

Design and Experiment of Orchard Gas Explosion Subsoiling and Fertilizer Injection Machine

Xiaobo Xi, Ruihong Zhang

Abstract—At present, the orchard ditching and fertilizing technology has a series of problems, such as easy tree roots damage, high energy consumption and uneven fertilizing. In this paper, a gas explosion subsoiling and fertilizer injection machine was designed, which used high pressure gas to shock soil body and then injected fertilizer. The drill pipe mechanism with pneumatic chipping hammer excitation and hydraulic assistance was designed to drill the soil. The operation of gas and liquid fertilizer supply was controlled by PLC system. The 3D model of the whole machine was established by using SolidWorks software. The machine prototype was produced, and field experiments were carried out. The results showed that soil fractures were created and diffused by gas explosion, and the subsoiling effect radius reached 40 cm under the condition of 0.8 MPa gas pressure and 30 cm drilling depth. What's more, the work efficiency is 0.048 hm²/h at least. This machine could meet the agronomic requirements of orchard, garden and city greening fertilization, and the tree roots were not easily damaged and the fertilizer evenly distributed, which was conducive to nutrient absorption of root growth.

Keywords—Gas explosion subsoiling, fertigation, pneumatic chipping hammer exciting, soil compaction.

I. INTRODUCTION

THE fertilizing operation is crucial in orchard planting and management process, which will directly affect the quality and output of fruit, and will decides the growth and development of fruit trees [1], [2]. The ditching machine is the most widely used in the existing fruit tree fertilization machinery. Fruit trees ditching fertilization is generally used ditching machinery firstly in the orchard spacing to dig a trench with the width of 30 cm and the depth about 30 ~ 50 cm, and then completing fertilization and filling soil artificially [3]-[5]. However, there are some problems such as high tillage resistance and easy tree roots damage in ditching operation. What's more, the fertilizers concentrate in the trench with uneven diffusion, which is not conducive to tree roots uniform fertilizer absorption [6], [7]. In addition, the soil is easily compacted due to perennial non-tillage, which is not conducive to the storage of natural precipitation, that resulting in the water, gas and heat not get through in soil. The nutrient delivery capacity decreases due to soil capillary damage, and the tree roots growth is blocked by sharp decline of soil biological and organic matter [8], [9]. Therefore, deep

subsoiling of orchard soil is very necessary. Although the trenching operation has the effect of loosening soil, the width of the ditches is small, and the degree of soil disturbance is low, that results in indistinctive subsoiling effect [10], [11].

In view of the above deficiencies of the ditching fertilization process, a kind of orchard gas explosion subsoiling and fertilizer injection machine was designed in this paper, which used high pressure gas to shock soil body and then injected fertilizer. The drill pipe mechanism was designed to drill the soil, which was driven by pneumatic chipping hammer and assistance cylinder. The PLC system was adopted to improve the whole machine control and reduce the manual operation burden. In addition, the effect of subsoiling and fertilizer injection was analyzed, and the field work efficiency of the machine was tested in this paper.

II. OVERALL STRUCTURE AND WORKING PRINCIPLE

A. Overall Structure

This designed orchard gas explosion subsoiling and fertilizer injection machine was mainly composed of machine frame, air compressor, hydraulic station, liquid pump, linear actuator, liquid manure tank, gasholder, swing arm, pneumatic chipping hammer, hydraulic rod, drill pipe, mounted frame, power input unit and other components. Fig. 1 shows the 3D model of the machine in SolidWorks software. The machine was connected with the tractor through mounted frame; the machine power was from tractor PTO shaft and transmitted by the tractor universal joint to the power input unit of the machine. The air compressor was driven by the power input unit through a belt, which generated high-pressure gas for soil drilling and gas explosion subsoiling of pneumatic chipping hammer. The linear actuator was driven by tractor accumulator and was connected with the swinging arm to form a pendulum mechanism, so that the fertilization position could be rapidly adjusted steplessly. The hydraulic cylinder was fixed on the swing arm, the pneumatic chipping hammer was installed on the top of the hydraulic piston rod, the drill pipe was fixed at the bottom of the pneumatic chipping hammer, and the drill pipe is drilled and picked up by pneumatic chipping hammer excitation with hydraulic assistance. The liquid manure tank was placed on the upper end of the machine frame, and liquid injection was completed by the liquid pump which was connected to the power input unit through a belt. In addition, the machine also contained gas and liquid pipes, while the machine operation was completed by the PLC control system.

