Overview of Current Research Situations of Subsoiler

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Abstract Modern subsoiling technology is a little ploughing measure in dry land protective farming technology system. The subsoiler can scarify soil, deepen the arable layer, break the plough layer, improve the soil permeability, increase soil infiltration speed and amount, and create an arable layer structure with coexistence of fictional and real situation. Also, it can effectively promote development and growth of crop root system and play a favorable role in drought resistance and yield increase of crops. This paper made a simple overview of the subsoiling technology, current development situation of subsoiler both at home and abroad, and classification of subsoilers.

Key words Protective farming, Subsoiler, Development and growth of crops, Home and abroad

With increasing attention to sustained farming and environmental protection, the existing large, medium and small sized machines and tools such as deep tilling plough and mould board plough have become unsuitable for farming in poor soil environment. The interrupted type vibrating subsoiler is an advanced farming method. This method is mainly characterized by scarifying hardened soil, solving soil hardening problem due to long-term rotary tillage, promoting growth of crop root system, and increasing absorption of crops to soil nutrients. Besides, it also increases water conservation property of soil, promotes development and growth of crops, and increases crop yield.

At present, in the condition of protective farming, before scarifying, soil is very hard; when scarifying, soil surface is covered with crop straws, and long straws will influence passing performance of the subsoiler. During subsoiling, horizontal subsoiler has a large influence area and will injure the crop root system, thus surface should be level, then it may be favorable for subsequent sowing and will not injure crop root system[1].

There have been wide researches, experiments and application of the subsoiler both at home and abroad, especially in Europe and American developed countries, it had been developed and applied as early as the 1930s and 1940s and had obtained excellent effect. China also made a considerable progress in development of the subsoiler. Especially since the autumn of 2008, Jilin Province implemented the subsidy policy for subsoiling, which provides favorable development market for large and medium sized combined implement for subsoiler and cultivation.

1 Current development situation of the subsoiler

1.1 Development situation at home and abroad The United States and Western European countries have already had perfect researches on subsoilers. The soil scarifying methods mainly include compressive scarifying and vibrating scarifying. At present, new subsoilers are mainly bent leg plough, vibrating subsoiler, and active and passive combined tillage machine.

(i) Bent leg plough. Williams, Cooksley and Pidgen *et al.* started research since the 1980s, and Canadian Harrison designed a bent leg plough (it can bend 45 degrees), as shown in Fig. 1. Bending part has 15 degree of cutting angle. Using cutting angle to replace the chisel-point tooth and break soil can improve the penetrating performance of machines and tools.

(ii) Vibrating subsoiler. Japanese Sakai *et al.* designed vibrating subsoiler with four mould boards for medium sized tractor (30 -45 kW) and determined the optimum parameter through test (1993). The amplitude of tooth tip is 50 mm and vibrating frequency is 3.4 Hz. When the vibrating angle is 30 degrees, its traction force is 40% less than rigid subsoiler, while the total power only increases about 2%[2]. It structure is shown as in Fig. 2.

(iii) Active and passive combined tillage machine. American Shinners *et al.* designed an active and passive combined tillage machine, which consists of two shovel type passive work pieces and two rotary active work pieces. Rotary tillage part is driven by power take-off shaft through conical gear reducer and chain drive. Forward rotation brings the machine with driving force and greatly reduces traction resistance of entire unit. Compared with machines and tools only mounted with 4 passive work pieces, the total power of active and passive combined tillage machine decreases 3.8%, but the traction resistance drops 87%, skidding of tractor drops 57%, and power utilization ratio of engine increases 34%[2].

1.2 Current development situation in China Subsoilers for protective tillage in China mainly include ISQ -240/250 bulk subsoiler and ISY -210 subsoiler with wings developed by China Agricultural University, IZS -180 vibrating subsoiler manufactured by Shandong Dahua Mechanical Co., Ltd, IS -3/4/5 series subsoiler manufactured by Xi'an Ocean Agricultural Science and

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Technology Co., Ltd, ISTF-3 subsoiler produced by Jilin Siping Agricultural Machinery Factory, ISL-300 subsoiler produced by Modern Agricultural Equipment Co., Ltd, ISB-57 subsoiler manufactured by Harbin Wo'er Science and Technology Co., Ltd, and 2 306 bulk combined tillage machine manufactured by Heilongjiang Bonong Xingda Machinery Co., Ltd[3-7]. Main technical parameters are listed in Table 1.

