

# PERFORMANCE EVALUATION OF AN OBSTACLE AVOIDANCE MOWER ASSEMBLY IN TRUNK TYPE PEAR ORCHARD

## 可避障复合式割草机在主干型梨园中的性能评估

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### ABSTRACT

To solve the problem of mechanized weeding in trunk type pear orchard, combined with the technology of stubble elimination and hydraulic obstacle avoidance, the authors designed an obstacle avoidance mower assembly. This paper carried out a field performance evaluation test to verify its usefulness. Six indexes were tested to evaluate its working performance. The results were: inter-row crushing rate of 89.99%, intra-row miss cutting rate of 2.42%, stubble stability coefficient variation of 4.25%, working efficiency of 0.32 hm<sup>2</sup>/h, fuel consumption of 16.25 L/hm<sup>2</sup>, profitable area of 0.75 hm<sup>2</sup>. The study could provide a reference for orchard mechanized weeding.

### 摘要

为了解决主干型梨园机械化除草问题, 结合割茬粉碎和液压避障技术, 作者设计了一款可避障复合式割草机。本文采用 6 项指标来对机具进行性能评估试验以证明其实用性。结果显示: 行间碎草率为 89.99%, 株间漏割率为 2.42%, 割茬稳定性变异系数为 4.25%, 工作效率为 0.32 hm<sup>2</sup>/h, 燃料消耗为 16.25 L/hm<sup>2</sup>, 盈利面积为 0.75 hm<sup>2</sup>。本研究可为果园机械化除草提供参考。

### INTRODUCTION

Weeding is a necessary agronomic section in pear orchard management. Herbicide causes droplet drift (Wang C. *et al.*, 2020), since it not only damages fruit tree but also destroys the ecological environment (Kehayov D. *et al.*, 2020). Also, abuse of herbicide promotes weed resistance (Gaines T. A. *et al.*, 2020). With the development of orchard grass planting technology (Arentoft B. *et al.*, 2013; Bai G. *et al.*, 2018; Martinelli R. *et al.*, 2017), chemical weeding has been replaced by mechanized mowing in recent years.

Research on mechanical orchard mower is little and started late in China, mostly focused on intra-row mower with sensor detection. Li X. *et al.*, (2019) developed an orchard offset traction type mower, on which the position of cutter can change shape with the ridge surface. Ma P. *et al.*, (2019), developed an orange orchard profile mower, which can adapt to profile work on mountain terrain. Xu L. *et al.*, (2018), developed an intra-row automatic obstacle avoidance mower for trellis grape orchard. The coverage rate of intra-row weeding was 98.1% in the field test. Related research is mature in European and American countries, who concentrated on developing new machines at early age, such as grape intra-row multi-process cultivator produced by Italy Orizzonti, Spraydome series under tree weed mower produced by America Micron Group, and DR series variable width mower produced by Dutch Van Wamel BV. In recent years, the researchers are focused on the effect evaluation of different mechanical weeding methods and new mowing robots. Mia *et al.*, (2020), studied the working performance of integrated weeding in orchards. The indexes include weed species diversity, soil coverage, weed biomass production, soil nitrogen status, and weed abundance. Muhammad Z. *et al.*, (2021), developed a robotic lawnmower for small Japanese pear orchard. It can control the growth of the weed for years automatically.

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Trunk type is a mainstream mechanized cultivation pattern for pear orchard. The current weeding method is inter-row rotary tiller combined with intra-row artificial weeding, demonstrating lower efficiency and poor effect. Combined with the technology of stubble elimination and hydraulic obstacle avoidance, the authors designed an obstacle avoidance mower assembly (OACM) that can be used for efficient mechanized weeding (Lei X. *et al.*, 2020). A field performance evaluation test was carried out in trunk type pear orchard. Six indexes were tested to evaluate the working performance, including inter-row crushing rate, intra-row miss cutting rate, stubble stability, working efficiency, fuel consumption and profitable area. The study could provide a reference for mechanized weeding in orchards.

