Proc. Fla. State Hort. Soc. 116:298-304. 2003.

A REFEREED PAPER

SPRAYER AIR ENERGY DEMAND FOR SATISFACTORY SPRAY COVERAGE IN CITRUS APPLICATIONS

MASOUD SALYANI AND MUHAMMAD FAROOQ
University of Florida, IFAS
Agricultural and Biological Engineering Department
Citrus Research and Education Center
700 Experiment Station Road
Lake Alfred, FL 33850

Additional index words. air-blast sprayer, citrus, nozzle, sprayer airflow

Abstract. **A standard PTO-driven air-blast sprayer was used to investigate the effect of air volume on spray penetration and deposition in citrus applications. Air volume and velocity were varied using interchangeable fans on the sprayer. For each fan size, applications were made at different spray volume rates. Spray penetration was determined by deposition of a fluorescent tracer on cotton ribbons within the entire canopy depth and the deposition was determined by fluorimetry. Air volume had a significant effect on mean deposition but spray volume did not. The interaction between air volume and spray volume was significant. Overall, the results suggest that high air volume rates may not give significant increase in spray deposition or canopy penetration. It appears that the air and spray penetration largely depend on tree canopy structure and prevailing wind direction.**

Most of the Florida citrus applications are made with air-carrier ground sprayers (Summerhill et al., 1989). These sprayers are equipped with one or more axial-, centrifugal-, or cross-flow fans to generate some air energy for transporting spray droplets to locations inside tree canopy. Nonetheless, there are substantial differences among air capacities of the sprayers. Whitney et al. (1986) reported a range of 3.8-25.0 m^3/s for airflow rates of 12 PTO-powered sprayers. The airflow rate may be as high as 50 $m^3 \cdot s^{-1}$ in some engine-driven sprayers (Salyani and Whitney, 1990). These differences could have significant impacts on the fixed and variable costs of the spray applications (Whitney, 1968).

Since air-blast applications depend on the sprayer air stream to deposit the spray on the tree, the air volume and velocity must be sufficient for efficient droplet transport, satisfactory spray coverage, and acceptable penetration inside the canopy. In our previous experiments, medium sized PTO-powered sprayers have shown comparable spray coverage (Salyani, 1997) and pest control (Salyani et al., 2002) to that obtained with very large engine-driven sprayers. Farooq and Salyani (2002) and Farooq et al. (2002) have also reported comparable depositions, in most citrus canopy locations, from using a tower air-blast sprayer at 28 and 37 $m^3 \cdot s^{-1}$ airflow rates. There was no significant difference in efficacies of the abscission sprays for mechanical harvesting of oranges, using both standard and tower air-blast sprayers at their normal and reduced airflow rates (Farooq et al., 2003).

Although larger sprayers generate more than twice the air volume of the smaller ones, they may not provide any improvement in spray coverage. Even in an experiment, a large sprayer has shown inferior deposition to that obtained with a smaller sprayer (Whitney et al., 1989). Review of previous studies indicates that beyond a certain amount of air volume and velocity, additional air capacities of the sprayers may adversely affect spray deposition, increase spray runoff from leaf surface (Salyani and Hoffmann, 1996), intensify the drift from spray site (Walklate et al., 1996) and increase the cost of the application (Whitney, 1968).

The main objective of this research was to identify optimum air energy for typical citrus applications. Specific objectives of the project were to: 1) determine the effects of the sprayer air volume and energy on spray penetration and deposition within citrus tree canopies; 2) determine the interaction of the spray volume and air volume in spray coverage.

Materials and Methods

A standard (low-profile) PTO-driven air-blast sprayer (PowerBlast 500, Rear's Manufacturing Co., Eugene, Ore.) was operated with four interchangeable axial-flow fans to obtain different air volumes and velocities independent of the spray volume rate. The number-angle of the fan blades were 4-18°, 9-22°, 9-28°, and 9-32°. These fans generated airflow rates of 11.4, 13.4, 16.6, and 16.4 $m^3 \cdot s^{-1}$ at mean outlet velocities of 33.4, 38.6, 48.1, and 48.1 $m \cdot s^{-1}$, respectively. The airflow measurements were made with a Pitot tube/water manometer, over a 45-node grid on each side of the sprayer air outlet, in three replications. It should be noted that the 9-32° fan was not able to generate more airflow than the 9-28° fan, despite having larger blade angle. This poor fan performance was attributed to non-streamlined design of the air deflectors at the fan outlet. Such crude designs could restrict the static pressure rise obtainable from the fan unit and reduce the airflow rate.

Using each fan, applications were made at 250, 980, and 3590 $L \cdot ha^{-1}$ volume rates (12 treatments). These rates were obtained by using 12 'Lilac', 'Red', or 'Blue' Albuz APT cone nozzles (Ceramiques Techniques Desmarquest, Evreux, France) on one side of the sprayer operating at ground speeds of 4.8, 4.8, and 3.2 $km \cdot h^{-1}$, respectively. For each fan size, all three-volume rates were applied the same day.