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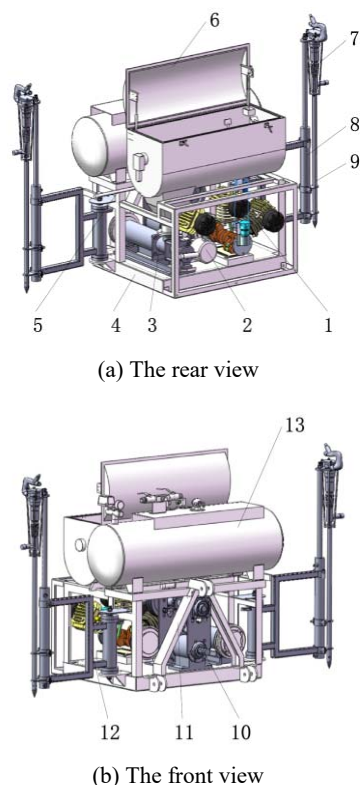


Fig. 1 Overall structure of orchard gas explosion subsoiling and fertilizer injection machine. 1. Air compressor, 2. Hydraulic station, 3. Liquid pump, 4. Machine frame 5. Linear actuator, 6. Liquid manure tank, 7. Pneumatic chipping hammer, 8. Hydraulic rod, 9. Drill pipe, 10. Power input unit, 11. Mounted frame, 12. Swing arm, 13. Gasholder

B. Working Principle

The air compressor was started to get high pressure gas firstly when the machine worked, then the linear actuator was opened to adjust the swing arm to the appropriate fertilization position, after that the pneumatic chipping hammer was worked and made drill pipe drill soil with hydraulic assistance, as shown in Fig. 2 (a). The high pressure gas was released when the drill pipe reached the required fertilizer depth, and made the soil explosion subsoiling and created of cracks which could provide space for liquid fertilizer injection and promote the air flow inside the soil, as shown in Fig. 2 (b). The liquid fertilizer was injected in soil after finishing the process of gas explosion subsoiling, and evenly dispersed in the soil cracks under the action of the pump, as shown in Fig. 2 (c). After the above operations, a little air flow was made to reduce the stick resistance between the drill pipe and the wet soil, and then the hydraulic rod was extended to make the drill pipe rise, as shown in Fig. 2 (d). Aiming at the characteristics of agronomic technology of low orchard planting at present, the main technical parameters of the designed machine were shown in Table I.

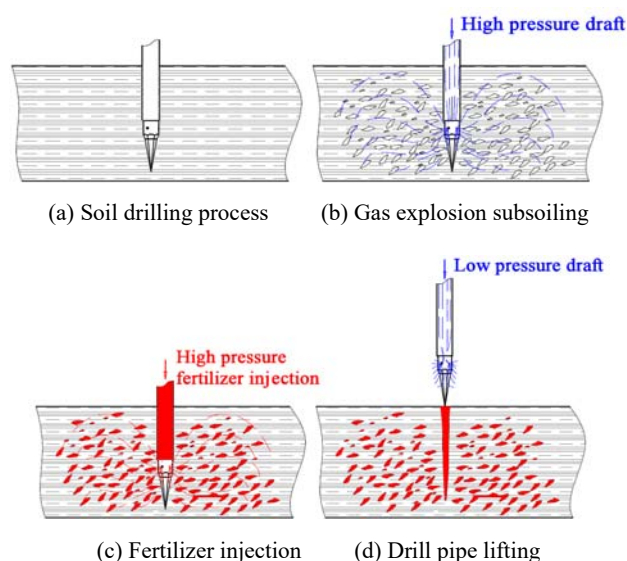


Fig. 2 Working process of orchard gas explosion subsoiling and fertilizer injection machine

