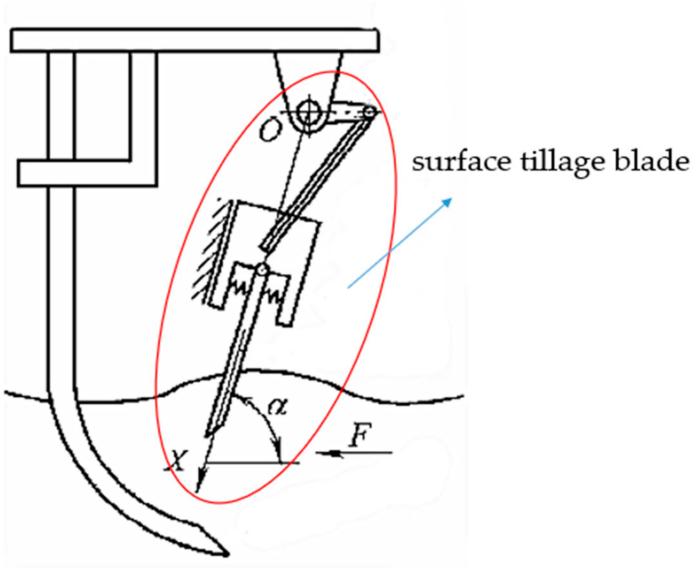


Figure 5. Surface tillage blade structure drawing.

Vertical tillage is a type of tillage in which the soil is sheared vertically without causing horizontal disturbance to break down the hardened layer and prevent new hardening. The disc cutter and disc harrow are the key parts of vertical cultivation in China. The disc cutter cuts up the stubble while rolling and crushing the soil, which promotes the mixture of straw and soil, accelerates the decomposition, increases the soil fertility and is conducive to the germination and emergence of seeds. The finely crushed straw can also reduce clogging and improve the trafficability of the no/minimum tillage planter [66]. Wei of Guangxi Academy of Agricultural Sciences first proposed the technology of smash-ridging in 2008 [74], using a special mechanical vertical spiral drill to grind the soil vertically and naturally suspend it into ridges [75]. At present, experiments have been carried out on corn, peanut, sugar cane, potato, rice and other crops, and the root developed markedly. Yield has been increased [75–79].

Table 5. Typical machines for topsoil tillage.

Models	Key Components	Pictures	Features
1BZ-3.0 type Traction type bigoted heavy harrow [80]	disc harrow		This machine is suitable to eliminate stubble before ploughing, break the surface compaction, straw returning, level the surface and so on. It has strong adaptability. The maximum depth of cultivation is 20 cm, and auxiliary power is 58.8~73.6 kW.
1BQ-3 type vertical driving-type surface rotary tillage machine [81]	vertical driving-type tillage machine		Powered by the tractor's output shaft of, the tillage layer is not disordered after the driving harrow operation, the rate of broken soil is reasonable, and the plowing depth is consistent. Auxiliary power is 88.2~132.4 Kw, and the operating depth is 3~18 cm.
1GQN-230B type rotary tiller [82]	rotary blades		The rotary tiller shaft is powered by the tractor's output shaft, rotating and shredding the soil, with a supporting power of 51.5–73.5 kW and an operating depth of 12~16 cm.

4. Problems and Discussion

Practical technology should focus on the basic theory, achieve the integration of agricultural machinery and agronomy under the guidance of the basic theory while relying on supporting machinery to carry out tests and extensions. Domestic research on tillage technology of subsoiling and topsoil tillage mainly focuses on optimizing and designing machine structure and researching the application benefits of tillage technology. However, it lacks research on the mechanism of action between crucial components and soil. At the same time, the research on minimal tillage in China is shallow, and the application degree of intelligence is not high.

(1) Subsoil

Playing an indispensable role in monitoring the depth of subsoiling operation is the key to ensuring the quality of operation. One is the type selection of the subsoiler by the mechanical performance testing device, which shows the optimization of the subsoiler's structure parameters, and the subsoiler's direction according to the different soil textures. The second is the measurement of the crucial technical parameters of the subsoiler, including the definition and measurement method of the working width of the subsoiler; The third is the application of "Internet +" information technology in remote monitoring of overall subsoiling of agricultural machinery.

