Discussion and Conclusions

The wash treatments were effective in removing basic Zn sulfate from the surface of the leaf.For Zn oxide, wash treatments including acid or EDTA were the best at removing Zn oxide from the leaf surface. This data supports the recommendation by Smith (1966) that analysis of leaves which had been sprayed with nutritional elements must be thoroughly washed. However, our data suggests that leaves need to be washed with detergent and a solution of 3% HCl by volume for maximum removal of leaf surface nutrients.

The suggestion that leaves that have been sprayed with Cu, Zn, or Mn should not be analyzed for these elements even if washed (Koo et al., 1984; Obreza et al., 1992) is questionable in light of our data. Our data suggests that the detergent plus HCl acid wash appeared to be very effective in removing Zn nutritionals applied to the foliage when compared to control treatments. Our data also showed that washes containing EDTA were as effective as the acid wash in removal of leaf surface Zn and other plant nutrients.

When comparing basic Zn sulfate and Zn oxide as sources of Zn for nutritional sprays, no consistent differences occurred for the majority of the washes at either 7 or 28 DAT. By the 42 DAT time period, Zn oxide was at significantly higher levels than the Zn sulfate. Citrus trees used in this study had high levels of Zn, Mn, Cu, and Fe nutrients on the surface of the leaves prior to application of Zn nutritionals due to the nursery spray program.

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EFFECTS OF APPLICATION TIME AND SPRAY VOLUME ON DEPOSITION

M. Salyani* and W. C. Hoffmann

University of Florida, IFAS

Citrus Research and Education Center

700 Experiment Station Road

Lake Alfred, FL 33850

Additional index words. Citrus, temperature, humidity, leaf wetness, colorimetry.

Abstract. **The objective of the research was to characterize the influence of weather parameters on spray application and determine the effects and interactions of the application time and spray volume on deposition. Spray applications were made in August, November, and February to plots of Dancy tangerine trees. In each month, the trees were sprayed at 6 nominal times (2, 6, and 10 a.m. and 2, 6, and 10 p.m.), 3 volume rates (470, 1890, and 4700 L/ha (50, 200, and 500 gpa)), and 4 replications. Spray mixtures contained a manganese tracer and spray deposition was sampled at 3 heights (1.2, 2.4, and 3.6 m (4, 8, and 12 ft)) and six radial locations at each height. Deposition was determined by colorimetry. Weather data including temperature, relative humidity, wind velocity, and wind direction were collected during the applications and leaf surface wetness was characterized by visual judgement.**

Application time and spray volume had significant effects on spray deposition. Overall, night-time applications (lower temperatures and higher humidities), made under dry leaf conditions, had higher deposition than day-time applications. However, wet leaf conditions could reduce deposition by increasing runoff from the leaves.

Spray application is a complex process and can be influenced by many variables. The magnitude and uniformity of spray deposition depend on the canopy geometry (Hall et al., 1991), pesticide properties (Sundaram and Sundaram, 1987), spray equipment design (Furness and Pinczewski, 1985), application parameters (Randall, 1971), and weather conditions (Threadgill and Smith, 1975).

Droplet size spectrum is an important factor in spray application and can affect spray deposition (Salyani, 1988) and drift (Akesson and Yates, 1988). Large droplets tend to bounce off the leaf surface and fall on the ground while small droplets are drift-prone and may move out of the application site. Retention of a certain droplet size on the leaf surface is, in turn, dependent on the physical properties of the pesticide, surface characteristics of the target, and atmospheric conditions. For a particular sprayer design, operating parameters, and droplet size spectrum, the amount of on-target spray deposition and drift can be affected significantly by weather conditions.

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Kincaid and Longley (1989) discussed the theoretical and actual changes in spray droplet size when released under different weather conditions. Smith et al. (1974), Colvin and Nichols (1986), and Brown et al. (1995) used different weather parameters such as temperature, relative humidity, and wind velocity to determine the right time for chemical applications. Threadgill and Smith (1975) found that atmospheric turbulence is also a major factor affecting transport of spray clouds, and both horizontal and vertical components of wind velocity are important in spray drift.