## MATERIALS AND METHODS

### Structure and working principle of OACM

Planting distances between rows in various orchards are different. For better general use, the mower was designed as unilateral obstacle avoidance type. The whole machine is suspended and driven by a tractor. It is composed by suspension bracket, hydraulic system, mechanical transmission system, inter-row crushing mechanism, intra-row obstacle avoidance cutting mechanism and soil compactor. The inter-row crushing mechanism adopted the roller type stubble cutter, which can crush and return the weed to the field. The intra-row obstacle avoidance cutting mechanism adopted the horizontal rotation obstacle avoidance cutting disc, which can cut weeds without harming the trunk and the root. The structure of the mower is shown in Fig. 1. As shown by the dotted line and arrows in Fig. 2, the mower works in the field along an S-shaped line.

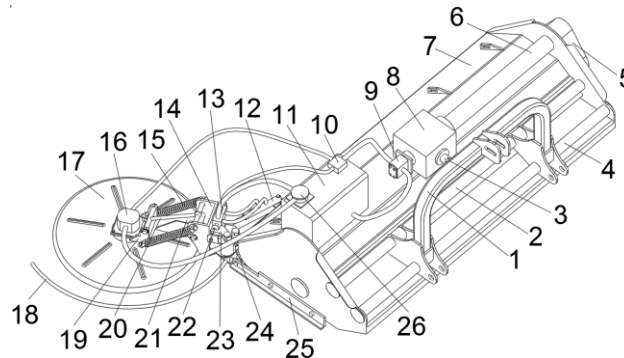


Fig. 1 - Structure of the OACM

1. Suspension bracket; 2. Lateral movement hydraulic cylinder; 3. Power input shaft; 4. Cylindrical rail; 5. Transmission belt shell;
6. Pulley transmission shaft cover; 7. Frame; 8. Bevel gearbox; 9. Gear pump; 10. Hydraulic distribution valve; 11. Hydraulic oil tank;
12. Obstacle avoidance hydraulic cylinder; 13. Hydraulic directional valve; 14. Rotation bracket; 15. Vibration damper;
16. Hydraulic motor; 17. Obstacle avoidance disc; 18. Detection rod; 19. Obstacle avoidance disc bracket; 20. I-shaped profiling bracket;
21. Profiling plate; 22. Plunger; 23. Press block; 24. Soil press roller; 25. Soil press roller bracket; 26. Filter

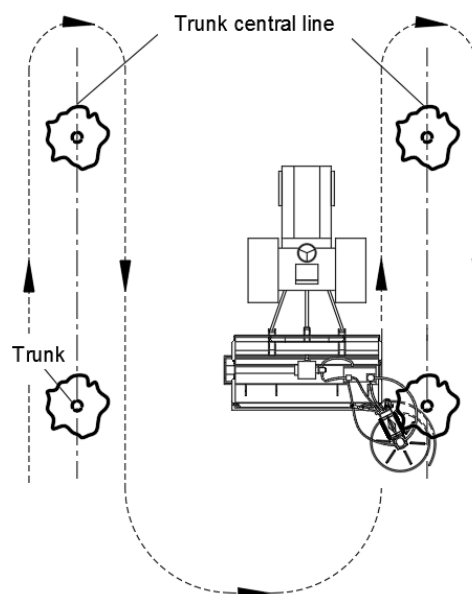


Fig. 2 - Movement path of OACM

The tractor should be equipped with a hydraulic output system to control the position of inter-row crushing mechanism. When the hydraulic cylinder extends, the whole machine moves to the right and the mower approaches the tree. When the hydraulic cylinder shrinks, the whole machine moves to the left and the mower gets far away from the tree. In the working process, tractor PTO drives the power input shaft to rotate through the universal shaft. The tractor transmits power to pulley transmission shaft and gear pump through bevel gearbox. Gear pump supplies hydraulic oil to the hydraulic directional valve and hydraulic motor. Pulley mechanism drives inter-row crushing roller to rotate and hydraulic motor drives intra-row cutting disc to rotate. Hydraulic directional valve drives the obstacle avoidance disc swing around the tree trunk by controlling the obstacle avoidance hydraulic cylinder. A rubber ring is fixed around the obstacle avoidance disc to prevent the steel structure from scraping the trunk. Parallelogram profiling mechanism connects obstacle avoidance disc and rotation bracket. Under the action of vibration damper and profiling slide disc, the longitudinal position of the obstacle avoidance disc can be adjusted according to the terrain around the trunk. The soil pressing roller is installed behind the inter-row crushing roller for soil surface compaction. The main structure and performance parameters of OACM are shown in Tab. 1.