(2) Topsoil tillage

At present, the rotary tiller is the main machine for topsoil cultivation, which has a large amount of soil disturbance and is not conducive to the protection of soil cultivation environment, so it is generally not used in protective tillage environment. However, the method of mechanical weeding in topsoil tillage can effectively control weeds, reduce the use of pesticides, protect the water area of farmland and further protect food security. Therefore, relevant research institutions should pay attention to it. Future research should focus on developing a highly targeted and efficient spraying shallow pine weeder.

(3) Plough layer construction

Reasonable plough layer positively affects soil physical and chemical properties, crop yield increase, etc. Domestic studies on plough layer construction mainly focus on models, the impact of crop yield and water use efficiency. Wide alternative narrow row planting technique [83–85], close seedling row and loose ridge furrow [86,87], rotational tillage [88], mechanized and ecological tillage pattern [89] and construction of fertile and cultivated upland soil layer have all constructed reasonable plough layers. Therefore, it is necessary to combine the agronomic planting requirements of different regions, use minimal tillage methods in an integrated manner and carry out the experimental promotion of reasonable plough layer construction according to local conditions to develop plough layer construction techniques regional characteristics.

5. Conclusions

Under the background of severe soil degradation in China, environmentally friendly tillage technology is crucial. Conservation tillage is an advanced tillage technology to improve soil fertility and drought resistance by carrying out minimal tillage and no-tillage on farmland and covering the ground with crop straw to reduce water erosion and wind erosion [66]. Under the circumstance that the country vigorously promotes conservation tillage for demonstration and promotion, the economic bearing capacity of small farmers and water pollution caused by excessive application of pesticides are the critical issues for implementing this technology. Minimal tillage is more accepted than no-tillage in China, so it should be used as a transitional technology for conservation tillage to guide demonstration and promotion.

Author Contributions: D.H., C.L., Z.T. and D.H. reviewed the literature and wrote the initial draft of the paper with assistance from X.M., C.L., Z.T. and G.Z. contributed to revising the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by Chinese Universities Scientific Fund (2021TC011). We are appreciative to all the members of Conservation Tillage Research Centre for their suggestions for this paper.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Xu, J.P.; Xu, T.; Xie, Y.F. Research on Development for Minimal or no-tillage System. *J. Agric. Mech. Res.* **2005**, *1*, 25–27.
2. Pan, G.X.; Gao, M.; Hu, G.H.; Wei, Q.P.; Yang, X.G.; Zhang, W.Z.; Zhou, G.S.; Zou, J.W. Impacts of Climate Change on Agricultural Production of China. *J. Agro-Environ. Sci.* **2011**, *30*, 1698–1706.
3. Zhai, Z.; Li, Y.Y.; Guo, J.J.; Wang, J.; Dong, G.; Guo, Z.; Pang, H. Effect of tillage depth on soil physical properties and yield of winter wheat-summer maize. *Trans. Chin. Soc. Agric. Eng.* **2017**, *33*, 115–123.
4. Gao, H.W.; Li, H.W.; Wang, X.W. A Testing Study of Dryland Subsoiling. *Agric. Res. Arid. Areas* **1995**, *4*, 126–133.
5. Han, Q.Z. A Field Study on the Bulk Deep Loading Tillage Technology in the Loess Plateau Area. *Trans. Chin. Soc. Agric. Eng.* **1997**, *1*, 286–290.
6. Wang, X.L.; Wang, Q.J.; Zhang, X.C.; Zheng, Z.Q.; Zheng, K.; Hu, H. The Soil Compaction Forms and Research Status. *J. Agric. Mech. Res.* **2016**, *38*, 264–268.
7. Zhang, X.Y.; Sui, Y.Y. Summarization on the Effect of Soil Compaction on Crops. *Trans. Chin. Soc. Agric. Mach.* **2005**, *10*, 161–164.
8. Zhen, K.; Chen, W.Z. Current situation and prospect of subsoiling machinery. *Jiangsu Agric. Sci.* **2016**, *44*, 16–20.
9. Zhu, R.X.; Zhang, J.C.; Xue, S.; Yao, W.; Li, J. Experimentation about subsoiling technique for conservation tillage. *Trans. Chin. Soc. Agric. Eng.* **2009**, *25*, 145–147.
10. Li, J.H.; Luo, X.W.; Zhu, Y.Q.; Yang, Z.; Li, J.; Huang, H.Q. Effect of Tillage Methods on Soil Physical Properties and Moisture Content of Latosol. *Trans. Chin. Soc. Agric. Mach.* **2006**, *12*, 62–66.
11. Song, R.; Wu, C.S.; Mu, J.M.; Xu, K. Effect of Subsoiling on Root Growth of Maize. *J. Jilin Agric. Univ.* **2000**, *22*, 73–80.
12. Du, B.; Li, W.Y.; Deng, J. Research on Surface Tillage in Conservation Tillage. *J. China Agric. Univ.* **2000**, *5*, 65–67.

