DESIGN AND PERFORMANCE TEST OF THE HALF-FED AND SELF-PROPELLED GARLIC HARVESTER

/

半喂入自走式大蒜收获机的设计及性能测试

Ph.D. Eng. LÜ Xiaolian*[1)], Prof. Ph.D. Eng. HU Zhichao[2)], Prof. Ph.D. Eng. LÜ Xiaorong[3)], Prof. Eng. PENG Baoliang[2)]

[1)] Chuzhou University, College of Machinery and Automotive Engineering / China;
[2)] Nanjing Research Institute for Agricultural Mechanization Ministry of Agriculture / China;
[3)] Sichuan Agricultural University, College of Machinery & Electronics / China
Tel: 13516412415; E-mail: lxl500@163.com

Keywords: *garlic combine harvester, working principle, structural design, slign-cut device, performance testing*

ABSTRACT

Garlic harvesting is an important part during the garlic production process. Currently, the major obstacles of the garlic industry development are labour intensity, high farming time, significant losses and low efficiency. According to the characteristics of garlic cultivation in China and based on the current design experience, a half-fed and self-propelled garlic harvester, suitable for garlic producing within most areas of China, was developed. The main working parts contain the devices of stalk-dividing, stalk-lifting, stalk-clamping and conveying, clod-removing, align-cut seedling, as well as garlic collecting system, etc. To ensure the digging effect and improve working quality and stability of the machine, the combined working principle of digging and lifting has been adopted. The functions of garlic align-cut device are to align garlic and cut garlic from seedling; the handle length of cut garlic is accordance with production requirements at the same time. Through the field performance test of the garlic harvester, the operation performance is tested for stalk lifting device and align-cut device in different operating conditions. The operating performance in field is assessed through testing the machine's key performance indicators for different operating speeds. Solutions were suggested after analysing the main causes that impact its operating performance. Testing results showed: the machine has good manoeuvrability and high working efficiency; garlic loss rate≤1.8%, garlic picking broken rate≤2.1%, containing soil rate≤12.8%; all the performance indexes met the design requirements.

摘要

大蒜收获作业是其生产过程的重要部分。当前，人工劳动强度大、占用农时多、损失大、效率低等已成为影响大蒜产业发展的主要问题。针对我国大蒜种植特点，在现有研究的基础上，研制了一种适合于我国大蒜主产区收获的半喂入自走式大蒜收获机。该机主要工作部件包括：分禾装置、扶禾装置、挖掘装置、夹持输送装置、清土装置、对齐切秧装置和集果系统等。采用挖拔组合式工作原理，保证了大蒜收获中挖掘效果，提高了整机的作业质量和稳定性；设计的对齐切秧装置实现了对齐及果秧分离，同时蒜果的留柄长度满足生产要求。通过该机田间作业性能试验，测试了不同作业条件下扶禾装置及对齐切秧装置的作业效果。通过对不同作业速度下该机的主要性能指标的检测，考核该机的田间作业性能，分析影响其作业性能的主要原因及解决办法。试验结果可知：该机工作灵活、作业效率高，作业中果实损失率不大于 1.8%，破损率不大于 2.1%，含土率不大于12.8%，各项性能指标均满足设计要求。

INTRODUCTION

Garlic is the cultivation crop of labour intensity, harvesting operations being an important part during its production process. Currently, the major obstacles of the garlic industry development are labour intensity, high farming time, significant losses and low efficiency. The mature production technology and equipment abroad are difficult to adapt to the actual needs in China *(Hu Z.C. and Wang H.O., 2007; Zhang H.J. and Hu Z.C., 2010).* Some garlic planting machine and garlic harvester have been developed by some research institutes and enterprises in our country, such as: the 2ZDS-5type and 2ZDC-5 type self-propelled garlic planter, the 4S-60 type garlic harvesting machine, the 4DS-1000 type garlic excavator *(Lü X.L. and Hu Z.C., 2015; Badoiu D., Petrescu M. and Toma G., 2014; Guan M., Chen Z.Y. and Gao L.X., 2015; Hu Z.C. and Wu*