Table 1

Main structure and performance parameters of OACM	
Parameters	Values
Tractor power [kW]	44.2
Weight [kg]	427
Size, lengthxwidthxheight [m]	1.72x2.33x0.89
Largest distance of lateral movement [m]	1
Crushing roller rotation speed [r/min]	2025
Y-shaped blade number	24
Cutting disc rotation speed [r/min]	2531
Blade number of cutting disc	2
Working speed [m/s]	0.44
Inter-row crushing width [m]	1.5
Largest swing distance of obstacle avoidance disc [m]	0.5

### Methods of field tests

In April 2021, performance tests were conducted in Yejia pear orchard, Taixing, China. The trees were seven years old (7 a) and planted with row spacing of 4 m and plant spacing of 3 m. The average trunk height was 0.6 m and the average trunk diameter was 8 cm. The road of the orchard was flat and the tractor type was LOVOL M604L-E (Lovol Heavy Industry Co., Ltd., China). Considering that the driver's sight would be affected by the branches and leaves, low speed gear II was chosen (average tractor moving speed was 0.44 m/s) during the test. Test indexes were inter-row crushing rate (*Chinese standard JB/T8401.3*), intra-row miss cutting rate (*Chinese standard GB/T10938*), stubble stability, working efficiency, fuel consumption and profitable area. Three rows 60 m in length were selected for the test on inter-row crushing rate, intra-row miss cutting rate and stubble height. Divide 60 m into six sections with each section 10 m in length. One sample point for inter-row crushing rate and two sample points for intra-row miss cutting rate were selected in one section. One sample point for intra-row miss cutting rate between trunks and one sample point for intra-row miss cutting rate around trunks were selected in one section. After the weed stems were collected, six sample points for inter-row crushing rate and six sample points for intra-row miss cutting rate were selected in each row for stubble height measurement. Ten rows with 100 m in length were selected for tests of working efficiency, fuel consumption and profitable area. The test site of OACM is shown in Fig. 3.

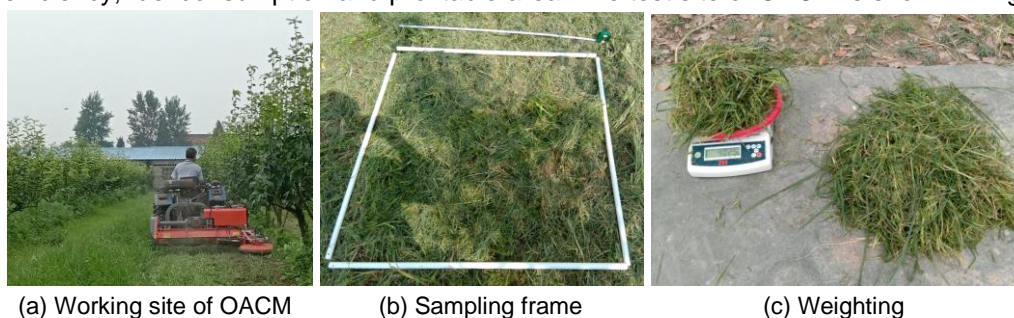


Fig. 3 – Test site

The side length of the sampling frame was 1 m and the sampling area of each point was 1 m<sup>2</sup>. In each inter-row crushing rate sample point, all weed stems were collected and their weight was measured. The stems with length more than 10 cm were taken out, and their weight was measured. The inter-row crushing rate was calculated by Equation (1).

$$C = \left(1 - \frac{G_{10}}{G_c}\right) \times 100 \quad (1)$$

where:

$C$  is inter-row crushing rate, [%];  $G_{10}$  is weight of weed stems over 10 cm in length within one sample point, [g];  $G_c$  is weight of crushed weed stems within one sample point, [g].

Miss cutting rate was defined as the miss cutting weight divided by the weight of harvested weeds per unit area. Intra-row miss cutting rate was calculated by Equation (2).

$$M = \frac{G_m}{G_t} \times 100 \quad (2)$$

where:

$M$  is intra-row miss cutting rate, [%];  $G_m$  is the miss cutting weight within one sample point, [g];  $G_t$  is the weight of harvested weeds within one sample point, [g].

For stubble height, five measure points were arranged diagonally within each sample point. Measurements were taken from the ground, and the average height at five measure points was the stubble height of the sample point. The stubble height was calculated by Equation (3).

$$h = \frac{\sum_{i=1}^n h_i}{5} \quad (3)$$

where:

$h_i$  is the stubble height at measure point  $i$ , [cm];  $h$  is the stubble height of each sample point, [cm].