Air temperature and relative humidity have direct effects on the rate of evaporation. Consequently, the size of water-based droplets can decrease significantly under hot and dry conditions (Göhlich et al., 1979). Evaporation may be as much as 25-50% of the spray mass by the time the droplets reach the tree top, about 30 ft from the sprayer (Brann, 1964).

Caseley et al. (1983) and Brown et al. (1991) reported that relative humidity and temperature significantly affected the efficacy of applied chemicals. Kirk et al. (1992) observed higher spray deposits in cotton at low temperatures and wind speeds and high relative humidities. Smith et al. (1974) stated that night-time applications had less chance of creating drift problems than did day-time spraying. Colvin and Nichols (1986) concluded that spraying at night reduced the chances of off-target deposition due to lower wind speeds.

Since the rate of evaporation is a function of air temperature and humidity, the size of water-based droplets would remain larger in night applications. This could result in reduction of drift-prone droplets and increase on-target spray deposition. However, leaf surface may be dry, damp, wetted with a thin film of moisture, or covered with dew droplets (condensed moisture). These characteristics, which are governed by weather parameters (Larcher, 1975), may interact with spray volume and show significant effects on spray deposition.

The overall objective of the research was to identify spray application practices that may increase on-target spray deposition and minimize drift, off-target deposition, and environmental contamination. Specific objectives of the research were:

1. To determine the effects and interactions of the spray application time and spray volume on deposition, and

2. To quantify the potential benefit of night-time spraying, for dry and wet leaf conditions.

Materials and Methods

Spray Applications

A tractor-drawn, PTO-powered, air-blast sprayer (Durand-Wayland AF500 DPS) was used to spray plots of Dancy tangerine trees, in Haines City, Florida. The trees were set at 5.7 m × 6.9 m (15 ft × 23 ft) spacings and their canopies averaged about 4.5 m (14.5 ft) in height and diameter. Each plot consisted of 3 rows of 5 trees. Three center trees of each plot were sprayed from one side and the center tree was sampled for spray deposition (Fig. 1).

The plots were sprayed in August, November, and February to obtain a wide range of weather conditions. In each MONTH, the applications were made at 6 nominal times (TIME: 2 a.m., 6 a.m., 10 a.m., 2 p.m., 6 p.m., and 10 p.m.) to get different weather conditions during the applications. At each TIME, a total of 12 plots were sprayed at 3 spray volumes rates (VOL: 470, 1890, and 4700 L/ha (50, 200, and 500 gal/acre)) and 4 replications (REP). The 12 plots (3 VOL × 4 REP) were sprayed in about 2 hours after each nominal TIME. The periods of daylight in August, November, and February applications were about 6:20 a.m. - 7:30 p.m., 6:45 a.m. - 5:45 p.m., and 7:20 a.m. - 6:15 p.m., respectively.

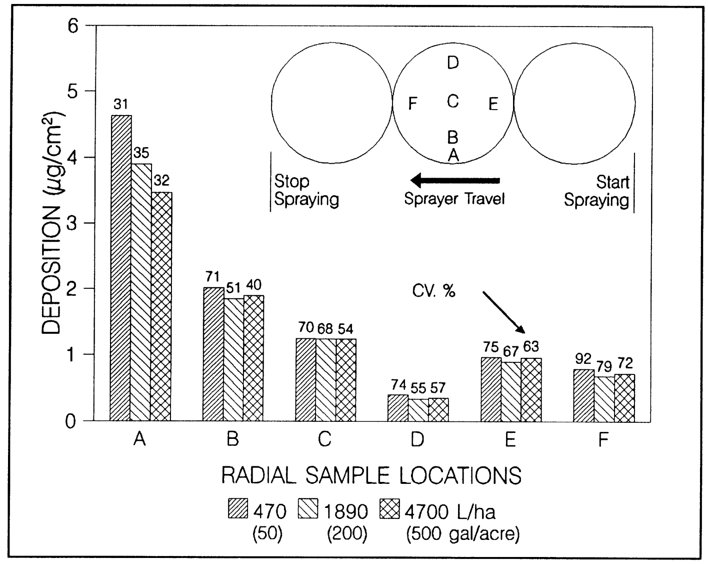

Figure 1. Schematic view of the sprayed trees and radial sample locations. Mean and CV of deposition for different volumes and sample locations.

