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Spray Penetration into the Citrus Tree Canopy from Two Air-Carrier Sprayers

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Abstract. *Field experiments were conducted to investigate The effect of sprayer type, application volume rate and airflow rate on spray deposition along depth of the citrus canopy. The trees were sprayed from one side using a tower sprayer with cross-flow fans and rotary atomizers (Curtec) at three spray volume rates and a tower sprayer with an axial-flow fan and hydraulic nozzles (Titan) at two spray volume rates and two airflow rates. Spray deposition was determined with fluorometry using cotton ribbons as targets within the entire canopy depth at two heights.*

For both sprayers, deposition decreased with canopy depth. The spray penetrated deeper at higher volume rates. The effect of volume rate became significant after about 1 m and 2 m depths for the Curtec and Titan sprayers, respectively. At high volume rate, mean depositions of the two sprayers were not significantly different at most canopy depths. In general, operating the Titan sprayer at lower airflow gave comparable mean deposition to that at normal (rated) airflow. The effect of airflow on spray penetration was significant beyond about 2 m depth.

Keywords. *Air-Blast, Cotton ribbons, Deposition, Spray volume rate, Airflow rate, Fluorometry*

Introduction

In most spray applications, transport of active ingredients to inner sections of the plants or trees (penetration) is a key requirement for effective control of pests. Adequate penetration has been a concern for some spray applications (Hoffmann and Salyani, 1996). Inefficiency of an orchard application system may be attributed in part to poor spray penetration inside the canopy. Spray droplet size affects spray movement to the target area and its deposition on the target (Salyani 1988; Farooq et al. 2001). Smaller droplets can be easily carried by wind and result in spray drift. The retention of large droplets by targets on impact is difficult, resulting in run-off and loss to the ground. Air-assistance is used to alter the droplet movement for better penetration and deposition. However, the air assistance effect may be different for different droplet sizes.

Spray deposition has been measured in numerous studies. Salyani et al. (1988) studied the effect of spray volume rate on deposition inside the citrus canopy when trees were sprayed with an airblast tower sprayer. Using copper as the tracer, they found that for all volume rates, there was more deposition on the exterior of the canopy than on the interior. The lowest volume resulted in slightly more deposition on leaves inside the canopy than the other volumes. Juste et al. (1990) studied spray deposition at inside locations of the citrus canopy from four sprayers at low and high volume application rates. They found higher spray deposition on the outside canopy than on the inside canopy. The deposition of air-assisted sprayers in the central part of the tree was higher at low volume than at high volume.

Salyani and Whitney (1990) studied the effect of sprayer ground speed on spray deposition at different locations within citrus canopy. Deposition of a copper hydroxide tracer was measured on citrus leaves and cotton ribbons. Results indicated no effect of ground speed (1.6 to 6.4 km/h) on mean spray deposition. However, there were large differences in deposits at different canopy locations. These differences were higher in denser foliage and were regarded as the normal representation of pesticide distributions in citrus applications. Deposition decreased with canopy depth. The reduction in deposition was not affected by the ground speed; however, deposition became more variable at higher speed and canopy locations farther from the sprayer discharge. These results were obtained with relatively high air volume sprayer having an airflow rate of 50 m^3/s.

Hall et al. (1991) studied spray penetration into four cultivars of apple tree using an airblast sprayer. Spray deposition decreased with distance away from the nozzle discharge. Deposition was higher on widely spaced trees than on those closely spaced. Koo et al. (2000) studied the effect of spray volume, nozzle flow rate and ground speed on citrus canopy deposition. Mean deposition was higher at low volume rate (940 L/ha) while it was more uniform at high volume rate (4350 L/ha). Mean deposition was higher but less uniform at low nozzle flow rate (19.1 L/min) compared to high nozzle flow rate (63.4 L/min). At constant sprayer output, the deposition increased with decrease in ground speed in the range of 1.6 to 4.8 km/h.

From the literature it is not quite clear how a spray cloud could effectively penetrate inside the citrus canopy. The objective of this study was to determine the effects of spray volume rate and airflow rate on spray penetration into the citrus canopy using air-carrier tower sprayers.

Materials and Methods

The study was conducted in a 'Valencia' orange grove near Lake Alfred, Florida. The trees were spaced at 4.5 m and 6.1 m within and between the rows (hedgerows), respectively.

