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Research on the Variable Rate Spraying System Based on Canopy Volume Measurement

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Abstract

Characteristics of fruit tree canopies are important target information for adjusting the pesticide application rate in variable rate spraying in orchards. Therefore, the target detection of the canopy characteristics is very important. In this study, a canopy volume measurement method for peach trees was presented and a variable rate spraying system based on canopy volume measurement was developed using the ultrasonic sensing, one of the most effective target detection method. Ten ultrasonic sensors and two flow control units were mounted on the orchard air-assisted sprayer. The ultrasonic sensors were used to detect the canopy diameters and the flow controls were used to modify the flow rate of the nozzles in real time. Two treatments were established: a constant application rate of 300 Lha^{-1} was set as the control treatment for the comparison with the variable rate application at a 0.095 Lm^{-3} canopy. The tracer deposition at different parts of peach trees and the tracer losses to the ground (between rows and within rows) were analyzed in detail under constant rate and variable rate application. The results showed that there were no significant differences between two treatments in the liquid distribution and the capability to reach the inner parts of the crop canopies.

Keywords

Canopy Volume Measurement, Tracer Deposition Device, Ultrasonic Sensor, Variable Rate Spraying System

1. Introduction

The variable rate spraying technology can reduce pesticide use, pesticide residuals in the crops and environmental contamination. Measurements of tree canopy volume and tree shape can provide important reference for variable rate spraying in orchard and forest spraying. Since the tree canopy volume and the tree shape were known, it was possible to determine an optimized spraying volume for each tree. Some efforts have been done in the measurement of canopy volumes and tree shapes. A formula was developed to calculate the canopy volume, and the geometric linear dimensions in the formula were obtained by manual measurement [1]. Another manual method was designed to measure the tree canopy volume, which also calculated the canopy volume using a formula. The measurement time of geometric linear dimensions in the formula was about 30 seconds [2]. An ultrasonic measurement system of canopy volume was introduced, which was mounted on an air-blast orchard sprayer. Three ultrasonic sensors were mounted at different heights on both sides of the sprayer, which were used to measure the distance

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between the sensors and the canopy foliage [3]. An ultrasonic measurement system was developed to measure the volume of plant, in which only one ultrasonic sensor was used [4]. A measurement system of canopy volume was designed, in which an ultrasonic ranging system was used. Ten ultrasonic sensors were installed on a vertical PVC mast, of which diameter was 0.1 m. The sensors were numbered 1–10 from bottom to top, and their spacing was 0.6 m. The canopy volume was calculated according to cross-sectional area of canopy and the ground speed of the truck [5,6]. A canopy diameter measurement system based on the ultrasonic sensors was developed [7]. A recognition system of fruit tree shape based on ultrasonic sensors was designed and developed. The canopy height could be measured by an airborne laser altimeter [8]. An airborne Lidar system was used to estimate the tree height and tree volume [9]. The performance of ultrasonic and laser beam sensors in crop height measurement was estimated [10-12]. Two manual methods for canopy volume measurement were compared, and similar measurement results were got in both methods. Similar measurement results were also found among the ultrasonic method, laser method and manual method [13,14].

Generally, measurement methods of canopy volume in the former studies were complex, and in poor generality. Thus, a new measurement method of canopy volume was proposed in this study, which is suitable for canopies of many species of fruit trees and has higher accuracy. Based on the new measurement method of canopy volume, a new variable rate spraying system was designed and developed. The application quality of the developed system and the conventional methodologies were compared and analyzed.

2. Materials and Methods

2.1 Measurement Method Design of Canopy Volume

A new measurement method of tree canopy volume, called addition of cylinder volumes, was designed in this study. The tree canopy volume was defined as the sum of a number of cylinder volumes. The number was depended on the amount of ultrasonic sensors used in this system. Pre-experiment showed that an ideal measurement result was gained when five sensors were used. Thus, five ultrasonic sensors were used to detect the distances between the sensors and the canopy foliage at the corresponding height in this study. The tree canopy volume was the sum of five canopy cylinder volumes. More details about the measurement method were introduced by Hu et al. [15] in a former publication.