All applications were made at a ground speed of 2.52 km/h (1.57 mph). The discharge rates for the 470, 1890, 4700 L/ha (50, 200, and 500 gal/acre) volumes were 6.8, 27.3, and 68.3 L/min (1.8, 7.2, and 18.0 gal/min) per side, respectively. The size and number of the selected nozzles for each volume are given in Hoffmann and Salyani (1996).

Deposition Samples

Spray mixtures contained manganese sulfate monohydrate ($MnSO_4$:H_2O, 32% Mn^{2+}), a commercially available fertilizer used in citrus groves, as a nonphotodegrading deposition tracer. It was applied at a constant rate of 4.5 kg (Mn) /ha (4.0 lbs (Mn) /acre) for all spray volumes, resulting in tank target concentrations of 9600-960 mg/L (1.28-0.128 oz/gal). Tank samples were taken at the beginning and end of each TIME × VOL application to determine the actual concentration of the material being applied. The final deposition reading was corrected for any deviations from the tank target concentration.

After spraying the 12 plots of each TIME, the center tree of each plot was sampled at 3 heights (HT: 1.2, 2.4, and 3.6 m (4, 8, and 12 ft)) and six radial locations (LOC) at each height. LOC A was located on the outer edge of the canopy nearest to the sprayer, LOC C at the center of the tree, and LOC B, D, E, and F were located at 0.7-0.8 m (2.3-2.6 ft) inside the canopy at their respective locations (Fig. 1). Three to 5 leaf samples were collected from each HT × LOC area, placed in prelabeled Zip-Loc plastic bags, stored in a cooler to prevent leaf wilting, transported to the laboratory, and stored in a refrigerator until they could be analyzed by manganese colorimetry (Hoffmann and Salyani, 1996).

After measuring deposition from each sample, the leaf area measurements were taken with a Delta-T Area Meter System. The average total leaf area (top and bottom surfaces together) in a sample bag was 240.4 cm^2 (37.3 sq. inch). All deposition data were converted to a weight per unit area basis (μg/cm^2) for the statistical analyses.

Weather Data

A weather station was installed inside the grove to record the temperature (T), relative humidity (RH), wind velocity (WV), and wind direction (WD) during the applications. The weather sensors were connected to a data logger (Model CR-10, Campbell Scientific) that had been programmed to sample and record every minute. Dry bulb temperature and wet bulb temperature were measured at 2.5 m (8 ft) above the ground and used to calculate the relative humidity. A cup anemometer and a vane wind direction sensor were positioned at 10 m (32 ft) high to measure the wind velocity and wind direction, respectively.

Since deposition is affected by droplet retention on the target surface after the droplet impacts the surface, the condition of the leaf surface in terms of moisture was important to take into account. The leaf surface wetness (defined as the leaf wetness index, WI) at the time of application was recorded by feeling and visually assessing the leaves. The WI was ranked from 1 to 4 (1 = dry, 2 = damp (slight trace of moisture), 3 = wet leaves with no visible condensation on them, 4 = leaves with visible condensation (dew) on them).

Table 1 shows a summary of the ranges of meteorological and leaf surface conditions under which the experiments were conducted. Details of the weather data transformation is given in Hoffmann and Salyani (1996).

Statistical Analyses

Several statistical procedures (SAS, 1985) were used to analyze the data. Analysis of variance was performed by the General Linear Models (GLM) procedure with TIME and VOL as the main effects, HT and LOC as subplot variables, and the weather parameters as covariables within a split plot design. Variability of deposition among samples was expressed as the coefficient of variation (CV). The Fisher's protected LSD mean separation procedure was used for determining difference between means. Regression analyses were done using the REG procedure. Statistical significance of results refer to the 5% level.