On average, the tree canopy had a diameter of about 4 m and a height of 5 m. Considering similarity of the canopy structure (foliage density), four trees in the last row of the grove were selected with buffer trees at each end of the selection. Each tree represented a replication that accounted for the variation within the tree canopy. The independent variables included sprayer type, spray volume rate, and airflow rate.

Spray Applications

Two sprayers were used: Curtec 648 (BEI Inc., South Haven, MI) and Titan 1093 (John Bean Sprayers, Hogansville, GA). The Curtec is an engine-driven tower sprayer equipped with three cross-flow fans and six rotary atomizers (two per fan) per side. The atomizer and fan units are stacked vertically to discharge spray at different heights to cover the whole canopy. The Curtec sprayer was set up to deliver 250, 980 and 1945 L/ha (low, medium and high, respectively) spray volume rates uniformly along the sprayer tower height. For this sprayer the

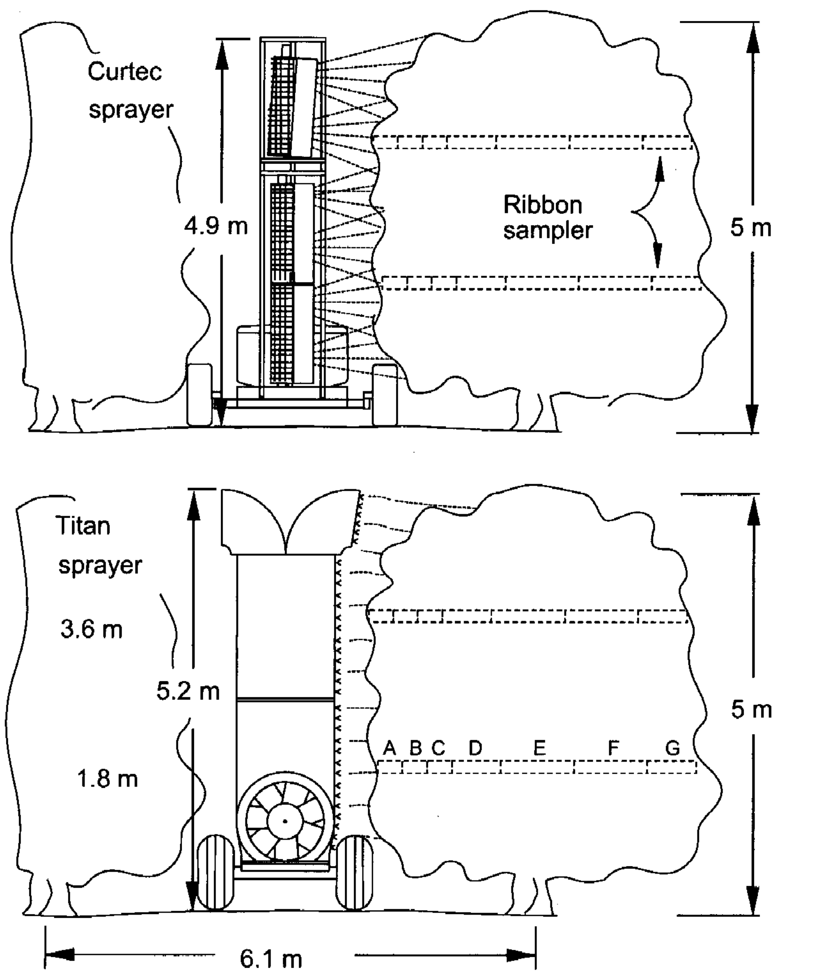

Figure 1: Schematic (rear view) of spray application with Curtec (top) and Titan (bottom) sprayers and sampling layout

total airflow rate of 6 fans was 27 m^3/s and could not be varied due to the sprayer design. The sprayer ground speed was 3.2 or 4.8 km/h depending on application volume rate. During these tests, the wind velocity ranged from 6.5 to 8.0 km/h in the sprayer travel direction. The ranges of temperature and relative humidity were 23 to 25 °C and 26 to 31 %, respectively.

The Titan is also engine-driven and equipped with a 1.2 m diameter axial flow fan and hydraulic nozzles. The sprayer fan was operated at 1600 and 2225 rpm that gave 28 m^3/s (low) and 37 m^3/s (high) airflow rates, respectively. At each airflow rate, the sprayer was used at 725 and 1875 L/ha (low and high volume rates, respectively) at 4.8 km/h. During these tests, the wind ranged from 1.5 to 9.7 km/h opposite to and in the sprayer travel direction. The ranges of temperature and relative humidity were 19 to 23 °C and 33 to 38 %, respectively. The trees were sprayed from one side with both sprayers (fig. 1). The spray mixture contained Pyranine-10G (Keystone Aniline Inc., Chicago IL) at 500 or 1000 ppm as fluorescent tracer.