Spray solutions, containing Pyranine-10G fluorescent tracer (Keystone Aniline Inc., Chicago, Ill.) at 500 $mg \cdot L^{-1}$, were applied from one side on a hedgerow of Valencia orange trees (Fig. 1). The trees were set at 4.5 m × 6.1 m spacing and had diameter and height of approximately 4 m and 5 m. Four trees along the row were used as four replications. These tar-

This research was supported by the Florida Agricultural Experiment Station, financial support form Florida Citrus Production Research Advisory Council, statistical consulting of Dr. Ramon C. Littell, technical assistance of Roy D. Sweeb, and approved for publication as Journal Series No. R. 09638. Mention of specific products is for information purposes only and does not imply recommendation of the products by the University of Florida over those not mentioned.

msi@lal.ufl.edu

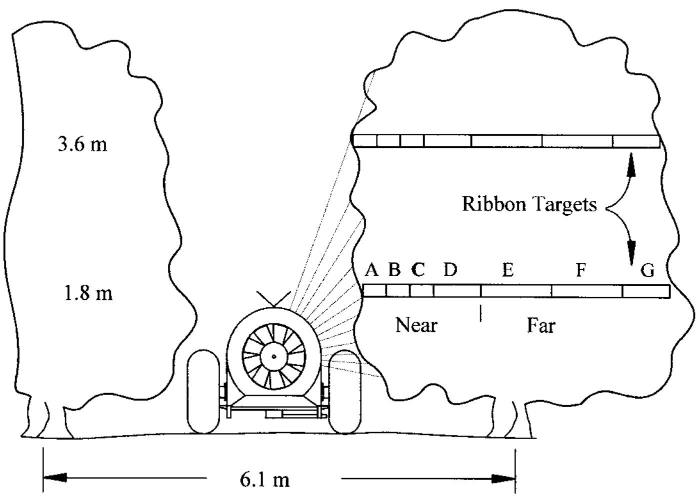

Fig. 1. Schematic view of spray application and target locations.

get trees were selected to represent the differences in canopy structure and foliage density of the trees within a grove. The same trees were used in all applications. In each tree, two lines of absorbent cotton ribbon (25-mm wide) were stretched horizontally through the canopy depth at 1.8 and 3.6 m heights (Fig. 1). All target trees had denser foliage at the upper sampling level. Soon after drying of the sprays, the ribbons were pulled out of the canopy, cut into sections, and collected in sealable plastic bags. Lengths of the cut ribbon sections varied (Fig. 1) based on expected deposition and sensitivity of the fluorometer. The samples were stored in a refrigerator until fluorometric analysis later (Salyani, 2000). Weather data, including temperature, relative humidity, wind velocity, and wind direction were recorded during the applications (Table 1).

The fluorometer readings of the spray deposit on the samples were adjusted for trace of fluorescence in cotton ribbons and normalized for differences in the volume rates. The data were used to characterize spray penetration within the canopy depth. Regression analysis was performed with SigmaPlot 6.00 software (SPSS Inc., 2000) and the relationships between spray deposition and canopy depth were expressed by the logistic curves (Farooq and Salyani, 2002) as:

$$Dep = Dep_0 + \frac{Dep_r}{1 + \left(\frac{D}{D_h}\right)^c}$$

Where,

Dep = tracer deposition at depth *D*, μg·cm^{-2}

Dep_0 = virtual minimum deposition, μg·cm^{-2}

Dep_r = range of deposition (max. – min.), μg·cm^{-2}

D = canopy depth in the spray discharge direction, m

D_h = canopy depth at which deposition has dropped by half, m

c = a constant proportional to the rate of decrease in deposition

Dep_r and D_h are indicators of overall spray deposition and penetration, respectively.

Statistical analyses of the data were performed by the General Linear Model (GLM) procedure (SAS Institute Inc., 1990), the Repeated Measures analysis of variance (Littell et al., 1998), and the Mixed-model analysis of variance procedure (Littell et al., 1996). The least-square means were compared at the 5% level. Variability of the data was expressed by standard error (SE) or by the coefficient of variation (CV).

Results and Discussion

Overall, the effects of replication, fan size (airflow rate), and target height on deposition were significant. Spray volume rate did not have a significant effect on deposition but its interaction with airflow rate was significant. Other interactions were not significant. Figures 2-5 show spray penetration within the canopy depth for fan sizes of 4-18°, 9-22°, 9-28°, and 9-32°, respectively. The regression lines indicate that, for all treatments, spray deposition on cotton ribbons decreased with canopy depth. The error bars represent SE of the data in four replications. Overall, depositions were more variable at locations nearer to the sprayer (Figs. 2-5). This high variabili-

Table 1. Spray application parameters and weather conditions.

Sprayer fan blade (No.-Angle)	Spray vol. rate (L/ha)	Ground speed (km/h)	Fan air flow rate (m^3/s)	Fan air velocity (m/s)	Weather data			
					Temp (°C)	R. H. (%)	W. Vel. (m/s)	W. Dir.[z] (deg)
4-18°	250	4.8	11.4	33.4	25	36	1.3	- 10
4-18°	980	4.8	11.4	33.4	22	38	1.8	- 20
4-18°	3590	3.2	11.4	33.4	25	35	2.2	+30
9-22°	250	4.8	13.4	38.6	21	60	1.3	+60
9-22°	980	4.8	13.4	38.6	23	57	0.4	+80
9-22°	3590	3.2	13.4	38.6	26	50	1.8	+30
9-28°	250	4.8	16.6	48.1	21	41	1.3	- 70
9-28°	980	4.8	16.6	48.1	23	39	0.9	+00
9-28°	3590	3.2	16.6	48.1	24	36	2.2	+20
9-32°	250	4.8	16.4	48.1	25	45	1.3	+30
9-32°	980	4.8	16.4	48.1	27	42	1.3	+10
9-32°	3590	3.2	16.4	48.1	28	44	1.8	+40

[z]Wind direction with respect to the spray direction (clockwise positive).