TABLE I
MAIN TECHNICAL PARAMETERS OF ORCHARD GAS EXPLOSION SUBSOILING AND FERTILIZER INJECTION MACHINE

| Item | Technical parameters |
|--|------------------------------|
| Matched power/kW | 29.4~36.7 |
| Hitch type | Standard three-point mounted |
| Drill pipe quantity | 2 |
| Liquid manure tank capacity/L | 100 |
| Maximum depth of injection/cm | 50 |
| Gas explosion pressure/MPa | 0.4~0.8 |
| Ventilation volume of single working/m ³ | 0.01 |
| Fertilizer injection pressure/MPa | 1.2 |
| Fertilizer type | Liquid |
| Working efficiency/(hm ² ·h ⁻¹) | >0.048 |
| Control mode | PLC |

III. KEY COMPONENTS DESIGN

A. Subsoiling and Fertilizer Injection Mechanism

Fig. 3 was the structure diagram of subsoiling and fertilizer injection mechanism which was mainly composed of swing arm, single-piston hydraulic cylinder, pneumatic chipping hammer, drill pipe and other components. The hydraulic cylinder is fixedly connected with the swing arm frame, the drill pipe is fixed at the bottom of the pneumatic chipping hammer. The structure of pneumatic chipping hammer & drill pipe was fixedly connected with the top of the piston rod through a bracket, and the drill pipe could drill and lift by pneumatic chipping hammer excitation and hydraulic assistance. The drill pipe was deeply drilled by squeezing the soil layer, realizing the subsoiling by gas explosion and fertilizer injecting by pump. Compared with traditional machine with the technology of ditching, subsoiling, fertilizing and earth-covering, this new designed machine had the advantages of small farming resistance, small working energy consumption, uniform fertilization and no the tree roots damage. The maximum drilling depth of the mechanism was

designed as 50 cm, which could meet the depth requirement of most fruit trees for fertilizer application.

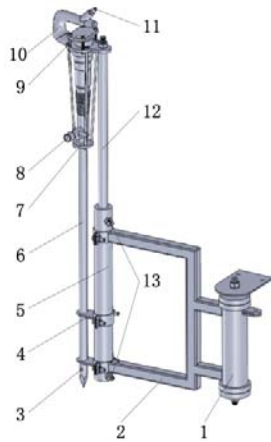


Fig. 3 Structure diagram of subsoiling and fertilizer injection mechanism. 1. Swing arm rotary column, 2. Swing arm frame, 3. Gas explosion and fertilizer injection hole, 4. Drill pipe holder, 5. Hydraulic cylinder, 6. Drill pipe, 7. Gas inlet, 8. Fertilizer inlet, 9. Pneumatic chipping hammer holder, 10. Pneumatic chipping hammer, 11. Gas inlet of pneumatic chipping hammer, 12. Piston rod, 13. Hydraulic fluid port

B. Gas and Liquid Piping

Fig. 4 was the gas and liquid piping layout of the machine which had two independent controlled subsoiling and fertilizer injection mechanisms at left and right side. The on-off control of the gas and liquid piping was by the electromagnetic valve by the control of PLC. These two subsoiling and fertilizer injection mechanisms could work alone and synchronously.

Gas piping control made high pressure gas in gasholder transmit to the left and right pneumatic chipping hammer and drill pipe through a five-way pipe. Electromagnetic valve A and B were placed in the gas path of the left and right pneumatic chipping hammer respectively, and the valve would open to made high pressure gas inside the pneumatic chipping hammer when drilling soil. Electromagnetic valve C and D were placed in the gas path of the left and right drill pipe respectively, and the valve would open to made high pressure gas explode inside the soil when subsoiling. In addition, a little air flow into drill pipe was necessary to reduce the stick resistance when pipe lifting. What's more, a check valve was arranged on the gas path between the drill pipe and the electromagnetic valve to prevent the liquid entering the gas piping and thus protecting the gas path.

Liquid piping control made the liquid fertilizer from the tank injected into the soil by the pump. Three liquid paths were arranged, two of them were connected to the left and right drill pipe, the other one was used for the circulation of liquid fertilizer in the tank. In order to prevent the path clogging caused by higher concentration liquid fertilizer when fertilizer injection was unneeded, the liquid fertilizer would be stirred by the agitation equipment constantly to keep uniform with the electromagnetic valve G opened, E and F closed. While the electromagnetic valve G would be closed, E and F

opened when fertilizer injection was needed.