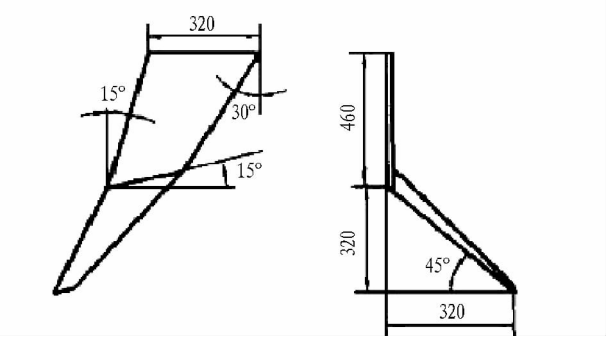
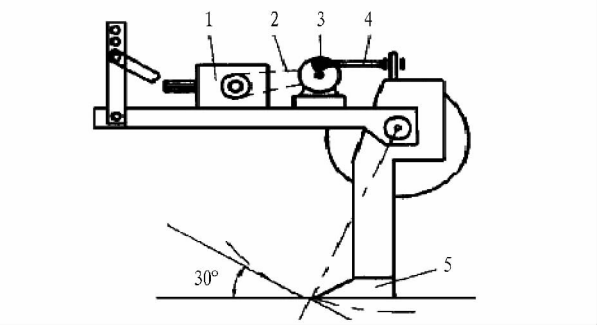


Fig. 1 Shape and size of bent leg plough



Note: 1. Gearbox; 2. Chain drive; 3. Passive work piece; 4. Active work piece; 5. Subsoiler

Fig. 2 Sketch for structure of vibrating subsoiler

Table 1 Main technical parameters of subsoiler at domestic market

Model	Shape of subsoiler	Auxiliary power//kW	Depth of deep scarification//mm	Working efficiency//hm^2/h
ISQ-250	V-shaped subsoiler	55-60	400-500	10-15
ISY-210	Chisel shovel with side wing	36-44	200-250	11-14
IZS-180	Chisel-shaped subsoiler	≥58.8	≥250	6-8
IS-7	Chisel-shaped subsoiler with single column and double wings	44.1-66.2	200-450	10-12
STF-3	Chisel-shaped subsoiler with single column and double wings	40-75	150-400	8-12
ISL-300	Arrow shovel	132	500	18-31
ISB-570	Chisel-shaped subsoiler with side wing	≥88.2	300-500	15-21
ILS-550	Chisel-shaped subsoiler	73.5-88.2	300-450	16.5-20.25

2 Brief introduction to deep scarification technology

2.1 Deep scarification technology The deep scarification technology has been widely applied both at home and abroad. Deep scarification means exceeding the normal soil breaking depth. It can break hard pan and deepen the arable layer, increase soil aeration and water permeability, and improve growth environment of crop root system. When conducting deep scarification, since soil is loosened but not turned, the hard pan can be scarified, so as to adjust the three-phase ratio of soil, create an arable layer with coexistence of fictional and real situation, reduce soil erosion, and keep fertility and water of arable layer. Therefore, the deep scarification technology can greatly increase crop yield, especially for crops with longer root system[3]. The deep scarification technology is helpful for increasing soil aeration, and its main functions are as follows:

(i) Breaking the pan and improving structure of arable layer. Mechanized deep scarification can break hard pan formed due to many years of tillage, improve physical and chemical property of arable land, and increase capacity of "water reservoir" of soil. Thus, it is favorable for absorbing large volume of rainwater, and favorable for using rat runway to drain flood. Also, it is favorable for enhancing soil fertility and holding water, favorable for vertical development of root system, so it is the optimum soil structure for crop growth[8].

(ii) Increasing utilization efficiency of water resource. The deep scarification technology breaks the pan, so it is favorable for penetration of surface water, reducing surface runoff, realizing self-adjustment of soil water, accumulate natural precipitation, and set up underground water reservoir. With increase of water storage, it is favorable for drought fighting before next rainy season. Besides, the deep scarification technology can solve the problem of rainfall not in step with crop growth. In rainy season, we can store excessive rainwater; in dry season, stored water can be absorbed by crop root system through capillary, so as to relieve dry situation[9].