F., 2007; Hu Z.C., Wang H.O. and Wang J.N., 2010; Jiang J.C., 2007). At present, garlic harvesting mainly relies on artificial work in China, the garlic mining plow is used in some areas. Garlic harvesting machine is used in few areas, such as Shandong, Henan provinces etc., but the garlic harvester needs to be developed. Overall, the garlic mechanized harvesting technology and equipment in our country is still in the initial stages, most part of the equipment is still in prototype testing stage. They need to be improved in the quality, adaptability, reliability and economic performance. Therefore, the research and development of the garlic harvesting equipment have important significance to accelerate garlic mechanized production in China.

MATERIAL AND METHODS

Overall structure and working principle

The half-fed and self-propelled garlic harvester has been developed by Nanjing Research Institute for Agricultural Mechanization Ministry of Agriculture. At present, the production and testing of the prototype have been completed. The main working parts of the garlic harvester contained the stalk-dividing device, stalk-lifting device, digging shovel, clod-removing device, clamping and conveying chain, align-cut seedling device, cleaning device, garlic collecting system, etc.(Fig.1).

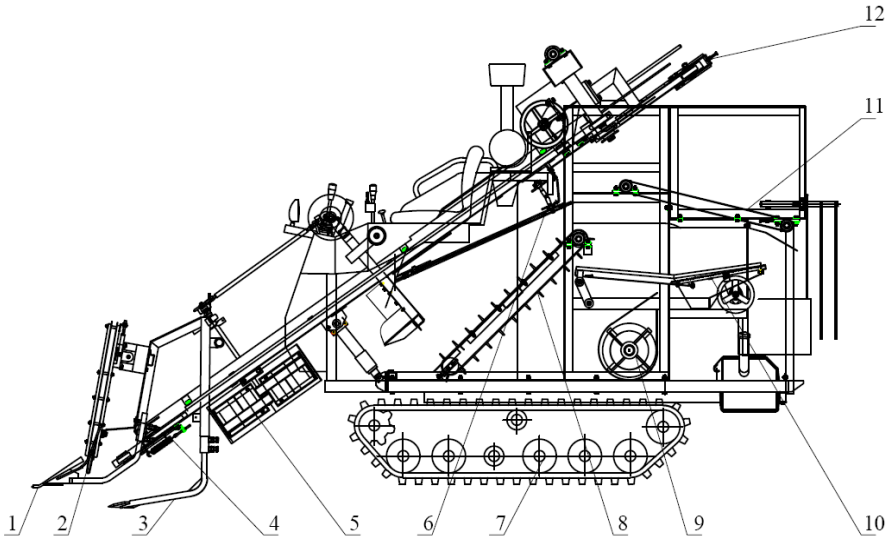

Fig. 1 - Structural scheme of the garlic harvester

1 - Stalk dividing device; 2 - Stalk lifting device; 3 - Digging shovel; 4 - Clamping and conveying chain; 5 - Removing clod device; 6 - Align-cut device; 7 - Chassis; 8 - Conveying belt ; 9 - Fan; 10 - Cleaning sieve; 11 - Seedling conveying belt; 12 - Seeding throwing chain

The harvester can complete the garlic lifting and digging, garlic seedling clamping and conveying, garlic and soil separating, garlic seedlings cutting, garlic cleaning, automatically collecting garlic, etc. *(D. R. LIU, X. J. WANG and Y.S. WANG, 2010; B. F. Li, 2008)*. When the harvester is working, garlic seedlings are separated from both sides seeding and lifted by the stalk lifting device; the digging shovel takes off the garlic roots. The garlic seeding is clamped and backward conveyed by the clamping and conveying chain. The removing clod device eliminates the soil on the garlic root. The garlic seeding is conveyed into the align-cut device with the clamping and conveying chain, and the stem according to the requirements of garlic stem length is cut off with the disc cutter. The garlic drops onto the conveying belt, and conveyed to the cleaning sieve to remove clod, fall into the collecting box at the rear of the cleaning sieve. The seedling continues to be backward conveyed, and discharged from the harvester rear.