2.2 Variable Rate Spraying System Design

The developed system was mainly composed of portable computer, ultrasonic sensors, single chips, flow control units and nozzle sets. The schematic view of the system is shown in Fig. 1. A PVC mast was fixed on the Hardi LB-255 sprayer, which was an orchard air-assisted sprayer. Ten ultrasonic sensors in total were mounted on both sides of the PVC mast. The sensors L1–L5 were mounted on the left side and R1–R5 were on the right side. Nozzles L1–L5 and flow control unit L were installed on the left side of the sprayer, and nozzles R1–R5 and flow control unit R were installed on the right side of the sprayer. Flow control units L and R were used to control the flow rates of Nozzles L1–L5 and Nozzles R1–R5 respectively. The ultrasonic sensors were used to detect the distances between sensors and canopy foliage.

The canopy diameters on different heights would be calculated according to the distances detected by the sensors. Then the canopy volumes could be calculated using the measurement method mentioned in Section 2.1. The single chips sent data from sensors to portable computer and transferred instructions from computer to flow control units in real time. Canopy volumes and cylinder volumes were measured by sensors, and canopy diameters on the installation heights of sensors were stored in the portable computer.

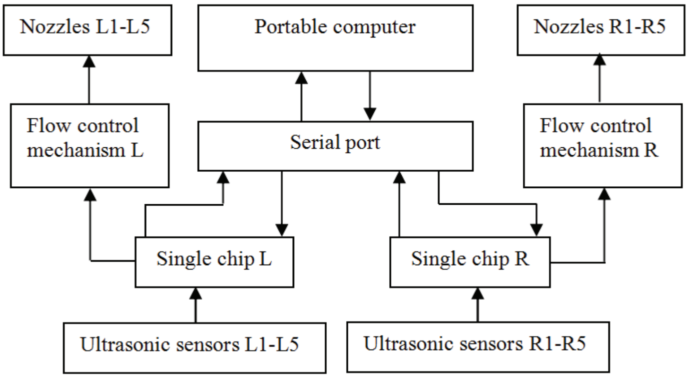


Fig. 1. Schematic view of variable rate spraying system based on canopy volume measurement.

2.3 Experiment Design

A peach grove with the tree spacing of 5.0 m (between rows) × 3.0 m (within rows) was chosen as the experimental area, which located in Changping District, Beijing. The varieties of the peach trees were fragrant mountain red, and the trees were 3 years old. There were 150 trees in this grove, which were averagely distributed in different 10 rows and had thick foliage and regular shape. These trees which had different canopy volumes were numbered from 1 to 150, and trees numbered from 61 to 75 were sprayed from both sides of the row in this research. In addition, the canopies of the chosen trees did not touch each other. The distance of the ultrasonic sensors was 0.226 m. A constant application rate of 300 Lha^{-1} was compared with a variable rate application at a 0.095 Lm^{-3} canopy. The liquid deposition at different parts of peach trees and the liquid losses to the ground (between rows and within rows) were analyzed under the two treatments. The experiments were conducted in April 30, 2017. The weather was fine and breezy. Rhodamine WT was used as the spray tracer. Rhodamine WT solution with concentration of 1 g/L was used for spraying. Trilogy fluorometer produced by America Turner Designs was used for fluorescence analysis.

Canopy volumes of tree 62, 68, and 74 were 3.156 m^3, 2.698 m^3, and 3.644 m^3, respectively, which had obvious representation of the 15 trees sprayed [15], so they were selected as the sampling objects. Peach trees were separated into 5 different zones according to their heights ('A' from 0.48 to 0.90 m, 'B' from 0.90 to 1.32 m, 'C' from 1.32 to 1.74 m, 'D' from 1.74 to 2.16 m, and 'E' from 2.16 to 2.58 m), and 3 zones according to depth within the crop ('1' external left, '2' center, and '3' external right). Three round filters with diameter of 7.0 cm were randomly placed in each of the 15 sampling areas to collect tracer deposition on trees. Schematic view of sampling placement of trees is shown in Fig. 2. The sampling areas in zone 1 were numbered from A1 to E1. The sampling areas in zone 2 were numbered from A2 to E2, and the sampling areas in zone 3 were numbered from A3 to E3. Four sampling areas (200 cm×100 cm) which were numbered from R1 to R4 were used to collect tracer deposition on the ground of between rows. More details about the sampling areas placements of tracer deposition on the ground were introduced in Fig. 3. Four sampling areas (200 cm×80 cm) which were numbered from S1 to S4 were used to collect tracer deposition within rows. R2, R3, S2 and S3 were under the canopy, while R1, R4, S1 and S4 were not under the canopy. Three round filters with diameter of 7.0 cm were randomly placed in each of the 8 sampling areas to collect tracer deposition on the ground.