(iii) Increasing organic matter of soil. The deep scarification technology can break the pan, improve soil permeability and aeration, adjust three-phase ratio of soil, and make the proportion of solid, liquid and gas more coordinated. Besides, the deep scarification technology can increase land utilization efficiency. It scarifies the soil at depth of 20-40 cm, causes dense part of root system to move down, which provides condition for survival of microorganism. Then, the non cultivated layer has anaerobic soil environment, corrosion and combination reaction becomes more intense, the content of organic matter gets increased, realizing the function of "improving and maintaining soil fertility".

(iv) Increasing soil capacity. The deep scarification breaks hard pan resulted from long-term tillage, increases tillage depth,

removes obstacle layer, and improves soil aeration. With increase of porosity of soil, the heat conductivity increases accordingly. Then, the soil temperature rises about 0.5 – 1℃, and it brings the mudding period of 7 – 8 days ahead of time.

(v) Benefiting development of crop root system. The deep scarification deepens the soil tillage layer, reduces soil volume weight, and increases total porosity. The increase of aeration promotes activity of aerobic microorganism, brings soil microorganisms to move to lower position, and expands range of nutrients. The deep scarification soil preparation reduces damage to soil pellet structure and soil capillary. This is favorable for formation of soil colloid. Increase of anion of soil colloid will make it absorb Ammonium for crop absorption. Consequently, it accelerates downward growth of root system and promotes early ripe and high yield of crop.

(vi) Increasing disaster resistance of soil. The deep scarification and soil preparation break the pan, deepen the arable layer, promote crop root system to extend downward to absorb more nutrients and water, so as to promote growth of root system and improve lodging resistance of crops. The deep scarification technology can improve physical and mechanical property of soil, adjust water, fertilizer, air and heat in the soil, and raise the ability of resisting drought and flood drainage. In addition, it can increase the soil temperature, accelerate growth of crop root system, promote early ripe, resist disasters and increase yield, and prevent early ageing of crops. According to calculation, when the arable layer increases 1 cm, 1 hm^2 land can hold 60 tons of water more. At the 15 cm of arable layer, the water content increases about 3%; at 20 cm, the water content increases about 6%[10].

(vii) Reducing damage to soil. Mechanical soil preparation has certain damage to soil. The more times of soil preparation, the larger damage it will bring about. The deep scarification combined soil preparation reduces working times of unit, reduces movement of soil tillage, protects soil colloid, avoids change of soil to sand, reduces cost for oil and mechanical soil preparation, and improves soil at low consumption but high efficiency.

2.2 Methods of deep scarification Mechanized protective tillage methods of deep scarification mainly include partial deep scarification, deep scarification in rows, and bulk deep scarification.

2.2.1 Partial deep scarification. It adopts single column 23 – 30 cm subsoiler to implement deep scarification according to different crops and soil conditions. Densely planted crops (such as wheat) have spacing of deep scarification about 40 – 80 cm; wide row crops (such as corn) have spacing of deep scarification about 40 – 80 cm (the same row spacing as local corns), and the depth of deep scarification is 23 – 30 cm. The deep scarification can be implemented before sowing. According to soil conditions and tillage times, generally 2 – 4 times of deep scarification are carried out and chisel shaped shovel subsoiler or subsoiler with wing are used.

2.2.2 Deep scarification in rows. This method is implemented at seedling stage of crops. The deep scarification spacing adopts the ridge spacing, and the depth is 25 – 30 cm. When it is too arid, soil dragger may be added to reduce evaluation of soil water. In dry areas, it is recommended to implement deep scarification in rows before rain days come, to absorb rainwater and create condition for sowing in the next year and crop growth.

2.2.3 Bulk deep scarification. Inverted V type bulk subsoiler is used. Deep scarification is implemented according to different crops and different soil conditions. The depth of deep scarification is 35 – 50 cm, and it is implemented after disposal of straws before sowing. During operation, the depth of deep scarification should be uniform and there shall be no repetition or missing of scarification. When it is too dry, the times of deep scarification should be determined according to soil conditions (generally one time of deep scarification every 2 – 4 years)[3].