Sample Collection and Analysis

The spray penetration was characterized by spray flux that was measured in terms of deposition of the fluorescent tracer at different depths into the canopy. A 25 mm wide absorbent cotton ribbon was used as the deposition target. Salyani and Hoffmann (1996) found that absorbent targets capture the impacting droplets while citrus leaf surfaces allow some droplets to rebound and run-off. Thus the measured deposition represents spray penetration. The ribbons were stretched through the canopy depth near the center of each tree perpendicular to sprayer travel at 1.8 and 3.6 m heights (fig. 1). It should be noted that orientation of the ribbon surface was not fixed and varied due to sprayer air movement. When the ribbons were collected, they were cut into seven sections representing depths (A: 0.0 – 0.3 m, B: 0.3 – 0.6 m, C: 0.6 – 0.9 m, D: 0.9 – 1.5 m, E: 1.5 – 2.4 m, F: 2.4 – 3.3 m, G: 3.3 – 3.9 m). The ribbon sections were cut into different lengths based on expected reduction of deposition and practical limitations in fluorometric analysis of the targets.

To minimize the tracer degradation, the samples were collected as soon as the leaves dried. Ribbons being inside the canopy had little exposure to direct sunlight. Salyani and Cromwell (1992) have shown that degradation of fluorescence was slower on filter paper compared to mylar sheets. The ribbon was pulled out from the sprayed side of the tree and cut to the lengths corresponding to the depths (A to G). Each sample was enclosed in pre-labeled sealable bag and stored in an ice chest and then stored in the refrigerator at about 4° C until analysis. To determine deposition, each sample was washed with de-ionized water and the tracer concentration was measured with a fluorometer (model 111, Sequoia-Turner Corp., Mountain View, CA). The deposition was adjusted for nominal tracer concentration and volume rate to obtain the same level of tracer concentration for all treatments. The deposition data were also adjusted for the trace of interfering fluorescence in the cotton ribbons.

Data Analysis

The data were analyzed using GLM procedure in SAS (SAS Institute Inc., 1990). Mean deposition at each depth (A – F) was compared to the last depth (G) with repeated measures analysis of variance of SAS (Littell et al. 1998). The logistic curves were fitted to relate deposition with tree depth using SigmaPlot 6.00 (SPSS Inc., 2000). The mean depositions for depths A – D (near), E – G (far) and A–G (whole) canopy sections were calculated separately. The near, far, and whole canopy deposition data were analyzed using MIXED procedure in SAS. The means for these parameters were compared using LSMEANS statement at 5 % level of significance.

Results and Discussion

Effect of Spray Volume Rate

Curtec Sprayer

The volume rate and the canopy height significantly affected the deposition at depths D, E, F, and G. The deposition generally decreased with increased canopy depth (fig. 2). The reduction in deposition with the depth was significantly affected by volume rate beyond about 1m into the canopy. The reduction rate at two heights became significantly different beyond about 1 m into the canopy.