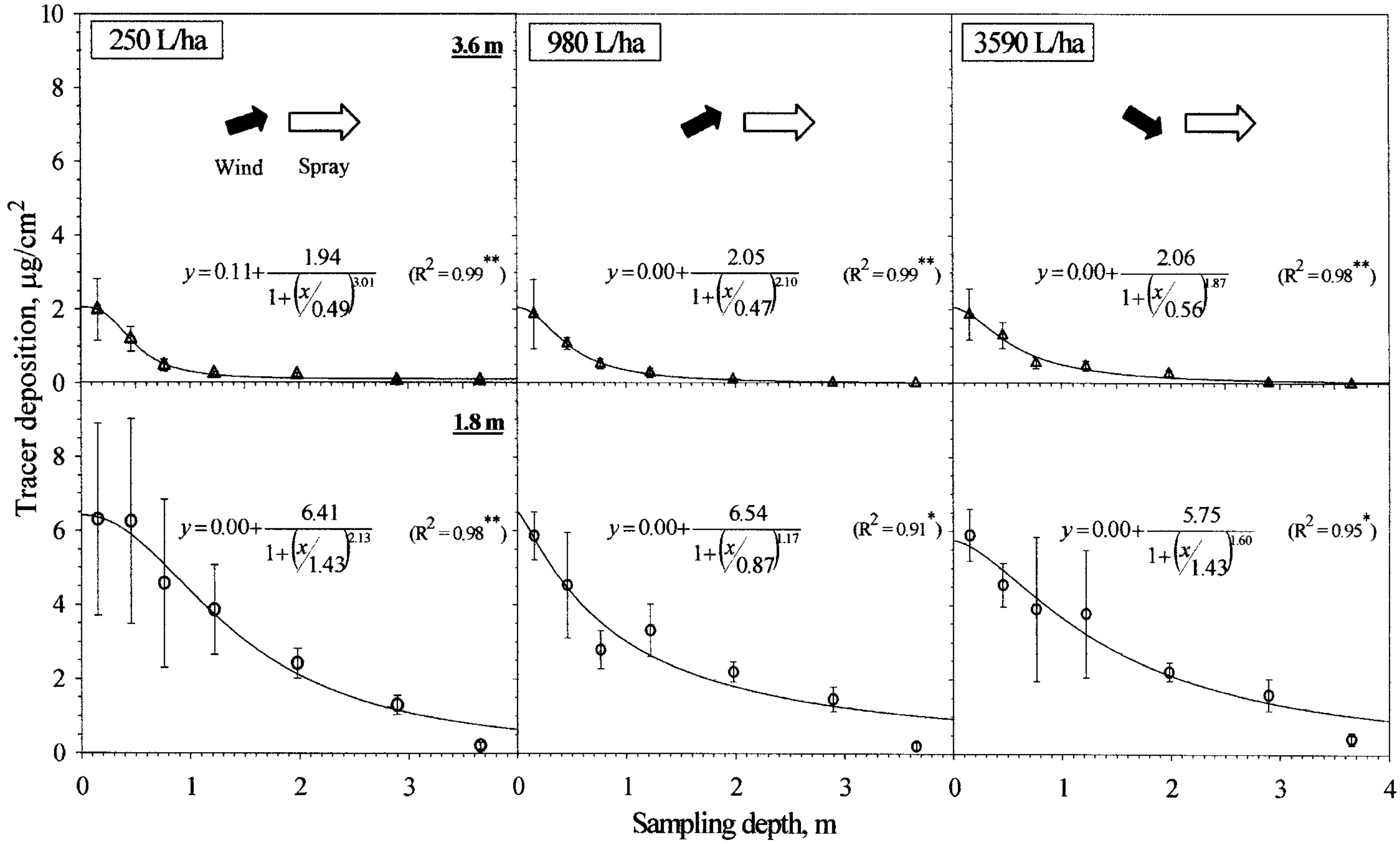

Fig. 2. Spray penetration into canopy depth using the sprayer with 4-18° fan.