The working time of OACM was recorded. Working efficiency is the mowing area per hour and was calculated by Equation (4), where working area equals the weeding width multiplied by moving distance.

$$E = \frac{A}{t} \quad (4)$$

where:

$E$  is working efficiency, [hm<sup>2</sup>/h];  $A$  is working area, [hm<sup>2</sup>];  $t$  is working time, [h].

Fuel consumption is the fuel volume required for tractor in unit mowing area and was calculated by Equation (5), where fuel volume was measured by graduated cylinder.

$$Q = \frac{V}{A} \quad (5)$$

where:

$Q$  is fuel consumption, [L/hm<sup>2</sup>];  $V$  is fuel volume consumed, [L].

The profitable area of OACM was calculated based on the working efficiency, so as to guide the orchard manager to choose the optimal operation method. The profitable area is the minimum planting area required by machines to replace labour in management cost. According to Equations (6)-(8), the profitable area was calculated. When the planting area of crops is larger than the profitable area, the machine can bring profits.

$$q = \frac{p}{y} \quad (6)$$

where:

$q$  is the annual depreciation of one OACM, [\$];

$p$  is the price of one OACM, [\$];

$y$  is the depreciable life, [year].

$$c = \frac{c_0 t}{t_0} \times \eta \quad (7)$$

where:

- $c$  is the saved cost of one OACM by replacing labour, [\$/hm<sup>2</sup>];
- $c_0$  is the labour cost in an eight-hour day, [\$];
- $t$  is the average artificial weeding time of one hectare, [h/hm<sup>2</sup>];
- $t_0$  is the working hours of one day, [h];
- $\eta$  is the time-saving proportion of mechanical weeding to artificial weeding.

$$A_p = \frac{q}{c} \quad (8)$$

where:

- $A_p$  is the profitable area of one OACM, [hm<sup>2</sup>].

## RESULTS

### Inter-row crushing rate

Weed crushing is the process in which the crushing roller assembly interacts with weeds on the ground. Inter-row crushing rate is used to evaluate the crushing quality between rows. Referring to Chinese national standard JB/T8401.3, the index of crushing rate should be no less than 86%. The higher the crushing rate is, the better the crushing quality becomes. The crushing rate of each sample point is shown in Fig. 4. Coefficient variation of sample points (Dai N. *et al.*, 2020) can reflect the individual stability. The calculation formulas of inter-row crushing rate, standard deviation, and coefficient variation are shown in Equations (9), (10) and (11). The results of inter-row crushing rate and coefficient variation are shown in Tab. 2.

Crushing rate is related to the flatness of orchard road, weed species and the design structure of crushing roller assembly. The inter-row crushing rates of three rows were 89.63%, 90.52% and 89.82%, respectively, indicating that the sample points had a higher crushing rate, and all could meet the requirement of stem crushing. Because the working speed and rotation speed of the crushing roller in each sample point were the same, the difference between them is related to the road flatness and weed species. The coefficient variation of three rows was 1.49%, 1.75% and 1.46%, respectively, and the maximum error of coefficient variation was 0.29%. The results showed that there was little difference between the sample points; road flatness and weed species of them were consistent. The average value of inter-row crushing rate and its coefficient variation is 89.99% and 1.57%, respectively. The average value of inter-row crushing rate is 3.99% higher than the index, indicating a better crushing effect. Good working effect benefits from the mechanical structure of inter-row crushing roller assembly: a 1.5 m long crushing roller with 24 Y-shaped stubble blades, which were arranged in a symmetrical double-helix structure with 60° in radial direction. There was no gap between the stubble blades, and the symmetrical double-helix structure of the stubble blades could effectively reduce the vibration caused by the rotation. The inter-row crushing rate of mower met the production requirements.