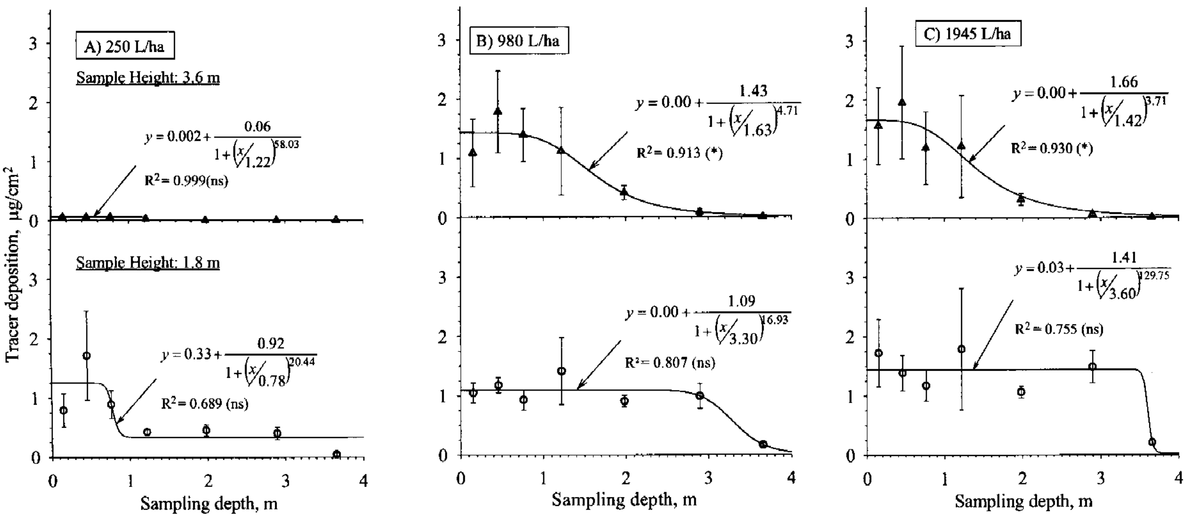

Figure 2: Variation in deposition of Curtec sprayer with canopy depth (Significance of model: ** significant at 1%, * significant at 5 %, ns –non-significant)

The spray generally penetrated deeper into the tree canopy when volume rate increased from low (250 L/ha) to medium (980 L/ha). However, the change in volume rate from medium to high (1945 L/ha) did not affect the penetration (fig. 2). The low volume rate deposition up to depth C (0.6 – 0.9 m) at 1.8 m height was uniform and high whereas for 0.9 – 3.9 m depth, the deposition was very low (fig. 2A). At 3.6 m height, the deposition was very low throughout the depth. Very low deposition at 250 L/ha could in part be attributed to the dominant effect of wind during the application. At low volume rates, generally more drift-prone smaller droplets are generated. The smaller droplets could readily follow the atmospheric wind or the sprayer air, resulting in increased drift potential at low volume applications. At medium and high volume rates (figs. 2B and 2C), the deposition was constant up to 3.0 m depth at lower height. At the upper height, the deposition decreased gradually with the increase in canopy depth. The relationships between deposition and canopy depth were expressed by logistic curves (fig. 2). These relationships might be useful in the development of spray penetration models.

The volume rate and sampling height significantly affected the whole and far canopy deposition while only volume rate affected the deposition at the near section. On average, low volume rate gave significantly lower deposition than the medium and high volume rates (fig. 3). The increase of volume rate from low to medium significantly increased the deposition but the deposition only slightly increased by changing volume from medium to high. This is contrary to the reports by Salyani et al (1988), Juste et al. (1990), and Koo et al (2000). The three studies reported higher deposition at lower volume rates. The difference could be attributed to the use of absorbent cotton ribbons instead of leaves as targets. As explained earlier, the deposition in this study was a measure of spray penetration. The capture of the run-off droplets from upper canopy leaves by the cotton ribbons, might also have contributed to this difference, although the nature of differences in deposition (at different volume rates) between two heights (fig. 4) does not support the occurrence of this error.

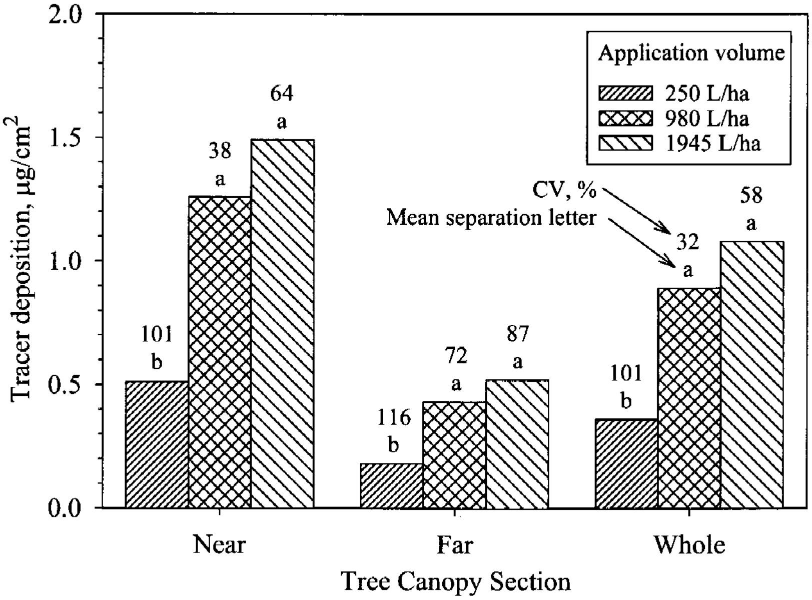

Figure 3: Mean deposition of Curtec sprayer at different volume rates

In general, the deposition was less at the upper height than at the lower height. The increase in volume rate increased the deposition at the two heights but the relative increase was more at the upper height than at the lower height (fig. 4). The deposition from low volume application on the near and far sections was significantly lower at 3.6 m height than the deposition at 1.8 m height. In the other two application rates, the difference in deposition between the two heights was significant only at the far section (fig. 4).