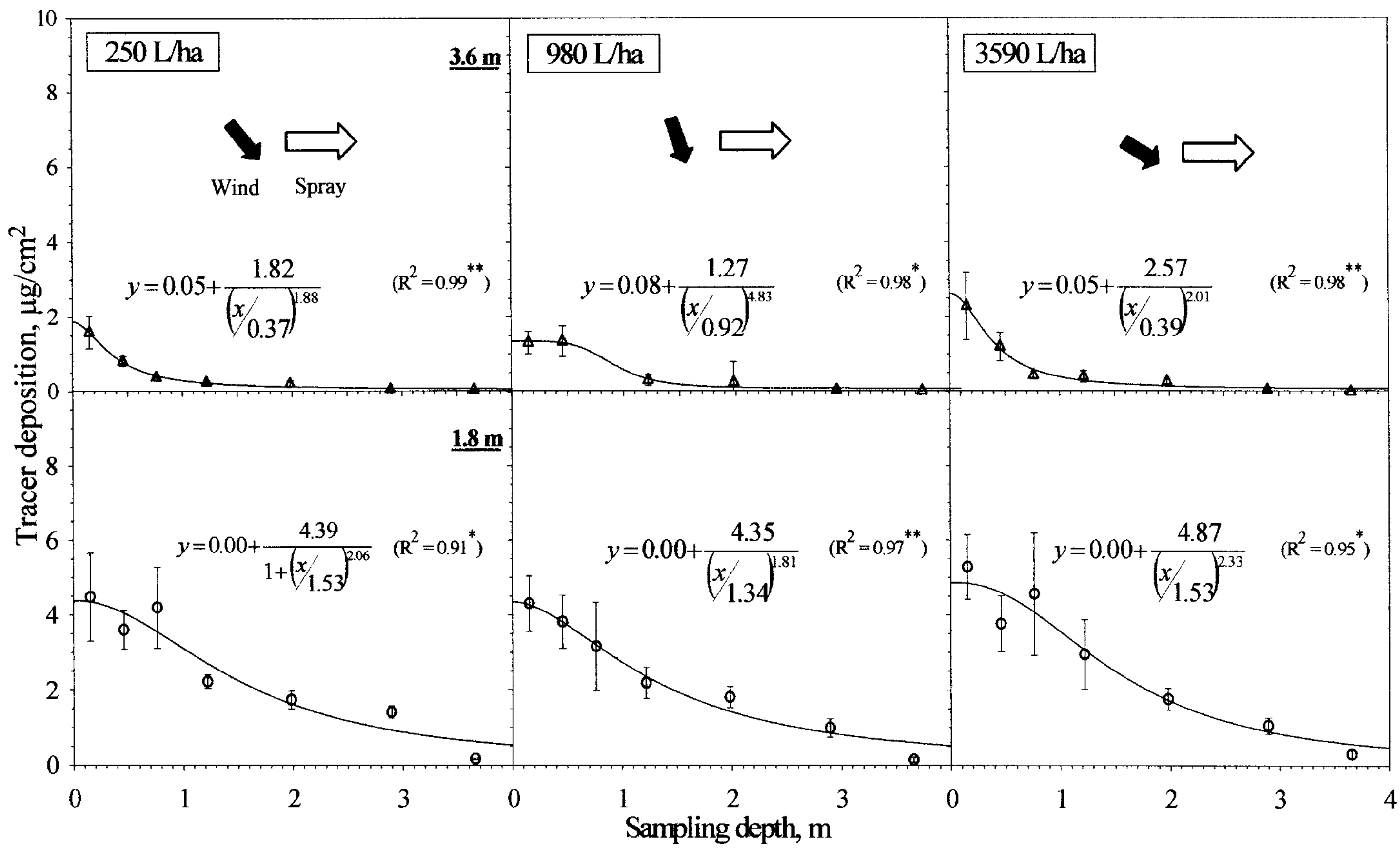

Fig. 3. Spray penetration into canopy depth using the sprayer with 9-22° fan.