Chassis

The chassis mainly consists of engine, speed transmission system, working system and console. The engine is of 490 Diesel type, with 33 kW set power and 2700 r/min output speed. Variable speed system includes the gearbox and hydraulic CVT. The CVT is used to adjust the speed or rotation direction of the gears. The working system is of rubber tracks style. The track centre distance is 950 mm, the track length on the ground is 1230 mm, the width is 400 mm, pitch is 90 mm and the section number is 45. Two transmission lines are designed according to the requirements of the driving system of the machine. In order to efficiently solve the power shortage, the belt tensioning wheel clutch is used. Removing clod device, conveying belt,

fan, cleaning sieve, seeding throwing chain and seedling conveying belt use a transmission line of driving system. The output power is directly supported by the engine and its speed is directly controlled by the engine. The clamping and conveying system, align-cut device and stalk lifting device use another transmission line of driving system. The power is outputted from the gearbox, and the speed varies with the working speed of the harvester.

Stalk dividing and stalk lifting device

The stalk-dividing and stalk-lifting devices separate plants on each row or furrow, upwardly lifts stalk, and feed seeding into the clamping and conveying chain (Fig.2).

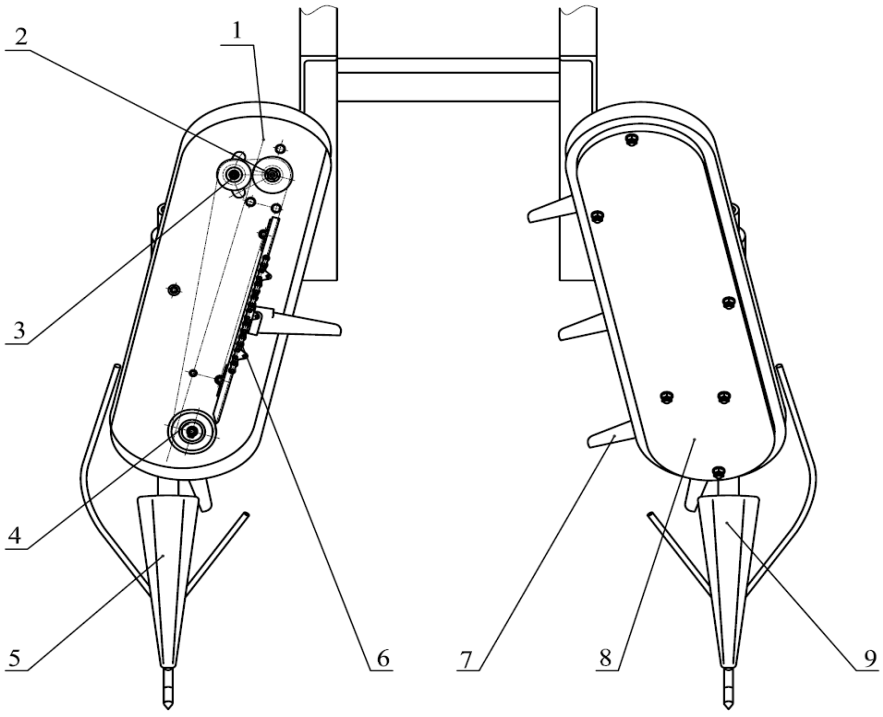

Fig. 2 - Structural scheme of the stalk dividing and lifting device

1 - Left finger chain box; 2 - Drive sprocket; 3 - Tension wheel; 4 - Pulley; 5 - Left stalk dividing device; 6 - Transmission chain; 7 - Finger; 8 - Right finger chain box; 9 - Right stalk dividing device

The stalk-dividing device is a fixed-guide structure, mounted on the front of dig-pull conveying device. The points and angle into the soil of the Digging shovel can be adjusted according to the different working conditions. The left and right finger chain boxes of the stalk lifting device have a symmetric configuration, and contain a drive sprocket, tensioned wheel, pulley, drive chain. The centre distance can be adjusted according to the garlic planting mode between the symmetrical pulley and drive chain of the stalk lifting device. The finger has two speed gears, and the gears can be chosen for the required speed of the harvester.