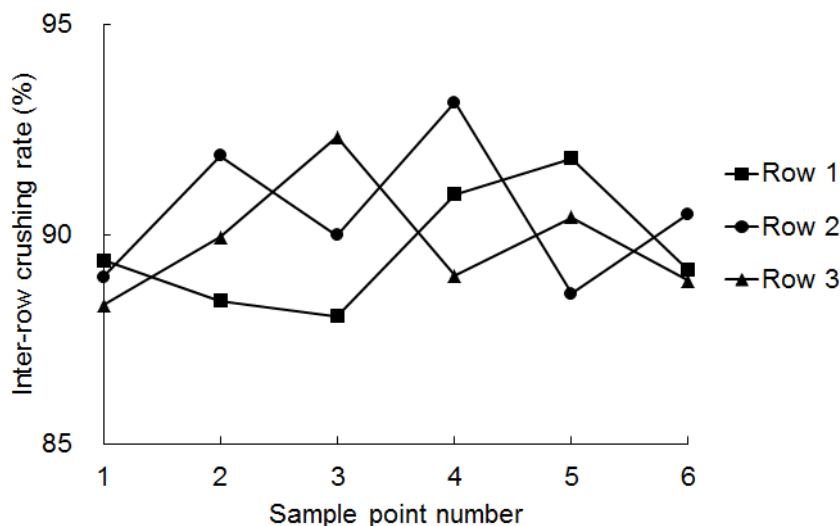


Fig. 4 – Inter-row crushing rate of each sample point

Table 2

Inter-row crushing rate  $C$  and coefficient variation  $CV$

Row number	Index	Values
1	$C$ [%]	89.63
	$CV$ [%]	1.49
2	$C$ [%]	90.52
	$CV$ [%]	1.75
3	$C$ [%]	89.82
	$CV$ [%]	1.46
Average value	$C$ [%]	89.99
	$CV$ [%]	1.57

$$C = \frac{\sum_{i=1}^6 C_i}{6} \tag{9}$$

$$S_c = \sqrt{\frac{\sum_{i=1}^6 (C_i - C)^2}{6}} \tag{10}$$

$$CV = \frac{S_c}{C} \times 100 \tag{11}$$

where:

- $C_i$  is the inter-row crushing rate of sample point  $i$ , [%];
- $S_c$  is the standard deviation of inter-row crushing rate, [%];
- $CV$  is the coefficient variation of inter-row crushing rate, [%].

**Intra-row miss cutting rate**

Intra-row miss cutting rate is used to evaluate the cutting quality within rows. Cutting disc rotation diameter should be a little less than obstacle avoidance disc diameter, so that it will keep the grasses close to trunks from cutting, and the miss cutting weight between and around trunks were different. During sampling, miss cutting rate between and around trunks were measured separately, and the results are shown in Fig. 5. The calculation method of coefficient variation is the same with the inter-row crushing rate. The average value of intra-row miss cutting rate and its coefficient variation are shown in Tab. 3.

The intra-row miss cutting rates of three rows between trunks were 0.22%, 0.23% and 0.22%, respectively. The average value of them is 0.23%, which is almost equal to 0. It shows that OACM had little miss cutting grasses between trunks. The intra-row miss cutting rate of three rows around trunks was 4.38%, 4.66% and 4.76%, respectively. The average value of them is 4.6%, which is higher than that between trunks. Because OACM leaves a certain safe zone around trunks, a few grasses around trunks have not been cut. The average values of coefficient variation between and around trunks were 7.91% and 4.87%, respectively. The coefficient variation around trunks was larger than that between trunks. Because miss cutting weight between trunks was less than that around trunks, the coefficient variation between trunks changed more significantly than that around trunks.