13. Liu, J.A.; Wang, X.Y.; Li, H.W.; He, J.; Wang, Q.; Li, W. Optimization of Structural Parameters of Subsoiler Based on Soil Disturbance and Traction Resistance. *Trans. Chin. Soc. Agric. Mach.* **2017**, *48*, 60–67.
14. Li, W.Y.; Li, H.W.; Chen, S. *Conservation Tillage Technology*; Popular Science Press: Beijing, China, 2006.
15. Li, H.W.; Chen, J.D. Study on surface tillage effect for dryland. *Agric. Res. Arid. Areas* **2000**, *18*, 13–18.
16. Xin, C.Y.; Guo, Q.Y.; Wei, Y.H.; Guo, L.Z.; Weng, H. Effect on Soil Moisture, Nutrient and Weed Control in Arid Farmland by Shallow Tillage. *Sci. Agric. Sin.* **2006**, *08*, 1697–1702.
17. Feng, G.L.; Yang, R.B. Dynamic changes in nitrogen and phosphorus concentrations and emission-reduction potentials in paddy field water under different tillage models. *Acta Ecol. Sin.* **2011**, *31*, 4235–4243.
18. Liu, L.G.; Wu, B.Z. Effects of different cultivation methods on soil erosion and yield. *Tillage Cultiv.* **1993**, *4*, 12–14.
19. Lu, Z.X.; Wu, X.P.; Perdok, U.D.; Hoogmoed, W.B. Analysis of Tillage Soil Surface Roughness. *Trans. Chin. Soc. Agric. Mach.* **2004**, *1*, 112–116.
20. Bai, W.; Sun, Z.X.; Zheng, J.M.; Hao, W.; Liu, Q.; Liu, Y.; Feng, L.; Cai, Q. Furrow loose and ridge compaction plough layer improves spring maize yield and water use efficiency. *Trans. Chin. Soc. Agric. Eng.* **2014**, *30*, 81–90.
21. Jin, Y.G.; Yuan, Y.Q.; Lin, W.; Wei, A.B.; Gao, P.F.; Sun, M.; Gao, Z.Q. Effects of Cultivation in Leisure Period on Soil Properties and Yield of Dryland Wheat Field. *J. Shanxi Agric. Sci.* **2020**, *48*, 382–386.
22. Zhang, R.; Liang, Y.F.; Xing, J.J.; Zhang, X.R.; Ru, S.F. Effects of Different Plough Layer Structure on Physical Properties of Banana Latosol in Hainan Province. *J. Agric. Mech. Res.* **2022**, *44*, 214–218.
23. Wang, Y.X.; Wang, J.H.; Ren, C.M.; Liu, Y.T.; Xu, Y.Y.; Gao, P. Effects of Different Deep Loosening Treatments on the Layer Structure and Yield of Maize in Saline Alkali Soil of Northeast China. *Heilongjiang Agric. Sci.* **2018**, *3*, 26–29.
24. Bai, W.; Sun, Z.X.; Zhang, L.Z.; Zheng, L.Z.; Zheng, J.M.; Feng, L.S.; Cai, Q. Effects of plough layer construction on soil three phase rate and root morphology of spring maize in northeast China. *Acta Agron. Sin.* **2020**, *46*, 759–771.
25. Zhang, Q.; Wang, H.; Wang, S.L.; Zhang, Y.H.; Wang, R.; Wang, X.L.; Li, J. Effects of tillage alternation pattern with subsoiling on soil physical and chemical properties and spring maize yield in the Loess Plateau, China. *Chin. J. Appl. Ecol.* **2020**, *31*, 459–466.
26. Zhen, K.; He, J.; Li, H.W.; Wang, Q. Meta-analysis on maize and wheat yield under subsoiling in Northern China. *Trans. Chin. Soc. Agric. Eng.* **2015**, *31*, 7–15.
27. Wang, L.; Guo, S.R.; Wumaierjiang, K.; Tian, L.W.; Lin, T.; Zheng, Z.P.; Xu, H.J.; Kong, F.Y.; Cui, J.P. Effects of subsoiling depth on water use efficiency and yield of cotton field under drip irrigation in south Xinjiang, China. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 144–152.