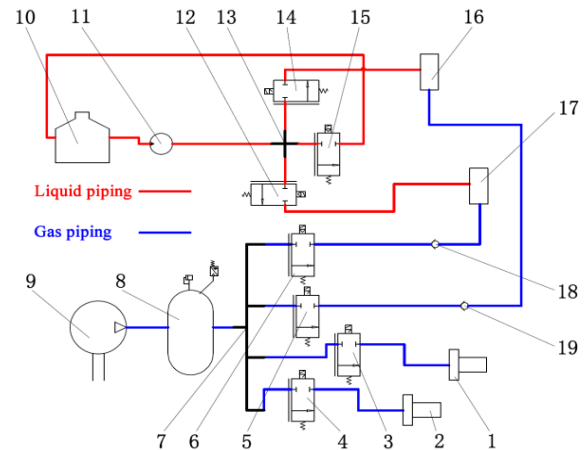


Fig. 4 Air and liquid piping layout of orchard gas explosion subsoiling and fertilizer injection machine 1. Left pneumatic chipping hammer, 2. Right pneumatic chipping hammer, 3. Electromagnetic valve A, 4. Electromagnetic valve B, 5. Electromagnetic valve C, 6. Electromagnetic valve D, 7. Fiveway pipe, 8. Gasholder, 9. Air compressor, 10. Liquid manure tank, 11. Liquid pump, 12. Electromagnetic valve E, 13. Fourway pipe, 14. Electromagnetic valve F, 15. Electromagnetic valve G, 16. Left drill pipe, 17. Right drill pipe, 18. Check valve A, 19. Check valve B

IV. FIELD EXPERIMENT

A. Experimental Process

Experimental prototype of orchard gas explosion subsoiling and fertilizer injection machine was shown in Fig. 5. The average soil compaction of the field was 4.353 MPa, the soil moisture content was 13.5%, and the outdoor temperature was 32 °C. Liquid fertilizer was used for injection with water concentration of 350 g/L and depth of 30~50 cm adjustable. The effect of subsoiling and fertilizer injection was analyzed, included the soil internal changes, the soil compaction and the fertilizer diffusion, also the machine field work efficiency was tested.



Fig. 5 Experimental prototype of orchard gas explosion subsoiling and fertilizer injection machine

B. Experimental Results

Fig. 6 showed the soil cross section morphology after gas explosion subsoiling with 30 cm gas explosion depth and 0.8 MPa gas explosion pressure. Fractures were generated in soil

after gas explosion, and extended radially outward from the gas explosion center with propagation disturbance radius about 40 cm. In addition, soil surface was uplifted by the role of gas explosion with the maximum rising height about 25 mm compared with the original, indicating that the gas flow would leak outwards from soil surface during gas explosion and promote soil loose.



Fig. 6 Soil cross section morphology after gas explosion subsoiling

Soil compaction test was carried out before and after the gas explosion with a soil compaction tester. When measuring, the soil surface should be centered on the gas explosion center and separated into rings by 10 cm apart, and the measure depth was 30 cm. The compaction value of each of the ring should be averaged at eight points, as shown in Fig. 7.

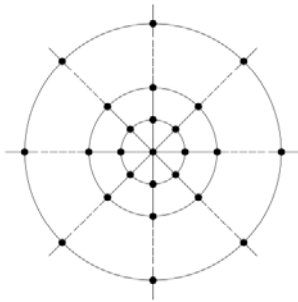


Fig. 7 Schematic diagram of soil compaction test points

Fig. 8 showed the relationship between soil compaction and radius from gas explosion center before and after gas explosion. It could be seen that the soil compaction increased with the increase of radius, so that the soil compaction decreased significantly within radius of 40 cm, and the average soil compactness descent rate reached 40.5%. The soil compaction was basically consistent with that before gas explosion when the radius reached 60 cm. It indicated that the significant subsoiling area achieved by gas explosion process was a circle with a radius of 40 cm, which was at the same length of fracture propagation disturbance radius.