Titan Sprayer

In general, deposition decreased with the increase in canopy depth (fig. 5). The reduction in deposition was significantly affected by volume rate beyond about 2 m depth. The higher volume rate (1875 L/ha) gave higher deposition than the low volume rate (725 L/ha) (fig. 5). In general, there was more deposition and deeper spray penetration at the lower height than at the upper height (fig. 5). The higher volume rate resulted in higher deposition at 0.0 – 1.5 m depth at both heights (fig 5). This is in agreement with results from the Curtec sprayer (in this study) but opposite to the results of Salyani et al. (1988), Juste et al. (1990), and Koo et al (2000). The results may have been different as explained in the earlier section (use of absorbent ribbon instead of leaves as spray target).

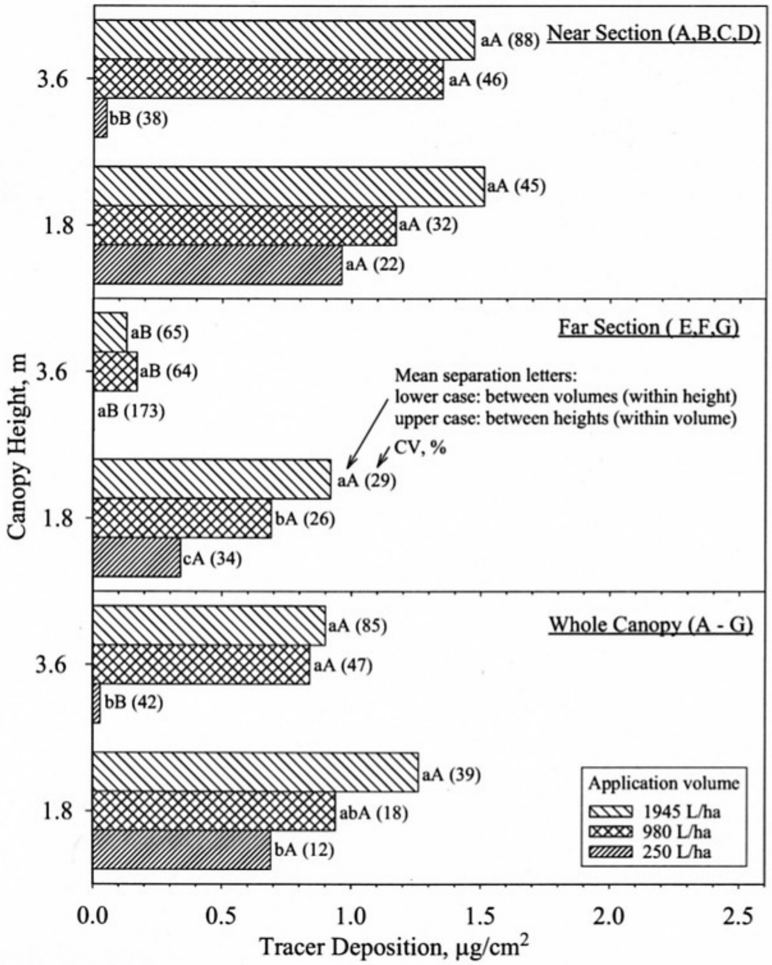

Figure 4: Deposition of Curtec sprayer at different heights and volume rates

In both volume rates, the deposition at the near section was much higher than the deposition at the far section (fig. 6). At both heights, the change in volume rate from low to high increased deposition at near and far canopy sections (fig. 7). However, the increase was not significant at the upper height. For both volume rates, the deposition was less at upper height than at the lower height in near and far sections.