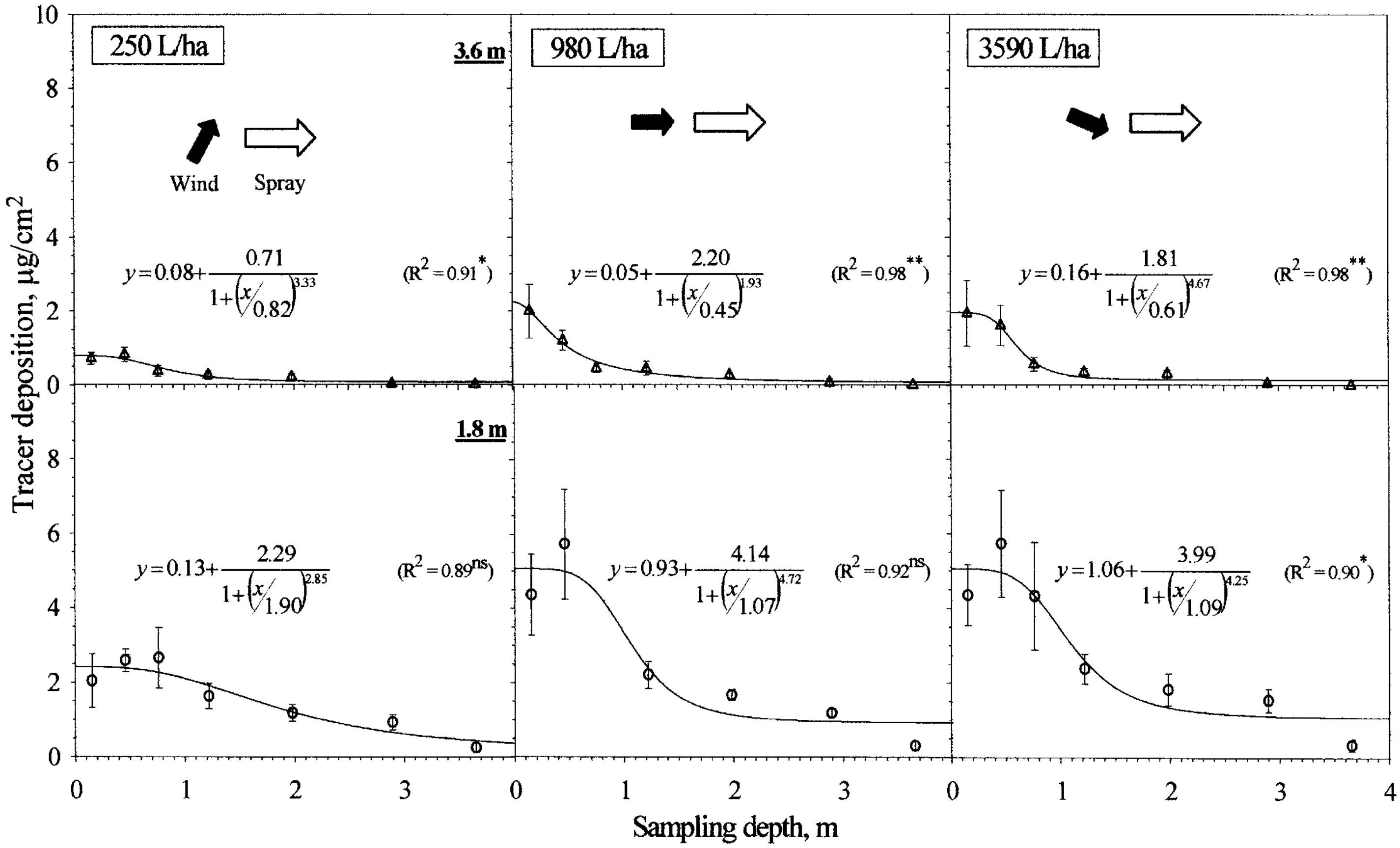

Fig. 4. Spray penetration into canopy depth using the sprayer with 9-28° fan.

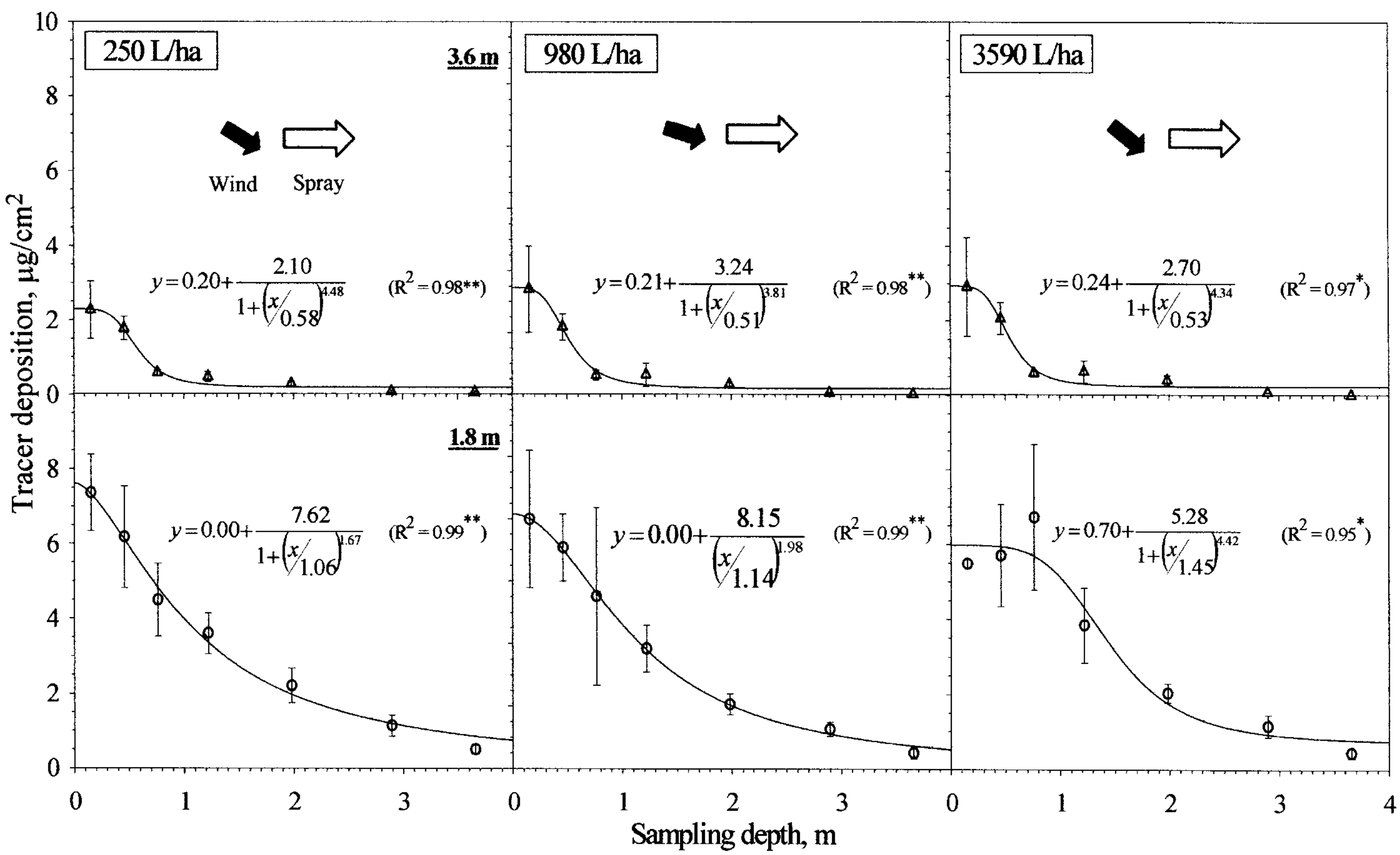

Fig. 5. Spray penetration into canopy depth using the sprayer with 9-32° fan.