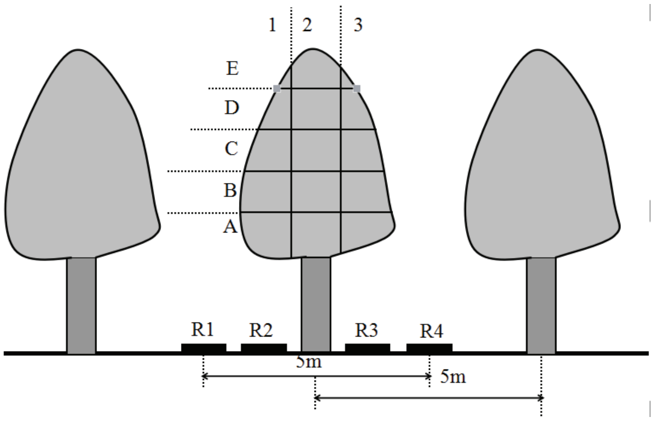


Fig. 2. Schematic view of sampling placement of tracer deposition on the trees.

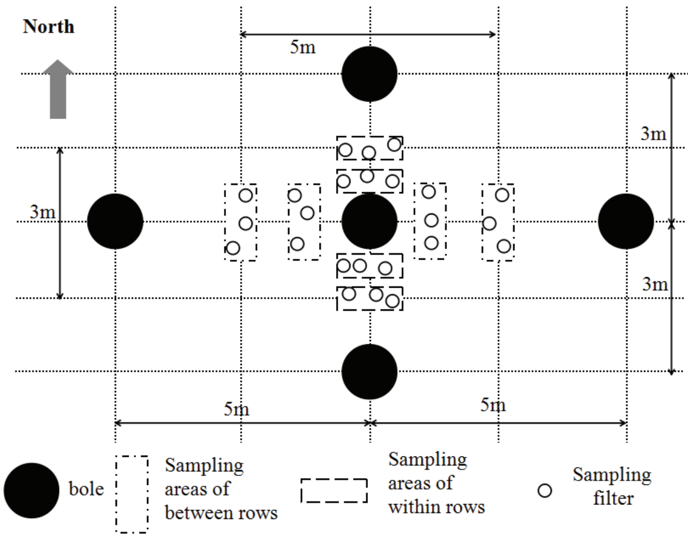


Fig. 3. Schematic view of sampling placement of tracer deposition on the ground.

Two treatments with constant and variable spraying rate were established. In the first treatment, a conventional sprayer was calibrated to apply a constant rate of 300 Lha^{-1}. In the second treatment, a variable rate application at a 0.095 Lm^{-3} canopy was conducted using the designed system. The constant treatment was conducted one hour before the variable rate treatment. In order to reduce the experimental error, the environmental conditions (temperature, relative humidity, wind velocity and light intensity) and the round filters placements of the two treatments were kept as similar as possible with each other.

Ten minutes after spraying, round filters were collected and stored into plastic bottles. Three round filters of the same sampling area were stored in the same bottle. Sixty-nine bottles of each treatment were gained. A 50 mL distilled water was added into each bottle, bottles were shaken lightly for 15 seconds, and then stored in seal. About 30 minutes later, Trilogy fluorometer was used to measure the concentration of the diluted solution in the bottles. Each measurement was repeated for three times, and the average of the three measurement values was taken as the final measurement value. The bottles were numbered as: tree number, application type and sampling area. Tree numbers were 62, 68 and 74. *C* represented the constant application, while *V* represented the variable rate application. For example, bottle number 62CC1 represented the tracer deposition on C1 sampling area of tree 62 with constant application.

The concentrations of the diluted solutions in the bottles could be measured by Trilogy fluorometer. As the solution volume in the bottle was 50 mL, the content of Rhodamine WT in the bottle would be calculated. The deposition concentration of Rhodamine WT could be calculated as follow:

$$C = \frac{m}{A} = \frac{\rho v}{A} \tag{1}$$

where C is the deposition concentration of Rhodamine WT, m is the content of Rhodamine WT in the bottle, A is the area summation of three round filters, ρ is the concentration of the diluted solutions in the bottle, v is the volume of the diluted solution in the bottle. The volume (v) of the diluted solution is 50 mL. The area of one filter is 38.5 cm^2, so the area summation of three round filters (A) is 115.5 cm^2. Since A and v are known, it is possible to calculate the deposition concentration of Rhodamine WT.