The comparison of spray penetration from two sprayers at comparable volume rates (1945 L/ha and 1875 L/ha) at normal operating conditions showed deeper penetration with Curtec at lower canopy height (figs. 2C and 5B). Overall, the differences in depositions of the two sprayers were not significant at near or far canopy sections at the two heights (fig. 8). It should be noted that the trees are normally sprayed from two sides. Therefore, superimposing deposition curves from the opposite side could represent a more realistic picture of spray penetration in normal grove applications.

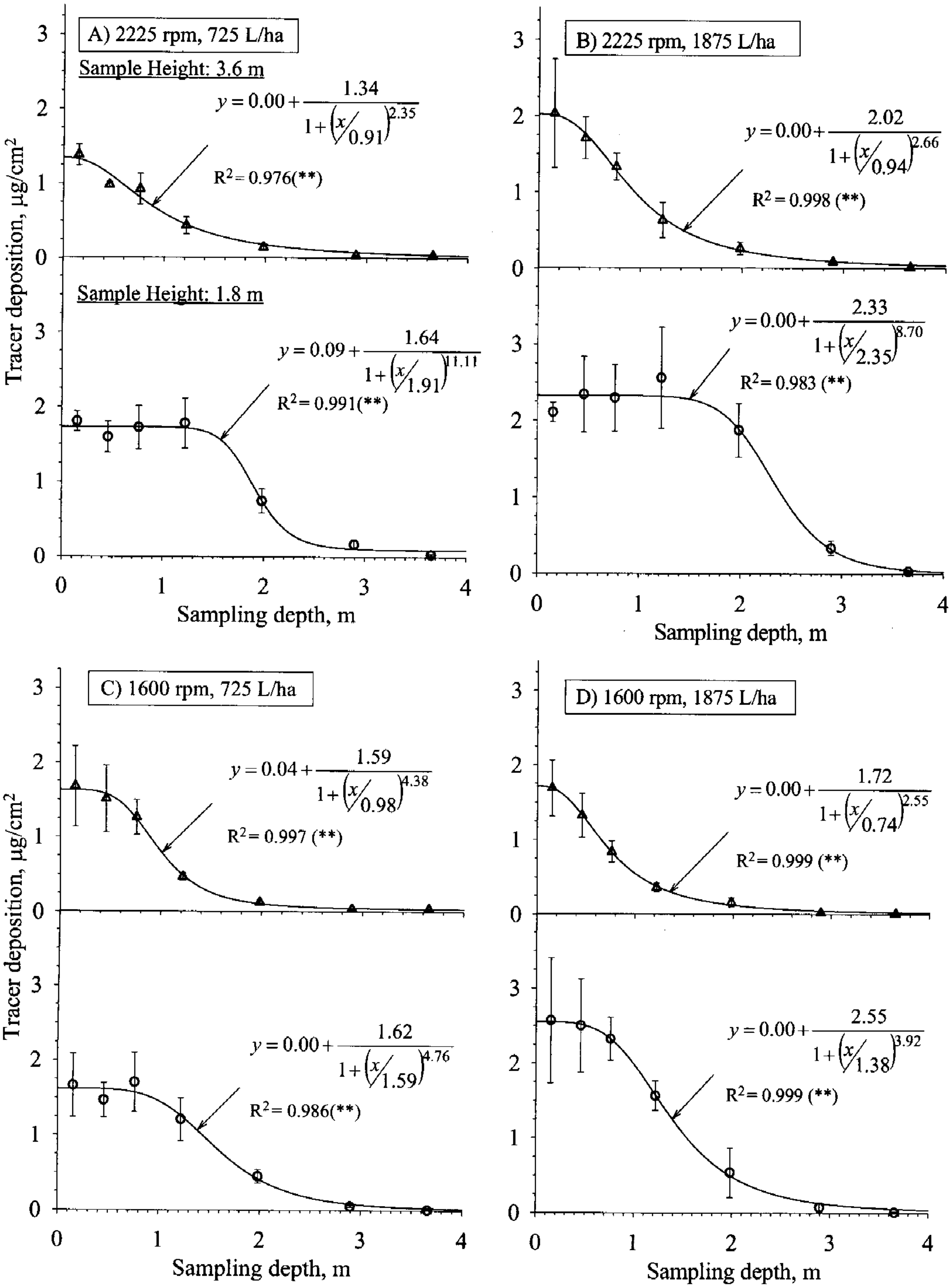

Figure 5: Variation in deposition of Titan sprayer with citrus canopy depth (Significance of model: ** significant at 1%)