Dig-pull conveying device

Dig-pull conveying device is composed of the digging shovels, clamping and conveying device (Fig.3). During working, dug shovel touches the garlic fibrous roots, loosens soil and lifts up the garlic. In order to meet enough dug depth and reduce forward resistance, the digging shovel is designed with rectangular shape and inclined plane. The shovel handle is fixed onto the tube holder of the rack on both sides. The digging point and dug depth can be adjusted according to the production requirement. The main design parameters are: the entry soil angle is 30°, the between spaces of the shovels is 0~45 cm, the digging width is 40~95 cm, the digging depth is 0~12 cm. The entrance of the clamping and conveying chain is in the V shape, the garlic seedling is clamped at about 20° to vertical direction and backward conveyed. In order to adjust the extracting height of the garlic seedling, the hydraulic lifting and the depth-limiting mechanic structure are designed. The opening size at entrance can be adjusted with the adjusting wheel, and the tension force of the clamping and conveying chain can be adjusted with the tension spring.

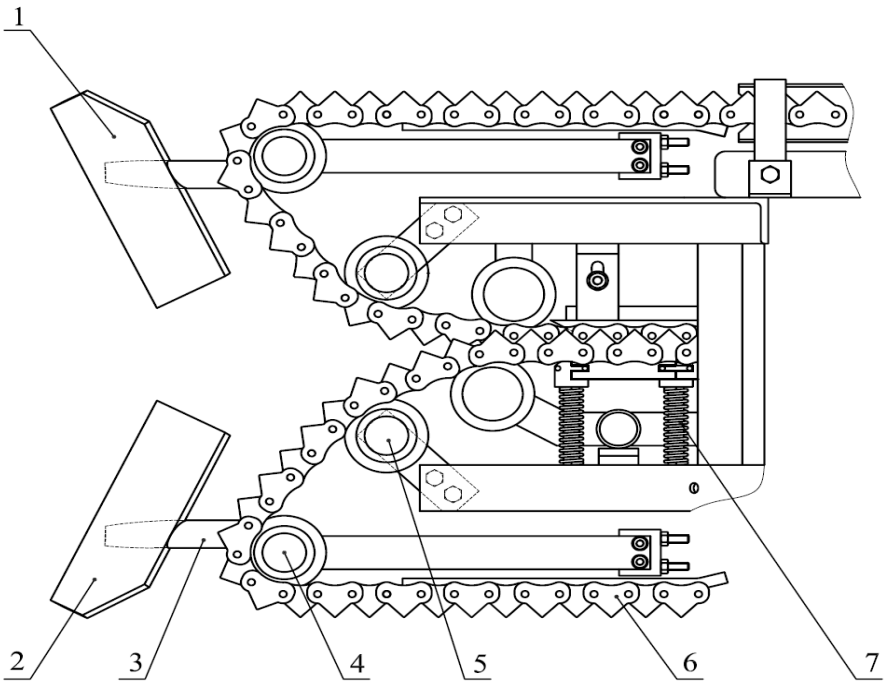

Fig. 3 - Structural scheme of the dig-pull device

1 - Left digging shovel; 2 - Right digging shovel; 3 - Shovel handle; 4 - Adjustment wheel I; 5 - Adjustment wheel II; 6 - Clamping and conveying chain; 7 - Tensioned spring

Align-cut seedling device

The device mainly composed of the left and right guide rod, upper clamping chain, alignment chain, arranged disk of garlic, hook, disk cutter, etc. (Fig.4). The garlic seeding is clamped with upper clamping chain and backward conveyed, and orderly arranged at the entrance on the guide bar. Each hook grabs a garlic seedling through combined action of arranged disk. The garlic is conveyed backward through combined action of the upper clamping chain and alignment chain, aligned and cut by the disc cutter. The garlic seedling continues to be backward conveyed by the clamping chain. The garlic remain handle length is determined by the position of the disc cutter.