3. Results

3.1 Analysis of Tracer Deposition on Trees

Comparison diagrams of the deposition concentration of Rhodamine WT on tree 62, 68, and 74 under two treatments are shown in Fig. 4(a), 4(b), and 4(c), respectively.

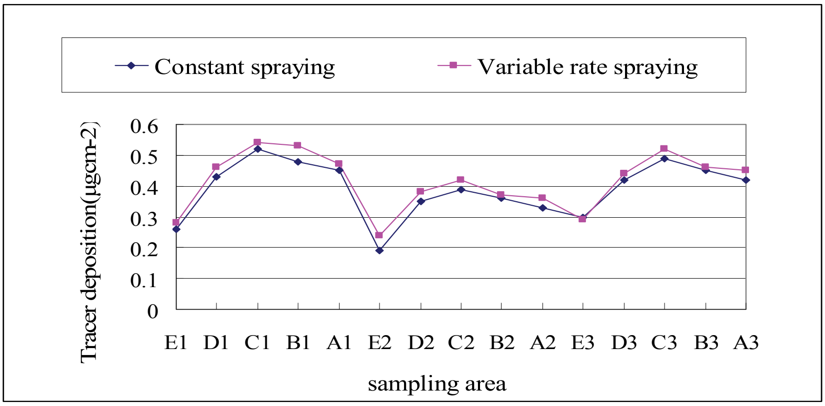
According to the Fig. 4, it can be found that,

(1) For deposition concentrations of Rhodamine WT, there were no significant differences between variable rate application and constant application. For most sampling areas, the deposition concentrations of Rhodamine WT under variable rate application were slightly higher than the deposition concentrations of Rhodamine WT under constant application.

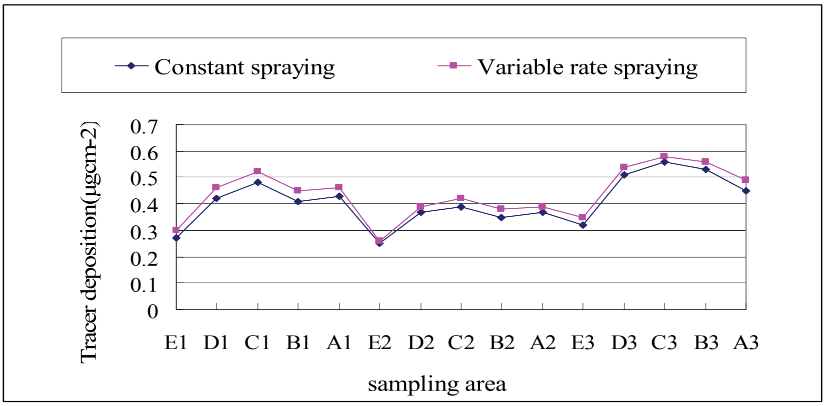
(2) Because of the lower installation positions of nozzles, the deposition concentrations of Rhodamine WT on E zone were obviously lower than the deposition concentrations of Rhodamine WT on zones at other heights. Therefore, only a small quantity of tracer liquid could reach the E zone.

(3) The deposition concentrations of Rhodamine WT on zone 2 were obviously lower than other vertical zones, because zone 2 was in the inner part of the tree canopy and some tracer liquid couldn't reach the zone 2.

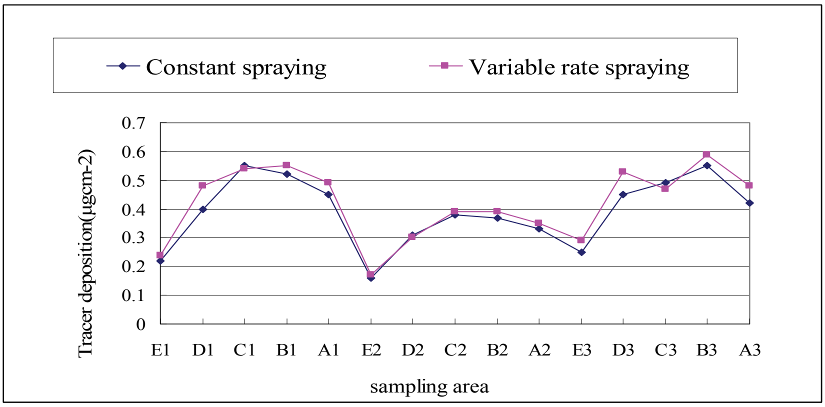
(4) The uniformity of the deposition concentrations of Rhodamine WT on tree 68 was better than the other two trees, because branches and leaves of tree 68 distributed uniformly and had good symmetry.