Results and Discussion

Application Time Effect

The TIME had a significant effect on spray deposition in each MONTH. The means separation letters (Fig. 2) shows that in August, the depositions were significantly higher in the early morning predawn hours (lower temperatures and higher relative humidity) as compared to other times of the day. The low deposits at the 10 a.m., particularly for the 500 gal/acre, may have been due to the presence of heavy dew on the leaves. In November, the 2 p.m. and 6 p.m. applications gave the lowest deposits; whereas in February, the highest deposit resulted from the 2 p.m. application. The latter may have been due to the presence of freezing temperatures during the night applications. In general, the data suggest that in the warmer months, deposition may be increased by night applications.

Table 1. Meteorological data summary and leaf surface wetness for each month.

	August	November	February
Temperature, °C	24.0 - 33.5	11.0 - 31.2	-0.8 - 19.2
(°F)	75.2 - 92.3	51.8 - 88.2	30.6 - 66.6
Rel. humidity, %	55 - 90	62 - 100	39 - 100
Wind velocity, m/s	0.4 - 1.8	0.5 - 2.3	0.5 - 2.4
(mph)	0.9 - 4.0	1.1 - 5.1	1.1 - 5.4
Wind direction[z], deg	356 - 220	333 - 175	340 - 329
Leaf wetness index	1 - 4	1 - 4	1 - 4

[z]0° = North, 90° = East, etc. (Tree rows oriented in N-S direction).

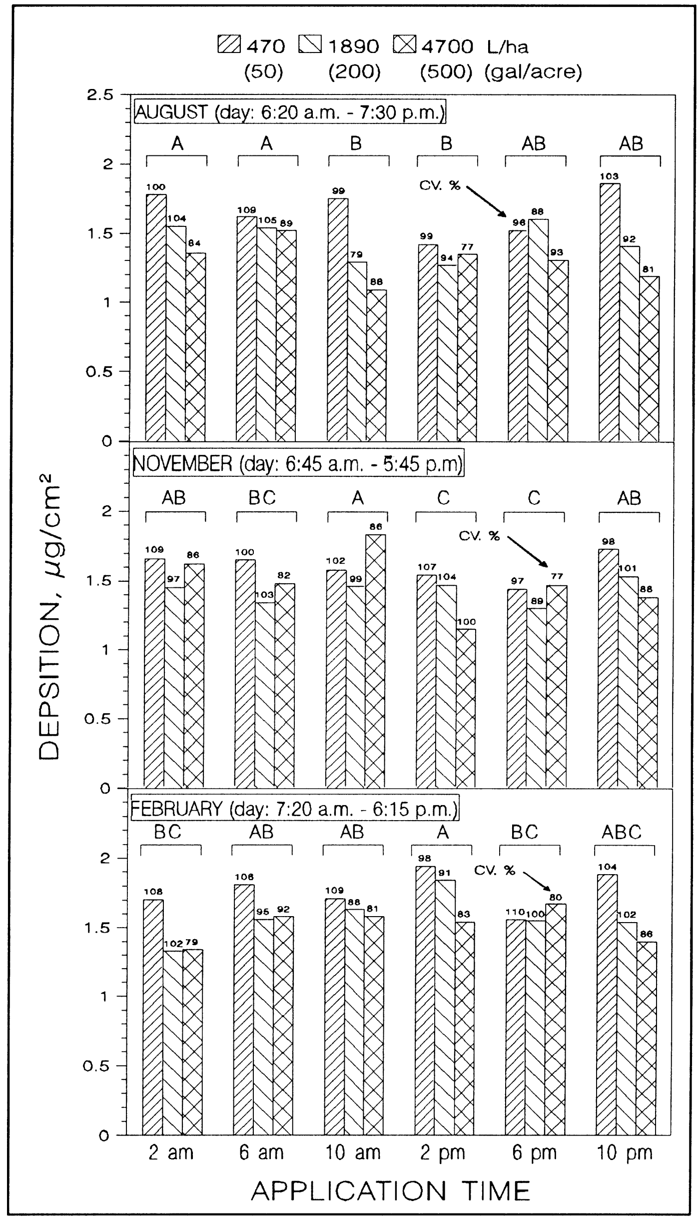

Figure 2. Mean and CV of deposition for different application times and spray volumes. Average deposits of the 6 application times (within each month) are separated by Fisher's protected LSD at the 5% level.