28. Raper, R.L. Subsoiler shapes for site-specific tillage. *Appl. Eng. Agric.* **2005**, *21*, 25–30. [CrossRef]
29. Yu, Y.C.; Liu, W.Y.; Zhao, Y.F.; Sun, J.Q. Force mathematical model and examination analysis of the column subsoiler. *Trans. Chin. Soc. Agric. Eng.* **2007**, *23*, 109–113.
30. Li, H.W.; Gao, H.W.; Wang, X.W. Experimental Study on Subsoiler with Adjustable Wine. *J. Beijing Agric. Eng. Univ.* **1995**, *2*, 33–39.
31. Li, H.W.; Chen, J.D.; Li, W.Y. Study on Subsoiling Technique for Conservation Tillage Field. *Trans. Chin. Soc. Agric. Mach.* **2000**, *6*, 42–45.
32. Li, J.J. Design of All-Round Adjustable Deep Loosening Machine. Master's Thesis, Jilin University, Changchun, China, 2010.
33. Jing, M. Design and Field Experiment on Two-Row Opposite Vibrating Subsoiler. Master's Thesis, Henan Polytechnic University, Jiaozuo, China, 2012.
34. Wang, F.Y. Utilization and Experimental Investigation of Omni-directional Deep Plough Machine. *J. Agric. Mech. Res.* **2010**, *32*, 173–175.
35. Guo, X.R.; Gu, Y.B.; Liao, Z.X. Capability Analysis to 1SQ–250 Type Bulk subsoiler. *Syst. Sci. Compr. Stud. Agric.* **2000**, *03*, 225–227.
36. Shi, J.L.; Qiu, L.C. Study on Subsoiling Technology of Bulk Subsoiler. *Shangdong Agric. Mach.* **2005**, *4*, 3–5.
37. Shao, C.F.; Zheng, Z.A.; Lin, Q.R. A study on affects of bulk subsoiling diggers in all directions for the sustainable agricultural development. *Trans. Chin. Soc. Agric. Mach.* **1999**, *5*, 81–85.
38. Lu, Q.; Wang, A.; Li, J.C.; Hao, J.J. Development and research status of deep loose shovel. *Agric. Mech. Using Maint.* **2017**, *8*, 9–12.
39. Peng, Z.M.; Ding, Y.; Zhu, J.P.; Yuan, D. Technical analysis and research of detection in energy-saving emission reduction to farming machinery. *Chin. Agric. Mech.* **2009**, *5*, 69–71.
40. Zhen, K.; He, J.; Li, H.W.; Diao, P.; Wang, Q.; Zhao, H. Research on Polyline Soil-breaking Blade Subsoiler Based on Subsoiling Soil Model Using Discrete Element Method. *Trans. Chin. Soc. Agric. Mach.* **2016**, *47*, 62–72.
41. Zhao, S.H.; Wang, J.Y.; Chen, J.Z.; Yang, Y.; Tan, H. Design and Experiment of Fitting Curve Subsoiler of Conservation Tillage. *Trans. Chin. Soc. Agric. Mach.* **2018**, *49*, 82–92.
42. Chen, K. Study on Structural Optimization of extroverted arc subsoiler. Master's Thesis, Jilin Agricultural University, Changchun, China, 2012.
43. Wang, X.Z.; Yue, B.; Gao, X.J.; Zheng, Z.; Zhu, R.; Huang, Y. Discrete Element Simulations and Experiments of Disturbance Behavior as Affected by Mounting Height of Subsoiler's Wing. *Trans. Chin. Soc. Agric. Mach.* **2018**, *49*, 124–136.
44. Zhang, B.; Shen, C.J.; Li, C.M.; Fu, W.; Tan, X.Z.; Dai, Y.M.; Li, F. Simulation Design and Test of Key Components of Self—excited Vibration Subsoiler. *J. Agric. Mech. Res.* **2021**, *43*, 51–57.
45. Cui, T.; Shi, Z.D.; Yang, L.; Wang, Y.X.; Han, D.D.; Zhang, D.X. Design and Experiment of Vibration Subsoiler with Adjustable Spring Pre-tightening Force. *Trans. Chin. Soc. Agric. Mach.* **2016**, *47*, 96–102.