(a)



(b)

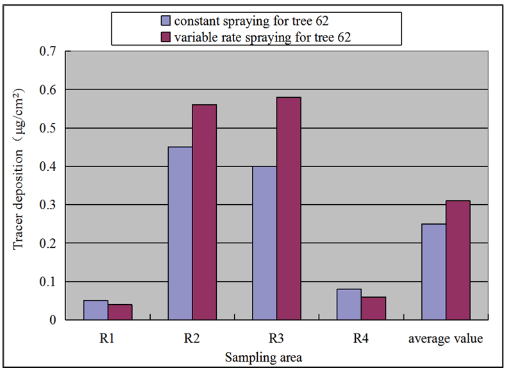


(c)

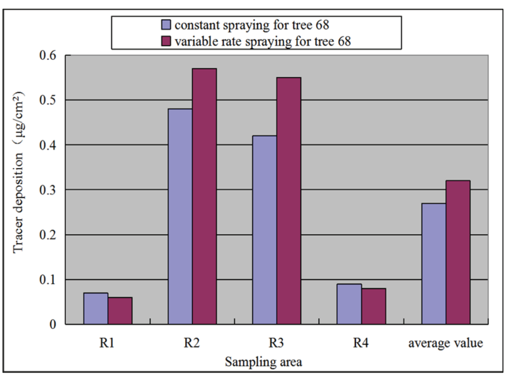
Fig. 4. Comparison diagram of the deposition concentration of Rhodamine WT on (a) tree 62, (b) tree 68, and (c) tree 74 under two treatments.

3.2 Analysis of Tracer Deposition on the Ground

The columnar comparison diagrams of deposition concentration of Rhodamine WT on the ground of between rows for two treatments are shown in Fig. 5. It can be found that,



(a)



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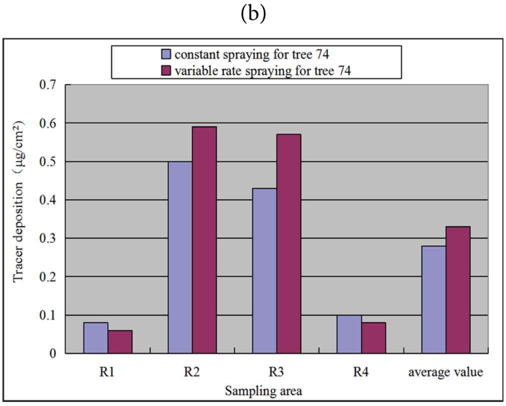
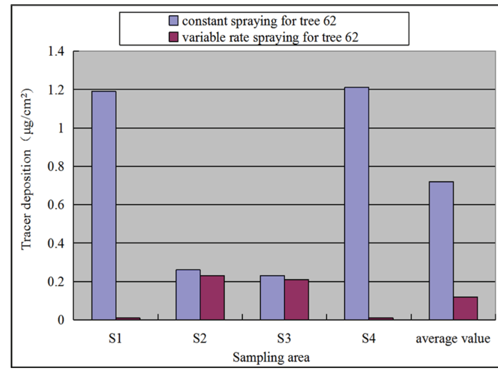
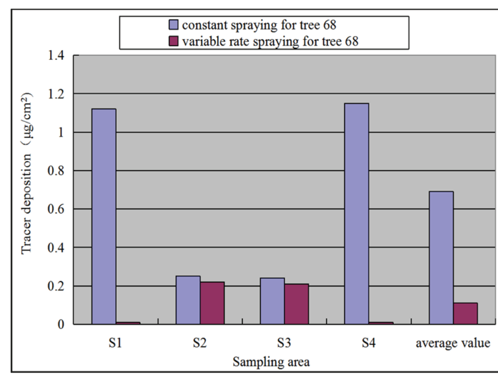