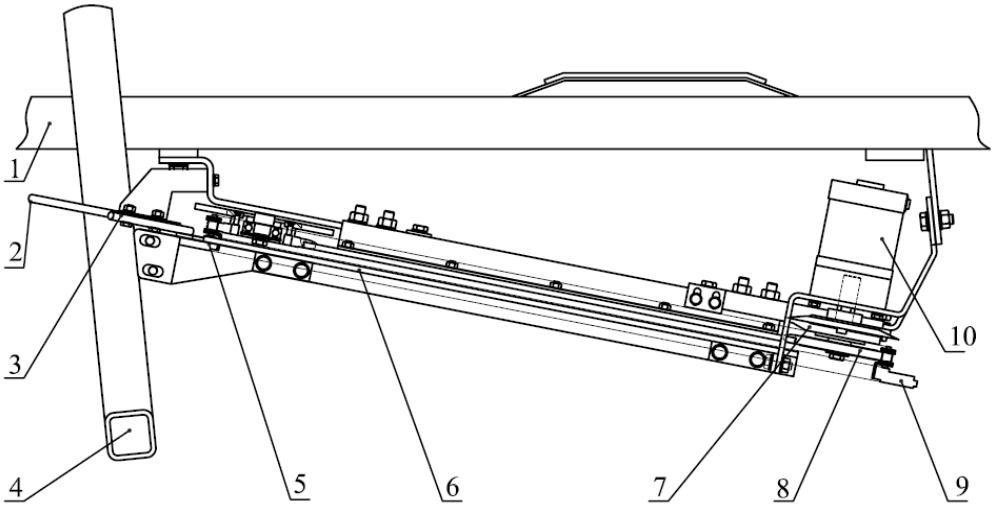

Fig. 4 - Structural scheme of the align-cut device

1 - The upper clamping chain; 2 - Left guide rod; 3 - Right guide rod; 4 – Rack; 5 –arranged disk of Garlic; 6. Align chain; 7 - Disc cutter; 8 – Sprocket; 9 - Hook; 10 - Motor

Performance test

Test content: (1) the performance test of the working parts. The operating performance of the stalk lifting device and align-cut device in different conditions are tested respectively. (2) the operations quality test of the whole machine. This test is destined mainly to assess the operation effect of the garlic combined harvester and provides the basis for further optimized and improved machine design.

Test conditions: the test is carried out at Pizhou City, Jiangsu province; it is in sand soil; the garlic planting pattern is wide and narrow planter suitable for mechanized operations, the narrow row space is 20 cm, the wide row space is 40 cm; the growth characteristic parameters of the garlic, soil compaction and moisture content are measured; the results are shown in Table 1.

Table 1

Garlic growing characteristics and soil conditions

Parameter	Measurement results
Height of garlic seeding, [cm]	34
The flower stalks diameter, [cm]	1.6
Bulb diameter, [cm]	6.5
Bulb height, [cm]	4.7
Garlic depth, [cm]	0-10
Plant spacing, [cm]	19.6
Row spacing, [cm]	13.3
10-15 cm soil moisture [%]	48.64
10-15 cm soil compaction, [kN/cm^2]	0.085

The indexes of the operations quality of the whole machine are as follows: injury garlic rate, loss rate, containing soil rate and the productivity. During the test process, the speed of the harvester is set at 0.36 m/s or 0.54 m/s, the digging depth is 120~130 mm. The test zero is 30 m long, and three testing cells are randomly chosen from the test zero.