In order to observe the effect of fertilizer diffusion in soil by high-pressure, the fertilizer injection test was conducted with the centre 10 cm outward the cross-section and the drilling depth of 50 cm, as shown in Fig. 9. It could be clearly seen that the liquid globules spilled in the trench, this demonstrated that the fertilizer could diffuse evenly in soil without blocking under the pump pressure of 1.2 MPa. This test proved that the machine could meet the operational requirements of orchard fertilizer injection.

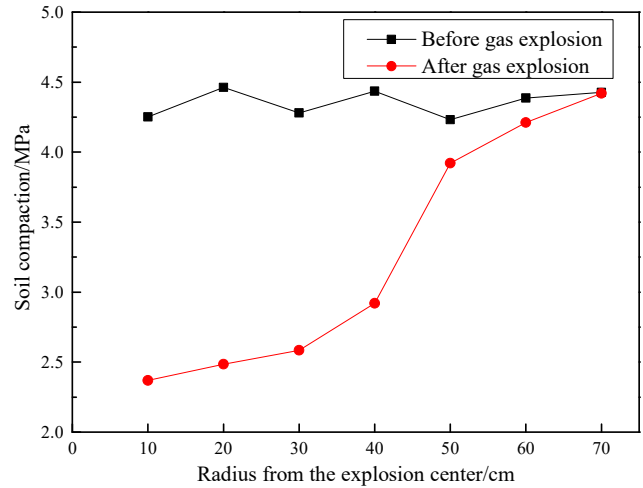


Fig. 8 Relation curve between soil compaction and radius from gas explosion center before and after gas explosion



Fig. 9 Fertilizer injection effect in soil by high pressure

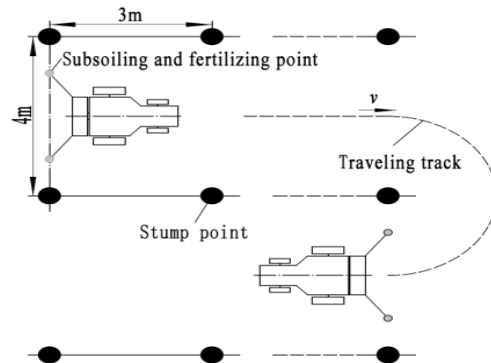


Fig. 10 Diagram of prototype operation way

The test field was planted trees with line spacing of 4 m and row spacing of 3 m, the subsoiling and fertilizing point was located between two trees at a distance of 1 m from the stump, as shown in Fig. 10. The machine would transfer to the adjacent row to continue working after finishing of one row work, so two fertilization points were set for each tree to ensure the uniformity of fertilization. Four-step process of drilling, subsoiling, fertilizing, lifting was considered as a test group, and both left and right subsoiling and fertilizer injection mechanism worked simultaneously. According to the statistics, the time required for completing 30 test groups was 30 min with the fertilizing depth of 50 cm and the single fertilizer injected amount of 1 L, so the machine work efficiency was 0.048 hm²/h. However, the machine work

efficiency would be different due to the difference of fertilization process, and it would be improved if a single tree needs only one fertilization point or the fertilizing depth was less than 50 cm. Therefore, the machine work efficiency was at least 0.048 hm²/h.

V. CONCLUSION

This designed orchard gas explosion subsoiling and fertilizer injection machine achieved the joint operations of subsoiling and fertilizing, and met the requirements of orchard planting agronomy. It changed the traditional orchard field management mode of first ditching, then fertilizing and last soil covering. It could complete soil subsoiling and fertilizer injection in an operation, and make perennial orchard field with no tillage be loosened with the increase of soil permeability and the reduce of soil structure damage. Meanwhile, it was conducive to trees growth with no roots damage.

Fractures were generated in soil after gas explosion and extended radially outward from the gas explosion center with propagation disturbance radius about 40 cm under the conditions of 30 cm gas explosion depth and 0.8 MPa gas explosion pressure. The liquid fertilizer could diffuse evenly in soil without blocking, and the machine work efficiency was at least 0.048 hm²/h.

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