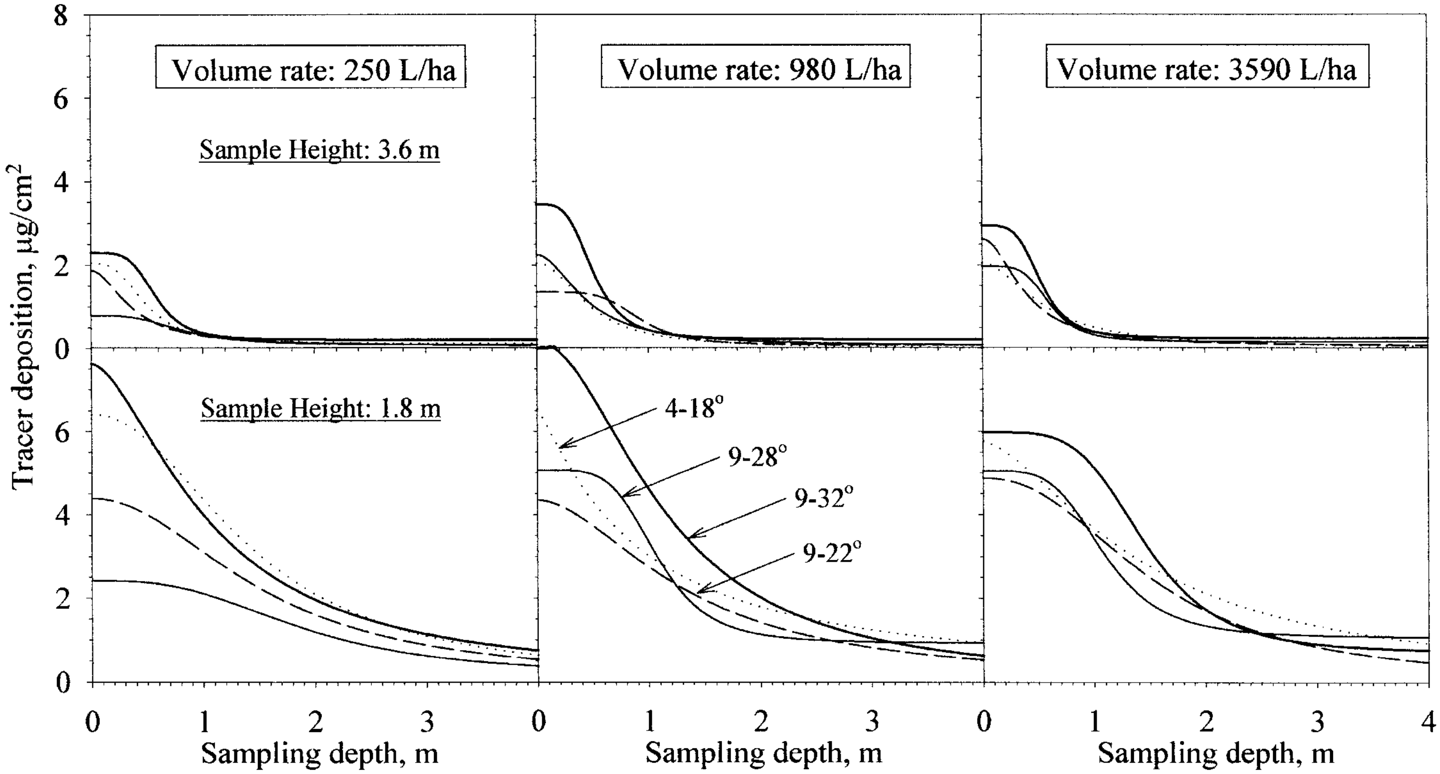

Fig. 6. Comparison of spray penetration from four fan sizes at different volume rates.

ty could be attributed to differences in foliage densities of the four target trees (replication effect). Deposition variability diminished at deeper canopy locations.

There were significantly lower depositions on the upper (3.6 m) targets throughout the canopy depth (Figs. 2-5). This could have been due to the longer distance of the targets from sprayer nozzles as well as presence of the denser foliage at the upper half of the canopies. Figure 6 overlays the regression lines of the four fan sizes at each volume rate and target height. At locations nearer to the sprayer the effect of the airflow rate was significant; however, there were inconsistent differences in deposition among the four fan sizes. The differences might be explained partially by instantaneous interactions of the sprayer airflow and atmospheric wind parameters, which diminish at farther canopy locations.

Comparison of the regression lines revealed that wind direction might have had a decisive effect on spray penetration and deposition. The +80° and -70° wind directions (nearly parallel to sprayer travel direction) during the applications at 9-22° fan-980 L·ha^{-1} (Fig. 3) and 9-28° fan-250 L·ha^{-1} (Fig. 4) have clearly reduced spray deposition at both sampling heights. With a few exceptions, probably related to wind direction, generally there were no significant differences in mean depositions of the four fan sizes at the near or far canopy locations (Fig. 7). The effect of spray volume rate within each fan size is shown in Fig. 8. In general, there were no significant differences among mean depositions of the three volume rates at either near or far side of the canopies.