The length of each test cell is 5 m. In the test cell, the garlic dug up manually in field (as buried garlic), the garlic dug up by the harvester but not clamped (as loss garlic), garlic harvesting by the harvester in the testing cell (as harvested garlic) and all the trauma of the garlic (as damaged garlic), were weighed. Harvested garlic weight is w_1, garlic loss weight is w_2, buried garlic weight is w_3, damaged garlic weight is w_4, the soil weight of harvested garlic is w_5, test indicators are shown as follows *(Liu J.J., 2008; Li S. X., 2015; Li Z.X., 2010; LU Z.M., 2011)*:

Loss rate:

$$r_1 = \frac{w_2 + w_3}{w_1 + w_2 + w_3} \times 100\% \quad (1)$$

Damaged garlic rate:

$$r_2 = \frac{w_4}{w_1 + w_2 + w_3} \times 100\% \quad (2)$$

Containing soil garlic rate:

$$r_3 = \frac{w_5}{w_1 + w_5} \times 100\% \quad (3)$$

Productivity:

$$P = \frac{LH/10000}{T/3600} = \frac{0.36LH}{T} \quad [\text{hm}^2/\text{h}] \quad (4)$$

In the formula:

P- Productivity [hm^2/h]; T- The time used by the prototype to pass through the testing zero, [s];

L- The length of the testing zero, [m]; H- Operating width, [m].

RESULTS

Performance test results

The performance of the stalk lifting device is tested in the garlic upright and lodging status (Fig. 5). The testing results show that more upright the garlic is, the better the operating effect of the stalk lifting device is.

(a) Plants upright *(b) Plants lodging*

Fig. 5 - Working effect of the stalk lifting device

The working quality of the align-cut device is mainly affected by the arranged status of plants, the clamping position and the feed quantity.

The effects of remain handle length is tested in different conditions. From the harvested garlic in test zero, 20 are randomly selected to test their handle length in each condition. The handle length is measured from the garlic fake stems to the top of the garlic bulb. The handle length is set 5 cm. In the test, the align-cut device performs better with plants upright status, the statistical results of the handle length in different conditions being shown in Table 2.

Table 2

Statistics result of garlic handle length

Plant status	Gear	Maximum	Minimum	Mean	Variance
		(cm)	(cm)	(cm)	
Upright	I	6.50	4.58	5.01	0.421
	II	6.50	4.60	5.06	0.447
Lodging	I	6.80	4.54	5.41	0.579
	II	7.00	4.58	5.46	0.696

Operating quality *test results*

The test results are shown in Table 3. Machinery harvest effect is shown in Fig. 6 and Fig. 7.

Table 3

Test result of the garlic combine harvester

Test parameters		Test indexes			
Speeds	Digging depth	Loss rate	Rate of injuries	Containing soil	Productivity
(m/s)	(mm)	(%)	garlic (%)	rate (%)	(hm^2/h)
0.36	130	≤1.8	≤2.1	≤12.8	0.078
0.54	120	≤3.1	≤3.8	≤14.5	0.116

Fig. 6 - The effect of the machine harvesting the garlic

Fig. 7 - The situation after the harvesting in field

CONCLUSIONS

The developed half-fed and self-propelled garlic combined harvester can complete a variety of functions from digging, cleaning clod, clamping and conveying, align-cutting to collecting, etc. The test results are shown:

(1) The upright status of the garlic seedlings has a more significant influence on the harvester operating effect. The better the garlic upright status is, the better stalk lifting device propped the garlic seedlings. The garlic can be orderly conveyed to the align-cut device, so that the uniformity of the garlic handle length is improved, and the harvester performance is stable and reliable. When the lodging status of the garlic is more serious, the stalk lifting device cannot propel the garlic seedlings. The garlic seedling cannot or cannot orderly be conveyed into the clamping and conveying chain, and the garlic seedling cannot be aligned or easily pulled off, so that it is difficult to ensure the accuracy and uniformity of the handle length.