46. Zhou, H.; Zhang, W.L.; Yang, Q.J.; Li, D.D.; Xia, J.F. Design and Experiment of Sliding Cutting Self-excited Vibration Drag Reduction Subsoiling Device. *Trans. Chin. Soc. Agric. Mach.* **2019**, *50*, 71–78.
47. Wang, Y.X.; Yang, L.; Cui, T.; Li, Y.; Liu, Y. Design and experiment of hydraulically self-excited vibration subsoiler. *Trans. Chin. Soc. Agric. Eng.* **2018**, *34*, 40–48.
48. Li, M.J.; Yu, J.C.; Wang, R.B.; Shao, R.R.; Dong, M. Design and experiment of hydraulic forced vibration subsoiling monomer. *J. China Agric. Univ.* **2020**, *25*, 90–101. [CrossRef]
49. Wei, Z.J.; Zheng, D.K.; Yang, D.T.; Sun, F.Y. Kinetic Characteristic Analysis and Experimental Study for Subsoiler with Wing. *J. Agric. Mech. Res.* **2017**, *39*, 32–37.
50. Teng, Y.; Zhang, Z.X.; Si, Z.J.; Huang, Y.; Wang, B. Impact of Vibration-tillage of Subsoils on Their Water Retention Curves. *J. Irrig. Drain.* **2017**, *36*, 52–58.
51. Sun, Y.P.; Dong, X.Q.; Song, J.N.; Wang, J.; Liu, C.; Xu, G. Self-balancing performance and simulation analysis of multi-group vibrating shovels of oscillatory subsoiler. *Trans. Chin. Soc. Agric. Eng.* **2018**, *34*, 92–99.
52. Zhang, Q.; Zhang, L.; Yu, H.Y.; Xiao, Y. Finite Element Analysis and Experiment of Soil Resistance of Multiplex-modality Subsoiler. *Trans. Chin. Soc. Agric. Mach.* **2012**, *43*, 61–65.
53. Zhang, J.B. Bionic Drag Reduction and Wear-Resistant Theory and Techniques of Subsoiler. Ph.D. Thesis, Jilin University, Changchun, China, 2014.
54. Li, W. Influence Research of Subsoiling in Tandem of Soil Disturbance. Master's Thesis, Northwest A&F University, Xianyang, China, 2017.
55. Zhao, Y.Z.; Yang, Y.; Zhang, C.G.; Qi, G.Y.; Liu, L. Effect of the configuration parameters of the layered subsoiling shovel type on the draft resistance. *J. Northeast. Agric. Univ.* **2016**, *47*, 102–108.
56. Zhao, S.H.; Yang, C.; Yang, L.L.; Gao, L.L.; Yang, Y.Q. Design and experiment of segmented layered rear subsoiler. *J. Northeast. Agric. Univ.* **2019**, *50*, 86–96.
57. Li, W.; Zhang, S.L.; Gao, X.J.; Huang, Y.X.; Zhu, R.X. Influence Research of Front Subsoiler Depth on Soil Disturbance of Subsoiling in Tandem. *J. Agric. Mech. Res.* **2018**, *40*, 147–150.
58. Zhen, K. *Study on Subsoiling and Rotary Tillage Operation Adjustable Combine Machine*; China Agricultural University: Beijing, China, 2018.
59. 1S-250A Type Subsoiler. Available online: https://www.nongjitong.com/product/hdxfeng_1s-250a_deep_loosening_machine.html (accessed on 15 March 2021).
60. 1S-250 Type Subsoiler. Available online: https://www.nongjitong.com/product/7005.html (accessed on 27 May 2021).