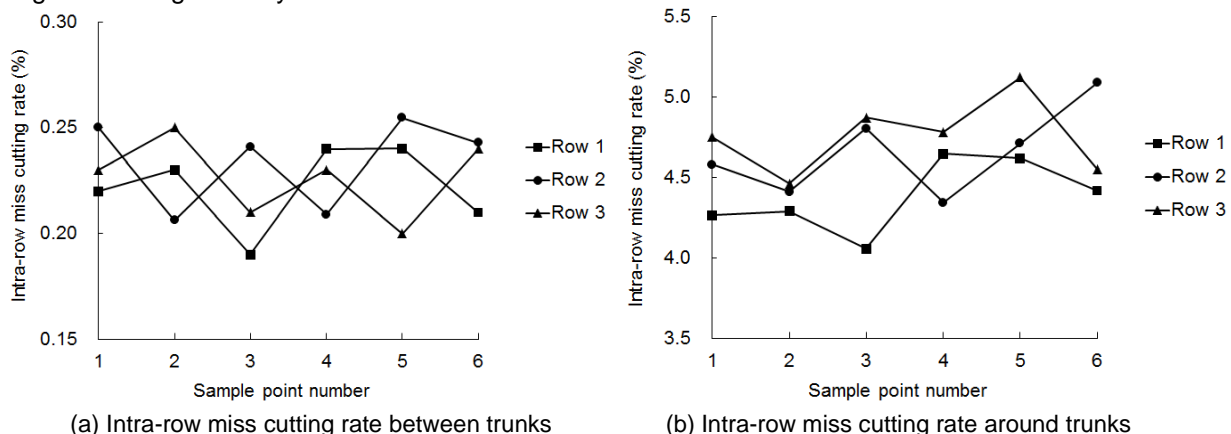


Fig. 5 – Intra-row miss cutting rate of each sample point

Table 3

Intra-row miss cutting rate *M* and coefficient variation *CV*

Row number	Position	Index	Values
1	Between trunks	<i>M</i> [%]	0.22
		<i>CV</i> [%]	8.01
	Around trunks	<i>M</i> [%]	4.38
		<i>CV</i> [%]	4.71
2	Between trunks	<i>M</i> [%]	0.23
		<i>CV</i> [%]	8.21
	Around trunks	<i>M</i> [%]	4.66
		<i>CV</i> [%]	5.38
3	Between trunks	<i>M</i> [%]	0.23
		<i>CV</i> [%]	7.5
	Around trunks	<i>M</i> [%]	4.76
		<i>CV</i> [%]	4.51
Average value between trunks		<i>M</i> [%]	0.23
		<i>CV</i> [%]	7.91
Average value around trunks		<i>M</i> [%]	4.6
		<i>CV</i> [%]	4.87

**Stubble stability**

Stubble stability is used to evaluate the working stability of OACM. Stubble height and its coefficient variation in different sample points were calculated. Inter-row and intra-row stubble height of three rows are shown in Fig. 6. The average value of stubble height and its coefficient variation are shown in Tab. 4.

The inter-row stubble height of three rows was 5.05 cm, 4.82 cm and 4.95 cm, respectively. The intra-row stubble height of three rows was 9.68 cm, 9.77 cm and 9.78 cm. The average value of them was 4.94 cm and 9.74 cm, respectively. It was consistent with the design value: inter-row stubble height of 5 cm, intra-row stubble height of 10 cm. The design stubble heights of inter-row and intra-row were different, which was related to the structure of crushing roller and cutting disc. The length of the crushing roller was 1.5 m, and the ground would inevitably have bumps and clods within the operation area. To avoid the mower from touching the soil, the stubble height should be set at 5 cm. The cutting disc was operated under the tree, the slope of the working area was greater, and the height of the stubble was set at 10 cm. The error between inter-row stubble height and the design value was 1.2%. The error between intra-row stubble height and the design value was 2.6%. The error was small because the orchard road was flat and OACM did not bump heavily during the mowing. The difference of two error values lies in the lower flatness of the intra-row than that of the inter-row. The inter-row stubble height coefficient variation of three rows is 4.39%, 4.39% and 3.82%. The intra-row stubble height coefficient variation of three rows was 5.07%, 4.41% and 3.41%, respectively. The average values of them were 4.2% and 4.3%, which are almost the same and reflect high working stability.