2.3 Functions and characteristics of deep scarification

2.3.1 Functions of deep scarification. The deep scarification is a tillage technology for solving the problem of large amount of soil breaking, high power consumption, and not favorable for water and soil conservation. Without the need of complete turnover of soil, using subsoiler to scarify soil can deepen the arable layer, keep surface coverage, reduce wind and water erosion of soil, reduce water evaporation, and improve the water conservation ability of soil. In addition, the deep scarification technology can fully break the pan, soften the arable layer, make the arable layer have good structure, deepen the depth of active soil stratum, coordinate the three-phase ratio to adapt to crop development and growth. Furthermore, it can greatly increase water permeability of soil, increase water content of soil, which is accordingly favorable for water supply at different stages of crop growth. The deep scarification technology also plays a significant role in alkalis removal and flood drainage. In land parcels unsuitable for turning up the soil, it is able to obtain excellent operation effect in combination with mechanical stubble – cleaning and soil preparation.

2.3.2 Characteristics of deep scarification. Mechanical deep scarification can break the pan, form loose soil structure, and greatly increase water storage ability of soil. In rainy season, there will be no surface runoff; in dry season, crop roots can absorb water. Thus, it is very suitable for crops, especially the growth of corns. According to calculation for areas along Yellow River and Huaihe River, the water storage volume in dry season can increase 165 – 370 m^3/hm^2, and the soil permeability can increase 5 – 10 times. It can effectively improve water keeping, storage, permeability, and drainage ability of soil, reduce saline and alkaline content, take full advantage of natural precipitation to satisfy growth demand of crops, and increase crop yield. Therefore, the deep scarification technology is also reputed as project of "rain-fed agriculture".

Mechanical deep scarification loosens the soil but not makes the soil messy, and also not damages the soil structure. Many years of practice proved that this technology effectively keeps water, fertility, extends period for cultivation and sowing. In anthropogenic mellowing of soil, it can increase activity of aerobic bacteria, raise decomposition ability of soil organic matter and release

of effective nutrients, improve absorption of crops to nutrients, restrict activity of anaerobic bacteria, increase concentration of nitrate nitrogen, accelerate soil metabolism, remove soil hardening, and restore original state of soil, so as to increase yield and quality of dryland crops[10-12].

3 Classification and characteristics of deep scarification machines and tools

3.1 Pole tooth type subsoiler This subsoiler mainly consists of deep scarification shovel and hanging part. With simple structure, low price and small scarification coefficient (only 0.2 – 0.3), this subsoiler has excellent operation effect in upper section, while the vertical pole and shovel tip in the lower section compress with soil in both sides, which increases energy consumption. Also, after tillage, there will be vertical gap in the soil, consequently leading to water loss. Now, the major type of this subsoiler is ISL – 435 pole tooth type subsoiler developed by Heilongjiang Institute of Agricultural Mechanical Engineering Science. Technical parameters of this subsoiler are as follows: auxiliary power: 48 – 58 kW tractor; depth of deep scarification: 30 – 35 cm; working width: 140 cm; productivity: 0.5 – 0.7 hm^2/h.

3.2 V-shaped bulk subsoiler For the bulk subsoiler, the major working part is rigid trapezoid framework. It consists of bottom cutter, side cutter, and vertical structure. When working, the deep scarification part cuts out trapezoid ridge from soil, makes it lift and move backward, then it flows out from the framework through two side cutter and horizontal cutter, later it falls and lays onto the field surface, and the bottom forms rat runaway, to absorb more rainwater. The scarification coefficient is higher than 0.75, and the specific draft of tillage is small. Falling soil will not leave vertical gap, which is favorable for keeping water in dry area. Major type of V-shaped bulk subsoiler is ISQ – 340 bulk subsoiler designed by Beijing University of Agricultural Engineering and manufactured by Heilongjiang Bonong Machinery Co., Ltd. Its main technical parameters: auxiliary power: 53.8 – 73.5 HP; depth of deep scarification: 30 – 50 cm; working width: 155 cm; productivity: 15 – 25 mu/h[1].

3.3 Subsoiler with soil preparation tools With the development water keeping technology for dryland tillage, it is required to develop new subsoiler with soil preparation tools, for example, ISL175 soil preparation combined subsoiler. It major technical parameters are as follows: 40 kW tractor; depth of deep scarification: 35 – 40 cm; working width: 175 cm; depth of soil preparation: 8 – 16 cm.