61. 1SZL Type Vibration Subsoiler. Available online: https://www.nongjitong.com/product/355140.html (accessed on 15 March 2021).
62. 1SQ-340 Type Bulk Subsoiler. Available online: https://www.nongjitong.com/product/7145.html (accessed on 16 March 2021).
63. 1S-310 Type Bulk Subsoiler. Available online: https://www.nongjitong.com/product/aolong_1s-300_deep_loosening_machine.html (accessed on 15 March 2021).
64. 1SZL-300 Type Subsoiling Combined Machine. Available online: http://www.taishanguotai.com/product/163.html (accessed on 16 June 2021).
65. 1SZL-300 Subsoiling Combined Machine. Available online: https://www.nongjitong.com/product/dahua_1szl-300_combined_soil_working_machine.html (accessed on 13 July 2021).
66. He, J.; Li, H.W.; Chen, H.T.; Lu, C.Y.; Wang, Q.J. Research Progress of Conservation Tillage Technology and Machine. *Trans. Chin. Soc. Agric. Mach.* **2018**, *49*, 1–19.
67. Wang, G.W.; Shu, C.X.; Xiao, W.L.; Zhang, Q.; Liao, Q. Design and simulation of hydraulic driven disc harrow. *J. S. China Agric. Univ.* **2017**, *38*, 117–124.
68. Xu, G.Y.; Xu, Z.; Ding, L.P. Formation and Wear Resistance of a New Cast Bainitic Steel Used in Manufacturing the Harrow Disk. *Trans. Chin. Soc. Agric. Mach.* **2003**, *5*, 154–156.
69. Wang, Y.B.; Rong, G.; Li, H.W.; Wang, Q.J.; He, J.; Lu, C.Y. Design and parameter optimization of vertical driving-type surface rotary tillage machine. *Trans. Chin. Soc. Agric. Eng.* **2019**, *35*, 38–47. [CrossRef]
70. Rong, G. Experimental Study on Vertical Driving Shallow Harrow Machine. Master's Thesis, China Agricultural University, Beijing, China, 2016.
71. Hu, Y.; Wang, X.; Li, H.; He, J. Sprayer-cultivator-combined Weeder for Permanent Raised Bed System. *Trans. Chin. Soc. Agric. Mach.* **2009**, *40*, 61–66.
72. Wang, Q.J.; Niu, Q.; Ge, S.L.; Du, R.C.; Li, H.W.; Zhang, X. Design and Experiment of Double-vane Symmetrical Rotary Blade for Surface Tillage. *Trans. Chin. Soc. Agric. Mach.* **2016**, *47*, 103–107.
73. Yang, Y.G.; Zhang, H.; Feng, T.; Lin, Q.G.; Xue, M.Z.; Li, Z.; He, W.; Mi, X. Topsoil and Subsoil Combined Cultivator and Top-soiling Experiment. *J. Mech. Eng.* **2012**, *48*, 163–168. [CrossRef]
74. Yang, J.; Chen, T.; Xiao, Y.; Li, H.; Li, J.; Li, Q.; Rang, Z.; Zhou, Q. Effects of Exogenous Organic Carbon Input Combined with Vertical Tillage on Soil Nutrients and Growth and Development of Flue-cured Tobacco. *Southwest China J. Agric. Sci.* **2020**, *33*, 1665–1670.
75. Wei, B.H. A brief report on cultivation techniques of dry land crop powder ridges. *Sci. Agric. Sin.* **2010**, *43*, 4330.