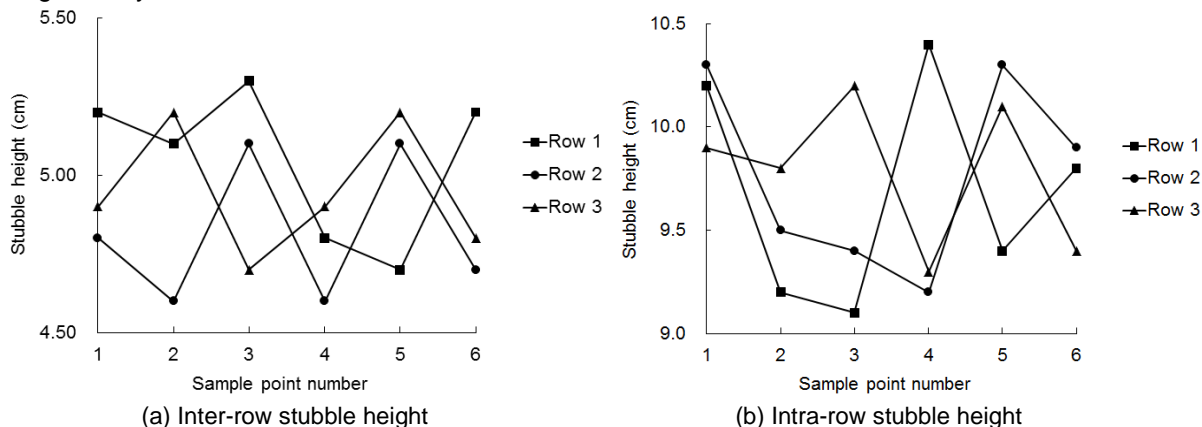


Fig. 6 – Stubble height of each sample point

Table 4

Stubble height $h$ and coefficient variation CV			
Row number	Position	Index	Values
1	Inter-row	$h$ [cm]	5.05
		CV [%]	4.39
	Intra-row	$h$ [cm]	9.68
		CV [%]	5.07
2	Inter-row	$h$ [cm]	4.82
		CV [%]	4.39
	Intra-row	$h$ [cm]	9.77
		CV [%]	4.41
3	Inter-row	$h$ [cm]	4.95
		CV [%]	3.82
	Intra-row	$h$ [cm]	9.78
		CV [%]	3.41
Average value inter-row		$h$ [cm]	4.94
		CV [%]	4.2
Average value intra-row		$h$ [cm]	9.74
		CV [%]	4.3

#### Working efficiency, fuel consumption and profitable area

The average weeding width of the mower was 2 m and the total mowing area of the test was 4000 m<sup>2</sup>. Substitute the value of working time and consumed fuel volume into Equations (4) and (5), and calculate the working efficiency and fuel consumption of OACM. As shown in Tab. 5, working efficiency of OACM was much higher than that of artificial weeding, which is 77 times to artificial weeding (about 0.0042 hm<sup>2</sup>/h). The mower price was 2333 \$, with five years of depreciable life. The labour cost was 19 \$ for an eight-hour day. The artificial weeding area was 0.03 hm<sup>2</sup> per day and weeding time per unit area was 266.67 h/hm<sup>2</sup>. The total time-saving proportion of OACM to artificial weeding was 98.83%. According to Equations (6), (7) and (8), the profitable area of OACM was 0.75 hm<sup>2</sup>. With a large number of farmers working in cities, the small-scale orchard farms have been replaced by modern fruit companies. Manual knapsack mower and artificial weeding, which were suitable for family farms, have become outdated in industry. In this condition, mechanized OACM was especially suitable for the orchard management. Orchard managers can appropriately use a certain amount of OACM according to their orchard planting area and affordable cost range.

Table 5

#### Working efficiency $E$ and fuel consumption $Q$

Name	Values
Working time [h]	1.26
Fuel volume [L]	6.5
Working area [hm <sup>2</sup> ]	0.4
$E$ [hm <sup>2</sup> /h]	0.32
$Q$ [L/hm <sup>2</sup> ]	16.25

#### CONCLUSIONS

The current mechanized weeding method is inter-row rotary tiller combined with intra-row artificial weeding, which demonstrates lower efficiency and poor effect. Combined with the technology of stubble elimination and hydraulic obstacle avoidance, the authors developed an obstacle avoidance mower assembly that can be used for efficient mechanized weeding in trunk type pear orchard. The roller type stubble cutter was adopted on the inter-row part of the mower, which can crush and return the weed to the field. The horizontal rotation obstacle avoidance cutting disc was adopted on the intra-row part of the mower, which can cut weeds without harming the trunks and roots.



Field performance evaluation test was carried out in trunk type pear orchard. Six kinds of indexes were tested and the results were: inter-row crushing rate of 89.99%, intra-row miss cutting rate of 2.42%, stubble stability coefficient variation of 4.25%, working efficiency of 0.32 hm<sup>2</sup>/h, fuel consumption of 16.25 L/hm<sup>2</sup>, profitable area of 0.75 hm<sup>2</sup>. Inter-row crushing rate, intra-row miss cutting rate and stubble stability coefficient variation reflected a better field test result. The working efficiency, fuel consumption and profitable area can guide the operator to make a reasonable choice for OACM. The study could provide a reference for mechanized weeding in orchards.

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