The results suggest that high air volume rates may not give significant increase in spray deposition or canopy penetration. In this study, all fan sizes resulted in comparable spray penetration and deposition in most canopy locations. Therefore, there seem to be no appreciable advantage in using larg-

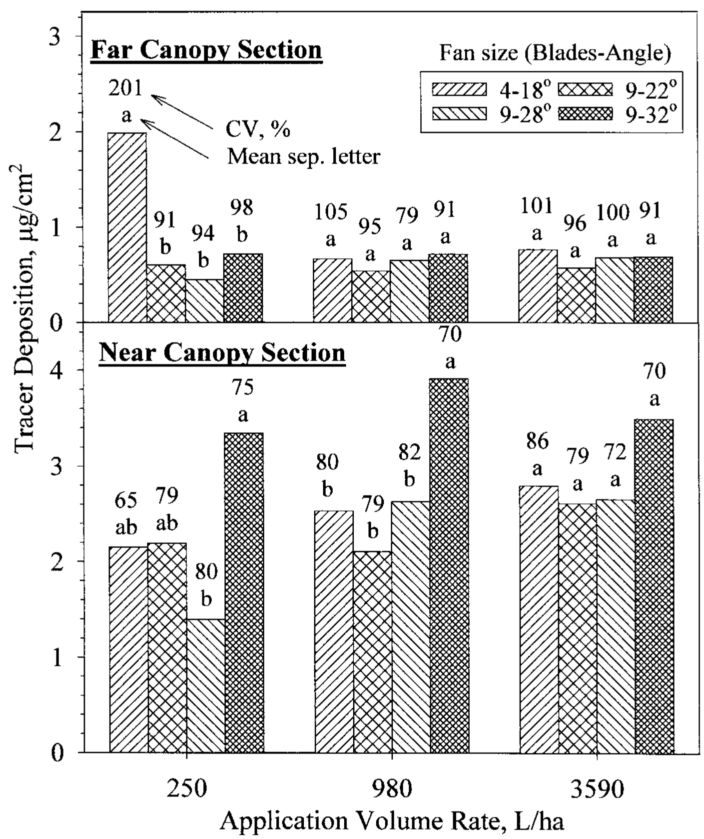

Fig. 7. Comparison of mean depositions of the four fans at near and far canopy locations.

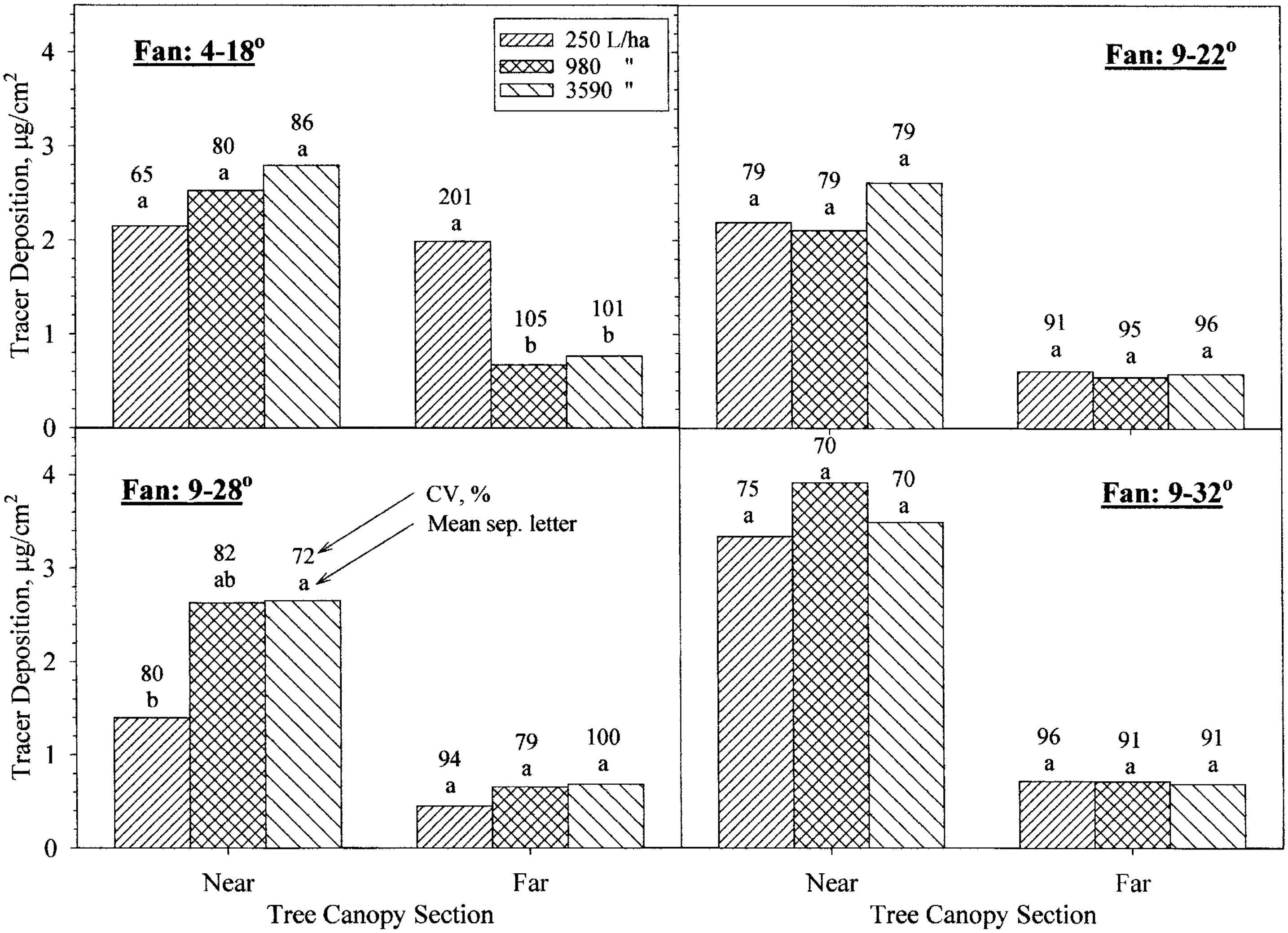

Fig. 8. Comparison of mean depositions of the three volume rates within each fan size.

er airflow rates in some citrus spray applications. Although the range of airflow rate was limited to 11.4-16.6 $m^3 \cdot s^{-1}$, the results are consistent with the earlier reports of Farooq and Salyani (2002) and Farooq et al. (2003). They found comparable deposition and biological efficacy in using a tower air-blast sprayer at normal (37.0 $m^3 \cdot s^{-1}$) and reduced (28.0 $m^3 \cdot s^{-1}$) airflow rates.