(c)

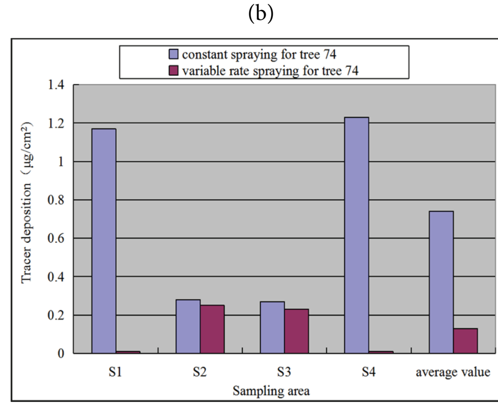
Fig. 5. The columnar comparison diagrams of deposition concentration of Rhodamine WT on the ground (R1–R4) of between rows under two treatments: (a) tree 62, (b) tree (68), and (c) tree 74.



(a)



(b)



(c)

Fig. 6. The columnar comparison diagrams of deposition concentration of Rhodamine WT on the ground (S1–S4) of within rows under two treatments: (a) tree 62, (b) tree (68), and (c) tree 74.

(1) The deposition concentrations of Rhodamine WT on R1 and R4 were lower than R2 and R3 under both of the two treatments.

(2) For R1 and R4, the deposition concentrations of Rhodamine WT under variable rate application were appreciably lower than that under constant application. For R2 and R3, the deposition

concentrations of Rhodamine WT under variable rate application were obviously higher than that under constant application, which could be explained as a consequence of some leakages in nozzles in adjusting the flow rate.

(3) For deposition concentrations of Rhodamine WT, the average values of variable rate application were higher than that of constant application, which was caused by some leakages in nozzles in adjusting the flow rate.

The columnar comparison diagrams of deposition concentration of Rhodamine WT on the ground of within rows under two treatments are shown in Fig. 6. It can be found that,

(1) For all sampling areas, the deposition concentrations of Rhodamine WT of variable rate application were lower than that of constant application, especially for S1 and S4, which were not under the tree canopy, and the variable rate sprayer stopped spraying when passing through them. Thus, the deposition concentrations of Rhodamine WT of variable rate application were very low and almost nearly to be zero in S1 and S4.

(2) For constant application, the deposition concentrations of Rhodamine WT on S1 and S4 were much higher than S2 and S3. S2 and S3 were under the tree canopy, whose tracer depositions mainly came from the drippage of tracer liquid. S1 and S4 were not under the tree canopy and almost all of the trace liquid sprayed by the sprayer passing through S1 and S4 was deposited on the ground.

(3) For variable rate application, the deposition concentrations of Rhodamine WT on S1 and S4 were much lower than S2 and S3. S2 and S3 were under the tree canopy, the tracer liquid dripping from the tree canopy would be deposited on them. While S1 and S4 were not under the tree canopy, the variable rate sprayer stopped spraying when passing through them. Thus, almost no tracer would deposit on them.

4. Conclusions

In this study, a new measurement method of canopy volume was presented. Based on this method, a variable rate spraying system was designed and developed. Comparison experiments between variable rate application and constant application were conducted. According to the results, it can be concluded that,

(1) For the same sampling areas on trees, there were no significant differences of the deposition concentrations of Rhodamine WT between variable rate application and constant application. For most sampling areas, the deposition concentrations of Rhodamine WT under variable rate application were slightly higher than that under constant application.

(2) For sampling areas on the ground of between rows, the deposition concentrations of Rhodamine WT on R1 and R4 were lower than R2 and R3 under both constant application and variable rate application. For R1 and R4, the deposition concentrations of Rhodamine WT under variable rate application were appreciably lower than that under constant application. For R2 and R3, the deposition concentrations of Rhodamine WT under variable rate application were obviously higher than that under constant application,

(3) For sampling areas on the ground of within rows, the deposition concentrations of Rhodamine

WT under variable rate application were lower than that under constant application. For constant application, the deposition concentrations of Rhodamine WT on S1 and S4 were much higher than that on S2 and S3. For variable rate application, the deposition concentrations of Rhodamine WT on S2 and S3 were much higher than that on S1 and S4.

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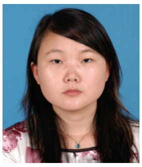

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