(2) The operating speed of the harvester has a significant influence on the operations quality. When the speed is too high, it easily leads to garlic leaking and clogging due to the garlic holder or backward transport untimely, and easily cause obstruction at the entrance of the align-cut device. At the same time, the garlic cannot be aligned and it is difficult to guarantee the length of the handle length.

(3) The main reason for damaging garlic is that the garlic makes friction and collision with the device in the process of clod removing and garlic cleaning. The harvester can be improved in terms of working surface, clod removing and parts cleaning with adopting rubber or plastic material to enhance its cushioning effect.

ACKNOWLEDGEMENT

The study was supported by Excellent Talents Training Program by the Ministry of Education (gxfx2017125), the National Natural Science Foundation of China (51375247) and planning project of Chuzhou University (2015GH43).

REFERENCES

[1] Badoiu D., Petrescu M., Toma G., (2014), On the Analysis and Synthesis of the Quadrilateral Mechanism, *J. Balkan Tibological Association*, Vol.20, Issue 2, pp.161-169, Ed. Elsevier, London/U.K;

[2] Guan M., Chen Z.Y., GaO L.X., (2015), Multifunctional modular full-feeding peanut picking testing device, *Transactions of the Chinese Society for Agricultural Machinery*, Vol.46, Issue 11, pp.88-94, Ed. Elsevier, London/U.K;

[3] Hu Z. C., Wang H.O., (2007), Summary of mechanized cultivation and processing of garlic in America, *Journal of Anhui Agricultural Sciences,* Vol.35, Issue 13, pp. 4059-4061, Anhui/CHN;

[4] Hu Z. C., Wu F., Wang H.O., (2007), The garlic harvesting machinery status in the world, *Farm Machinery,* Issue 6, pp. 47-49, Beijing/CHN;

[5] Hu Z.C., Wang H.O., Wang J. N., (2010), Experiment on 4HLB-2 Type Half Feed Peanut Combine Harvester, *Transactions of the Chinese Society of Agricultural Machinery*, Vol.41, Issue 4, pp.79-84, Ed. Elsevier, London/U.K;

[6] Jiang J.C., (2007), Present status of the technology and development direction of garlic harvesting mechanization, *Agricultural Equipment & Technology,* Vol. 33, Issue 12, pp.18, Jiangsu/CHN;

[7] Li B.F., (2008), Agricultural machinery study, *China Agriculture Press*, Beijing/CHN;

[8] Li S.X., Shang S.Q., (2015), Researching design and experiments of spring tined type peanut mechanism, *Journal of Agricultural Mechanization Research,* Vol. 3, Issue 2, pp.136-139, Heilongjiang/CHN;
[9] Li Z.X., Du S. K., (2010), Experimental optimization design and statistical analysis, Science press, Beijing/CHN;
[10] Liu J.J., Song J.N., (2008), Analysis and discussion of garlic harvesting machine, *Journal of Agricultural Mechanization Research,* Issue 1, pp. 32-39, Heilongjiang/CHN;
[11] Liu D.R., Wang X.J., Wang Y.S., (2010), Experiment and analysis on optimizing parameters of 4S-6 type garlic harvester, *Journal of Qingdao Agricultural University (Natural Science),* Vol.27, Issue 1, pp. 81-83, Shandong/CHN;
[12] Lu Z.M., Kuai J., Rao Y., (2011), Test and analysis of segmented garlic bulb harvest machine, *Agricultural Equipment and Vehicle Engineering,* Vol.234, Issue1, pp. 28-31, Shandong/CHN;
[13] Lü X. L., Hu Z.C., Zhang Y.H., (2015), Design and performance testing of the half-feed peanut picker, *Journal of Huazhong Agricultural University,* Vol.34, Issue 3, pp. 124-129, Hubei/CHN;
[14] Zhang H. J., HU Z. C., WU F., (2010), The planting and harvesting overview of garlic mechanization in China, *Jiangsu Agricultural Sciences,* Issue 3, pp. 460-461, Jiangsu/CHN.