Spray Volume Effect

The volume effect was significant in each month. Fig. 2 shows the means for each nominal application time in August, November, and February. The 470, 1890, and 4700 L/ha (50, 200, and 500 gal/acre) deposition means were 1.67a, 1.49b, and 1.44b μg/cm^2, respectively, when the means were averaged across the months. The CV generally decreased as volume increased (Fig. 1 and Fig. 2).

Sample Location Effect

Sample height (HT) had a significant effect on deposition. The highest and lowest overall mean depositions were found at the 1.2

and 3.6 m (4 and 12 ft) heights, respectively (Fig. 3). This could be attributed to the nozzle arrangement.

Radial sample location (LOC) had a highly significant effect on deposition. The highest to lowest mean deposits were measured at the following locations: A, B, C, E, F, D (Fig. 1). The deposition at LOC A was 2.1 times greater than that at LOC B, which was in agreement with the results found by Whitney et al. (1989). This large difference suggested that the outer canopy acts as a barrier to lower the amount of material that moves into the canopy as suggested by Salyani and McCoy (1989).

The average deposition along the trunk line (LOC E, C, and F) was approximately one-half of that measured at LOC B. Deposition at LOC E (leading edge) was significantly higher than LOC F (trailing edge). This may be a result of bringing the spray cloud into the leading edge of the canopy while at the trailing edge the spray was moving away from the canopy.

Day and Night Depositions

Since TIME effect was found to be significant, this indicated that deposition changed with changes in meteorological conditions; however, the effects of individual weather parameters (covariables) were not significant (details in: Hoffmann and Salyani, 1996).

In order to identify trends in the collected data, deposition under 3 meteorological-based conditions were computed from regression equations. The predicted daytime deposition (DAY) was calculated by using the highest T, lowest RH, and dry leaf conditions (WI=1). The corresponding night-time deposition for dry leaf surfaces (NIGHT-DRY) was computed with the lowest T, highest RH, and WI=1. The predicted deposition for wet leaf surfaces (NIGHT-WET) was calculated by using the lowest T and highest RH, measured during wet leaf conditions (WI=4). Only the extremes of leaf surface moisture (WI = 1 and 4) were used because these values represent the largest difference in leaf moisture conditions. The results for each month and each radial location are shown in Fig. 4, and Fig. 5, respectively.

Six of the 9 regression equations predicted greater NIGHT-DRY deposits than the DAY deposits, suggesting potential benefits from night-time applications. However, the NIGHT-WET deposits were also lower than NIGHT-DRY deposits in 5 equations. This means that the benefits of the night-time applications may be mitigated once dew forms on the leaf surface, especially at higher spray volumes. The predicted means generally increased as the volume decreased (Fig. 4).

Although no published literature was found relating leaf surface wetness to deposition, the relationship between droplet size (or spray volume) and leaf wetness can be rationalized. The leaf surface conditions can affect deposition when large droplets, usually associated with high spray volumes, come into contact with the leaf. Under dry leaf conditions, the droplets impinge on the leaf and become almost hemispherical resulting in a large droplet-leaf contact area which may help to hold the droplet onto the leaf. If the droplets are large enough or several droplets coalesce, the droplets may have sufficient mass to roll off the leaf resulting in runoff under high volume rates. Under wet leaf conditions, particularly when dew is present, the surface has little capacity to hold addi-