3.4 Column subsoiler with side wing shovel This type of subsoiler is developed by China Agricultural University. It is mainly applied in deep scarification of protective farmland. It can realize deep scarification with intervals and bulk scarification on the surface. In 200 kg/mu field covered with crushed straws, it can smoothly pass. Apart from a high strength shovel handle, slightly raising wing shovel is mounted in both sides of shovel handle (as shown in Fig. 3). The upper and lower position can be adjusted. When working, the shovel tip penetrates into 30 cm deep soil and loosens soil in reverse direction at 45 degrees. At the same time, two side wings loosen the soil at 45 degrees. The corresponding subsoiler is ISY – 210 chisel type subsoiler with wings. The major technical parameters are as follows: auxiliary power: 40 kW tractor; depth of deep scarification: 30 – 35 cm; working width: 210 cm; productivity: 0.73 – 0.93 hm^2/h.

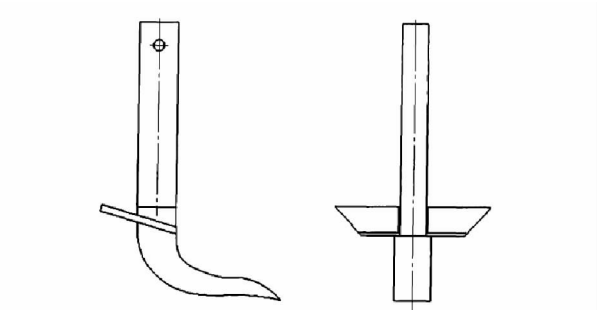


Fig. 3 Schematic drawing for side wing structure

3.5 Vibrating deep scarification technology and its application

3.5.1 Functions and characteristics of vibrating deep scarification. The vibrating deep scarification technology adopts tractor to drive the vibrating subsoiler. Output shaft of tractor brings vibrating body of vibrating subsoiler, to make the subsoiler move upward and downward, and loosen the arable layer. It vibrates but not turns over soil layer, and not damages upper and lower structure of soil layer.

In 1979, Israel Wolf and Luth. H. J initially designed the vibrating subsoiler suitable for arid and semi-arid areas. This vibrating subsoiler breaks the pan and can realize water storage, fertility keeping and soil aeration. The vibration is mainly to reduce traction resistance and increase looseness within the soil. Vibrating deep scarification has following features:

(i) Breaking soil through vibration, favorable for reducing soil mass and favorable for sowing.

(ii) Vibrating and scarifying at the same time easily forming coexistence of upper real and lower fictional situation, and loose soil favorable for increasing soil fertility, water storage and promoting growth of crop root system.

(iii) At the same deep scarification effect (depth and width), the vibrating deep scarification breaks little surface soil, continuously implements impact cutting of soil, and the power consumption obviously decreases.

(iv) It can fundamentally solve the problem of influence of surface straws on deep scarification and thus it is more suitable for protective farming.

3.5.2 Current situation of researches of vibrating deep scarification. In 1983, Germany developed the first set vibrating subsoiler. Its operation principle: (i) eccentric vibrator brings the plough beam to make transverse vibration, so as to reduce working resistance. (ii) The eccentric vibrator drives the plough to vibration up and down, to reduce working resistance. (iii) The eccentric vi-

brator brings connecting plate of shovel handle to vibrate up and down, and drives the shovel tip to make transverse movement, which increases the loose area of soil in front of plough beam and reduces working resistance. The vibrating subsoiler can solve the problem of large resistance of deep scarification and high energy consumption. In this machine, the output shaft of tractor drives the eccentric vibrator to make the plough vibrate. The vibration frequency is generally 540 times/minutes, and it can reduce traction resistance about 20 – 40% [13].

Japan has made extensive work in research and development of multi-functional vibrating subsoiler and has made significant achievement. After the World War II, Japan originally used animal power to drive the subsoiler. With the improvement in agricultural mechanization, it used tractor to drive the plough. The largest subsoiler has 9 cutters, and the depth of deep scarification is up to 38 cm and the maximum working width is up to 244 cm. In 1989, it developed new vibrating subsoiler. This vibrating subsoiler features excellent scarification effect and small traction force. Thus, it is not only suitable for large field, but also for vegetable field, orchard, and tobacco field. It is also suitable for harvesting tuber crops. Japanese Sakai designed vibrating subsoiler with four mould boards for medium sized tractor (30 – 45 kW) and determined the optimum parameters through test in 1993: the amplitude of tooth tip is 50 mm and vibrating frequency is 3.4 Hz. When the vibrating angle is 30 degrees, its traction force is 40% less than rigid subsoiler, while the total power only increases about 2%.