76. Wei, B.H.; Gan, X.Q.; Chen, B.S.; Shen, Z.Y.; Yu, J.; Ning, X.C.; Lu, L.Y.; Wei, G.P.; Hu, B.; Mo, R.X.; et al. Comparison of the Cultivation of Maize and Peanuts by Smash-ridging and Traditional Land Preparation Methods. *J. Anhui Agric. Sci.* **2011**, *39*, 3216–3219.
77. Wei, B.H.; Gan, X.Q.; Shen, Z.Y.; Ning, X.; Lu, L.; Wei, G.; Li, Y.; Hu, P.; Liu, B.; Wu, Y. Yield Increase of Smash-Ridging Cultivation of Sugarcane. *Sci. Agric. Sin.* **2011**, *44*, 4544–4550.
78. Wei, B.H.; Gan, X.Q.; Chen, Y.F.; Shen, Z.; Luo, X.; Lu, L.; Hu, P.; Li, Y.; Wu, Y.; Liu, B.; et al. Planting Winter Potato in Rice Field by Using Smash-ridging Technique. *Chin. Potato J.* **2011**, *25*, 342–344.
79. Wei, B.H.; Gan, X.Q.; Shen, Z.Y.; Hu, P.; Li, Y.Y.; Wu, Y.Y.; Lu, L.Y. Effect of Fenlong Cultivation on Yield and Quality of Rice. *Sci. Agric. Sin.* **2012**, *45*, 3946–3954.
80. 1BZ—3.0 Traction Type Bigoted Heavy Harrow. Available online: http://item.nongji360.com/36044 (accessed on 22 May 2011).
81. 1BQ-3 Type Vertical Driving-type Surface Rotary Tillage Machine. Available online: http://www.dewojt.com/product_er.php?class_id=13&id=57 (accessed on 16 June 2021).
82. 1GQN-230B Type Rotary Tiller. Available online: https://www.nongjitong.com/product/6471.html (accessed on 16 June 2021).
83. Tan, G.B.; Bian, S.F.; Liu, W.R.; Zheng, J.Y.; Ma, H.; Zhang, L.H.; Feng, Y.C. Analysis on Planting of Corn About Wide Alternative Narrow Row with Cultivation Technique. *J. Maize Sci.* **2002**, *2*, 80–83.
84. Luo, Y.; Zhang, J.Y.; Zheng, H.B.; Li, R.P.; Li, W.T.; Liu, W.R.; Dong, Y.S. Effect on Growth of Maize in Different Soil Plough Layer by Tillage. *J. Maize Sci.* **2014**, *22*, 113–116.
85. Zheng, H.B.; Zheng, J.Y.; Luo, Y.; Li, R.P.; Li, W.T.; Sun, Y.D.; Liu, W.R.; Qi, H. Effect of Different Tillage Layer Structures on Growth of Maize in Black Cropland Zone of Northeast of China. *Tillage Cultiv.* **2014**, *4*, 7–9.
86. Liu, W.R.; Zheng, J.Y.; Luo, Y.; Zheng, H.B.; Li, R.P.; Li, W.T. Effects of Different Tillage Layer Structures on Soil Compaction and Soil Water Content. *J. Maize Sci.* **2013**, *21*, 76–80.
87. Wang, L.C.; Ma, H.; Zheng, J.Y. Research on Rational Plough Layer Construction of Spring Maize Soil in Northeast China. *J. Maize Sci.* **2008**, *16*, 13–17.
88. Nie, L.P.; Guo, L.W.; Niu, H.Y.; Wei, J.; Li, Z.; Ning, T. Effects of Rotational Tillage on Tilth Soil Structure and Crop Yield and Quality in Maize-Wheat Cropping System. *Acta Agron. Sin.* **2015**, *41*, 468–478. [CrossRef]
89. Zhang, Y.P.; Du, R.C.; Diao, P.S.; Geng, D. Mechanical and ecological tillage pattern improving soil quality and crop yields. *Trans. Chin. Soc. Agric. Eng.* **2015**, *31*, 33–38.