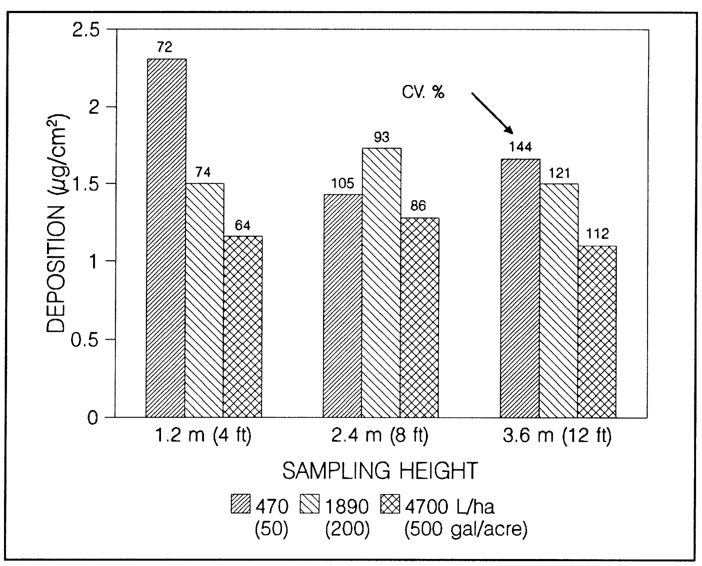

Figure 3. Mean and CV of deposition at different sample heights.

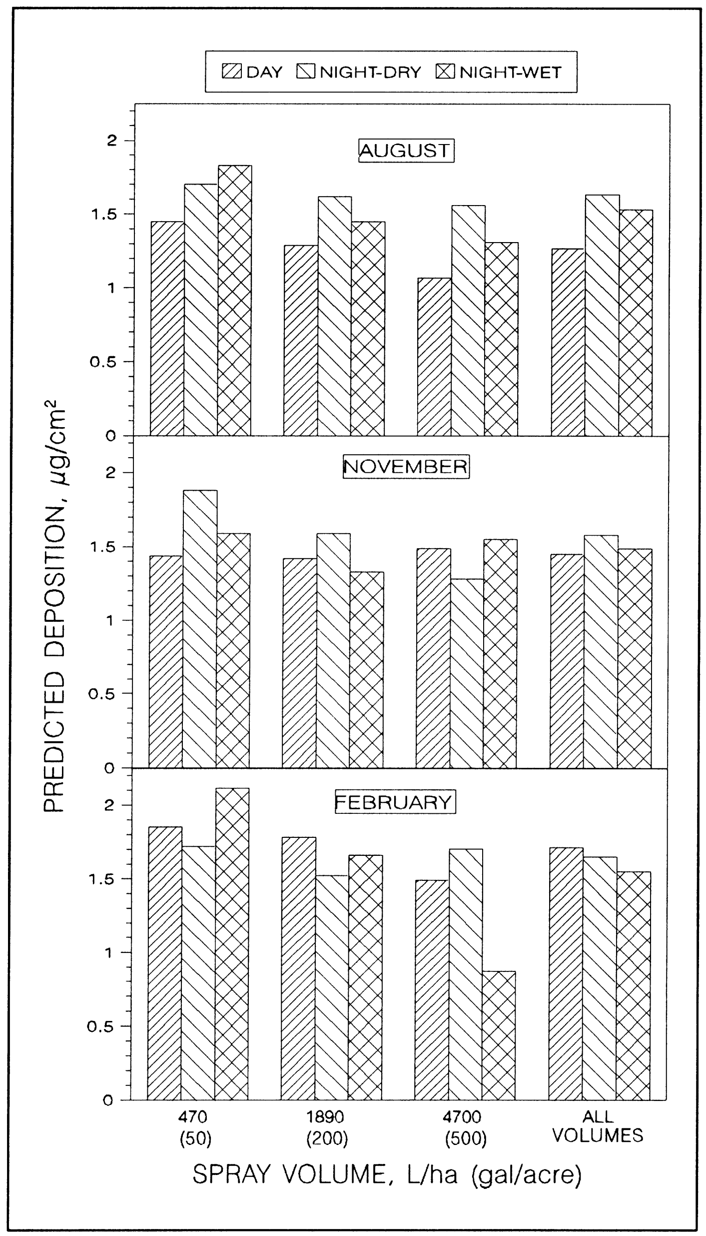

Figure 4. Predicted deposition for day and night applications at each month.