Since the fan power requirement increases by the cubic factor of the airflow rate (Jorgensen, 1961) additional air capacities dramatically increase the needed horsepower for fan operation. Therefore, the use of smaller fans could offer substantial reduction in energy expenditure. The lower fan power demand in turn reduces fuel consumption and operating cost of the application. In this study, the smallest fan size (4-18°) had about 67% less air energy demand compared to the 9-32° fan. The airflow measurements revealed that the 9-32° fan could not generate more air volume than the 9-28° fan. This limitation is believed to be due to the absence of streamlined deflectors in the air outlet of this particular sprayer. When the airflow could not be discharged efficiently some air energy is dissipated in the process.

It appears that the air and spray penetration largely depend on the tree canopy structure and prevailing wind direction. If the goal is to spray medium-sized trees, sprayers with small air capacities should be sufficient. However, for large and densely foliated trees, higher air volume and energy may be justifiable.

Conclusions

1. Air volume had a significant effect on spray deposition at locations nearer to the sprayer but the effect was not consistent and diminished at farther locations.
2. Overall, lower airflow rates gave comparable spray penetration and deposition to higher airflow rates in most canopy locations.
3. Spray volume rate did not affect spray penetration or deposition.
4. Lower airflow rates could reduce the fan energy requirement of the sprayer by up to 67%.

Literature Cited

Farooq, M. and M. Salyani. 2002. Spray penetration into the citrus tree canopy from two air-carrier sprayers. Trans. ASAE 45:1287-1293.

Farooq, M., M. Salyani, and J. D. Whitney. 2002. Improving efficacy of abscission sprays for mechanical harvesting of oranges. Proc. Fla. State Hort. Soc. 115:247-252.

Farooq, M., M. Salyani, and J. D. Whitney. 2003. Effect of application techniques on abscission chemical deposition and mechanical harvesting of 'Valencia' oranges. HortTechnology 13:344-351.

Jorgensen, J. (ed.). 1961. Fan Engineering. Buffalo Forge Company, Buffalo, New York. 700 p.

Littell, R. C., P. R. Henry, and C. B. Ammerman. 1998. Statistical analysis of repeated measures data using SAS procedures. J. Anim. Sci 76:1216-1231.

Littell, R. C., G. A. Miliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS Systems for Mixed Models, SAS Institute Inc., Cary, NC. 633 p.

Salyani, M. 1997. Performance of sprayers in Florida citrus production. 5th Intl. Conf. on Fruit, Nut, and Vegetable Production Engineering, Davis, Calif. 6 p.

Salyani, M. 2000. Methodologies for assessment of spray deposition in orchard applications. ASAE Paper No. 00-1031, 10 p., ASAE, St. Joseph, Mich.

Salyani, M. and W. C. Hoffmann. 1996. Air and spray distribution from an air-carrier sprayer. Appl. Eng. in Agr. 12:539-545.

Salyani, M. and J. D. Whitney. 1990. Ground speed effect on spray deposition inside citrus trees. Trans. ASAE 33:361-366.

Salyani, M., L. W. Timmer, C. W. McCoy, and R. C. Littell. 2002. Petroleum spray oils in Florida citrus applications, pp. 595-600. In A. Beattie, D. Watson, M. Stevens, D. Rae, and R. Spooner-Hart (eds.). Spray Oils Beyond 2000 - Sustainable Pest and Disease Management.

SAS Institute, Inc. 1990. SAS User's Guide: Statistics, Ver. 6, SAS Institute, Inc., Cary, N.C.

SPSS. 2000. SigmaPlot for Windows, Ver. 6, SPSS, Inc. Chicago, Ill.

Summerhill, W. R., J. L. Knapp, J. W. Noling, G. D. Israel, and C. L. Taylor. 1989. Citrus pest management. University of Florida, IFAS, Coop. Ext. Ser. PE-6, 17 p.

Walklate, P. J., G. M. Richardson, and J. V. Cross. 1996. Measurements of the effect of air volumetric flow rate and sprayer speed on drift and leaf deposit distribution from an air-assisted sprayer in an apple orchard. AgEng. Madrid Paper 96A-131, 9 p.

Whitney, J. D. 1968. An analysis of application costs of airblast spraying in Florida citrus. Proc. Fla. State Hort. Soc. 81:6-15.

Whitney, J. D., D. B. Churchill, S. L. Hedden, and R. P. Cromwell. 1986. Performance characteristics of pto airblast sprayers for citrus. Proc. Fla. State Hort. Soc. 99:59-65.

Whitney, J. D., M. Salyani, D. B. Churchill, J. L. Knapp, and J. O. Whiteside. 1989. A field investigation to examine the effects of sprayer type, ground speed, and volume rate on spray deposition in Florida citrus. J. Agr. Eng. Res. 42:275-283.