For another example, E979 vibrating subsoiler produced by Uzel Company from Turkey has auxiliary power of 29.4 kW and working depth of 60 cm. In addition, there are many types of subsoilers abroad. The major difference lies in working curved surface of subsoiler. To reduce working resistance, some subsoiler shovels are mounted with small round curter.

At present, following institutions are engaged in research and production of deep scarification machinery.

(i) ISZ – 360 vibrating subsoiler designed by Hebei Agricultural Machinery Making and Repairing Station and manufactured by Hebei Huaqin Machinery Co., Ltd.

(ii) Dual spindle vibrating subsoiler jointly developed by China Agricultural University and Hebei Agricultural Machinery Making and Repairing Station, suitable for three northern areas of China.

(iii) IZS – 2 vibrating subsoiler designed by Shenyang Agricultural University, suitable for inter-row operation in intertillage. It can solve the problem of injury of crop root system due to excessively wide transverse influence area.

(iv) ISZ – 140(210) multi-functional vibrating soil modifier developed independently by Heilongjiang Water Conservancy Institute on the basis of introducing, digesting and absorbing foreign technologies. It was put into production in batches after verification by Heilongjiang Agricultural Machinery Testing Center. Combined with 37 – 59 kW tractor, this machine can complete soil breaking, rat hole drainage, fruit tree root breaking, and harvesting root type vegetables and traditional Chinese medicinal materials. It is mainly used in improving low and damp farmland, sticky soil farmland (not suitable for hanging cultivation); keeping water and fertility in slope farmland; promoting new root growth of perennial plants in pasture land and orchard. For soil with gravels, other machines are not suitable, while this machine can bring into its full play and reduce the traction force of 25% – 30% [14].

4 Conclusions

The bulk deep scarification technology is a feasible active drought fighting and effective water utilization measure. This technology breaks the pan, improves the soil permeability and aeration. Soil profile forms the structure of "upper fictional and lower real, left and right real and fictional alternately, and rat runway at bottom". After deep scarification, the soil structure is favorable for release and storage of nutrients, and also favorable for in-depth development of root system, so it is the optimum soil structure for crop growth. It causes dense part of root system to move down, which provides condition for survival of microorganism. Then, the non cultivated layer has anaerobic soil environment, corrosion and combination reaction becomes more intense, the content of organic matter gets increased, realizing the function of "improving and maintaining soil fertility". Besides, it creates excellent aerobic soil environment for arable layer, enhances aerobic decomposition, increases supply of quickly acting nutrients in soil, improves soil fertility, and realizes renovation and regeneration of agricultural resources.

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4 To strictly implement the budget

4.1 No random change of budget The implementation of budget should strictly follow the plan, and avoid any random changes of budget. Any change of expense on materials, test and experiment, fuel and energy, publishing and information broadcasting, *etc.* should be applied for by the leader of the research group and then approved by the research institute, while the expense on equipments, trips, meetings, international cooperation, labors and consultation generally allows no increase[12]. Any decrease should also be applied for first and then approved by the institute.

4.2 The expenses of the program should be specified The budget shall be used exclusively for the scientific research, and any misuse of the fund for other purposes should be forbidden. And even the necessary expenses shall be spent after careful planning and detailed calculation.

4.3 To regulate the allocation of expenses Both the man in charge of the whole research and the people in charge of each research subject should plan the use of money in advance to ensure the effective implementation of the budget.

4.4 Government procurement Government procurement aims to improve the openness and transparency of fund use. It overcomes some drawbacks of the decentralized procurement in the past. Besides, the whole procedures of government procurement are complete.

5 To execute the approval system of budget

The institute in charge of the research program should make sure reasonable expense of budget. The expense on consultation shall not be paid to those researchers from government institutes and who have been already paid.

In conclusion, both the preparation and implementation of the agricultural research budget should be carefully and seriously dealt with. Budget plays a vital role in the expense of agricultural studies. It is also of great importance to reasonably and effectively use the budget to the successful implementation of agricultural research projects. The preparation and implementation of budget should be given equal attention to. The research department should supervise the application, execution and approval of the research project, while the finance department should examine the implementation of research budget regularly. The higher organization could assign the law firm to examine the use of budget and seriously punish those illegal uses of research budget. Only when the financial and research staff work together and the preparation and implementation of budget are strictly regulated will the budget be effectively used for agriculture research.

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