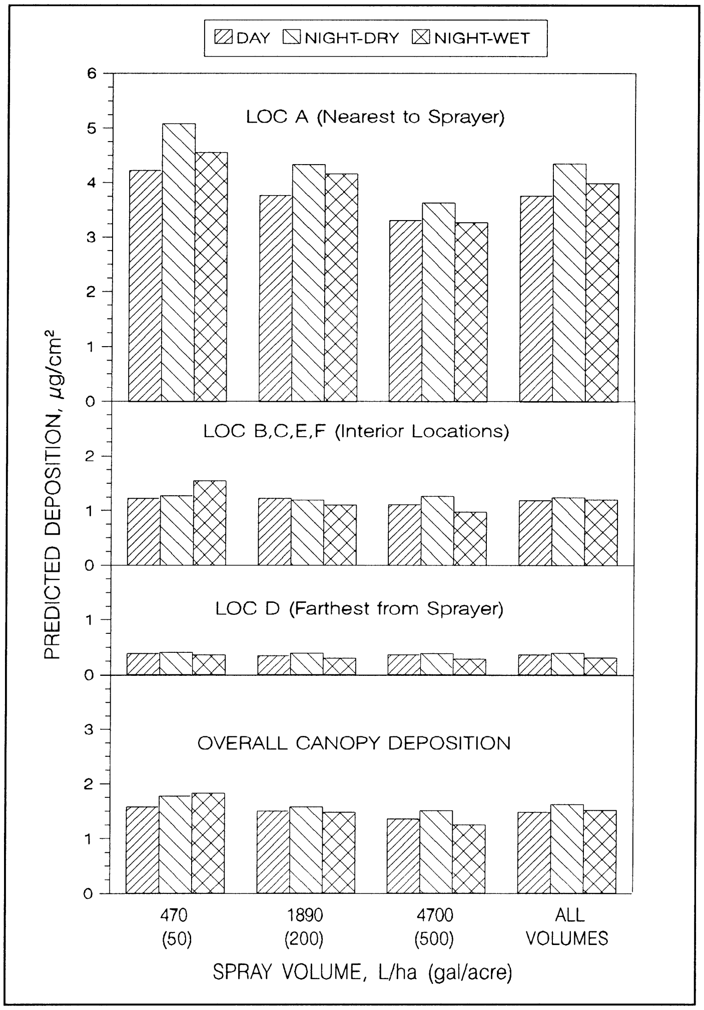

Figure 5. Predicted deposition for day and night applications at different radial locations.

tional liquid without runoff occurring, as seen in the 4700 and 1890 L/ha (500 and 200 gal/acre) rates. However, smaller droplets, usually associated with lower spray volumes, would be less affected by leaf surface wetness because they have less mass and would be less likely to run off.

The predicted means at different locations, averaged across the months, are shown in Fig. 5. The NIGHT-DRY deposits were generally greater than DAY deposits at most locations. However, they decreased when the leaf surface changed from dry to wet (except for the low volume at the interior locations). The differences were clearer at LOC A, nearest to the sprayer. This indicated that spraying under high leaf moisture conditions may not be advisable, especially in high volume applications since any advantages gained by spraying at night were probably lost by increased runoff from wet leaf surfaces. The low volume application showed improvement in deposition in nighttime applications; however, the effect of leaf surface wetness was not as consistent as in high volume applications. The combined values shown in the bottom chart of Fig. 5 were averages of the three volumes and reinforced the general trends that were discussed. Generally speaking, deposition increased in night applications but the benefit was reduced by wetness of the leaf surface.

Conclusions

1) Spray application time had a significant effect on deposition. In general, depositions were higher for night-time (lower T and higher RH) as compared to daytime (higher T and lower RH) applications. However, the increase in deposition for higher volumes was counteracted by runoff from the wet leaf surfaces.

2) Spray volume had a significant effect on deposition. The lowest and the highest spray volumes gave the highest and lowest depositions, respectively. The variability of deposition, generally, increased as spray volume decreased.

3) Deposition generally decreased and CV increased as the sampling height or distance from the sprayer increased.

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