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# Wind Speed and Direction Influence Nursery Spray Stake Performance

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## Abstract

Water resources are under increasing constraints worldwide due to rising global populations creating greater demands on agricultural production, thus creating a need for more efficient water utilization. This study investigated the effects of wind speed, wind direction, water pressure, and spray stake height on irrigation efficiency in nursery containers. Experiments were conducted in a controlled wind environment, evaluating three wind speeds (0, 15, and 30 mph), two water pressures (15 and 25 psi), and spray stake placements (0, 1, and 2 inches) above the container rim. The factorial experiment (3 wind speeds × 2 water pressures × 3 spray stake placements × 8 replications) was observed over a series of 10-minute periods in which water was captured within the nursery containers, measured, and recorded. Results indicated that lower spray stake height positioning and lower wind speeds significantly improved the amount of water volume captured within nursery containers (ml). Orienting spray stakes against prevailing wind further enhanced water retention, particularly at 0 and 1 inch heights. In contrast, higher stake elevations led to increased water loss due to overspray and wind distortion, especially under prevailing wind conditions. While increasing water pressure improved delivery volume, it was insufficient to fully mitigate wind-related losses. These findings suggest that nursery irrigation systems should utilize low spray stake positioning and orient emitters opposite to prevailing winds. Installing stakes at or just below the container rim may offer additional protection against water loss, promoting more sustainable irrigation in wind-prone environments.

## Keywords

Irrigation Efficiency, Spray Stake Height, Wind Speed, Water Pressure, Nursery Container Production, Overspray Reduction, Precision Irrigation

## 1. Introduction

Prevailing wind speed and direction are critical factors influencing the performance of spray stakes in commercial nursery operations. Projections indicate an average wind speed increase of 4.6% across the United States over the next 25 years, with numerous coastal regions (particularly along the Gulf of America and the southern Atlantic shorelines) expected to experience increases between 25 and 40% [1]. Inland locations are generally projected to have little to no change in the 50-year wind speed between 2000 and 2050. High winds, gusts, vortices, and inconsistent irrigation applications or inadequate water pressures in supply lines lead to superfluous overspray and a loss of irrigation water in nursery container plant production systems. Irrigation management is essential for the delivery of water to nursery plants and reduces unnecessary negative environmental impacts [2]. A combination of improper pressures, varied mister or stake heights, and high winds can result in a considerable amount of irrigation water loss [3]. Previous economic studies suggested that the reduction in cost related to irrigation water consumption is offset by the cost related to purchasing and implementing more efficient irrigation systems, resulting in a zero-sum game [4]. Environmental scarcity, such as limited water availability, would justify costs related to more efficient irrigation systems. Furthermore, optimizing irrigation efficiency can be achieved by substrate management [5] and/or cycling irrigation applications [6]. By optimally positioning a spray stake in the container relative to the environmental conditions, irrigation water can be more efficiently applied for plant use. Spray stakes reduced irrigation requirements by up to 80% compared to nursery impact sprinklers, and reduced N and P irrigation surface by > 98% irrigation return flow [7]. The impact of increasing wind speeds due to climate change and worsening environmental conditions cannot be overstated. Nursery irrigation management is critical to reduce overspray and water waste due to high wind speeds and gusts in nursery containers at elevated wind speeds. In recent years, coastal climates have experienced an increase in wind speed and intensity, which negatively impacts the coverage of nursery container irrigation. Many management strategies have been shown to increase irrigation efficiency [2] [6] [7]. However, interactive effects of stake height, wind direction, and water pressure in a controlled factorial design are not well documented. The objective of this study was to determine strategies to optimize spray stake positioning exposed to increasing wind speeds and various water pressures caused by changing environmental factors.

## 2. Materials and Methods

A controlled wind environment experiment was conducted to evaluate the effects of wind speed, wind direction, water pressure, and spray stake height on irrigation water volume (ml) captured in nursery containers. The study established a factorial design consisting of three wind speed levels (0, 15, and 30 mph), two water pressure levels (15 and 25 psi), and four spray stake positions (0, 1, and 2 inches above the container rim, and a control position where the maximum amount of water was captured without the influence of wind). Each treatment combination was replicated eight times.

Wind simulation was achieved using a custom-built controlled wind apparatus consisting of an eight-vane fan (**Figure 1**) with a diameter of 6 inches, powered by a 120-volt electric motor operating at up to 2,450 revolutions per minute. This configuration provided airflow rates up to 390 cubic feet per minute. Wind speeds were adjusted using a variable resistor and calibrated with a HoldPeak® HP-866B anemometer. All experiments were conducted indoors to eliminate external airflow interference.

**Figure 1.** A custom-built controlled wind apparatus was used to simulate wind conditions. The system includes an eight-vane, 6-inch diameter fan powered by a 120-volt electric motor (2450 RPM), generating airflow up to 390 CFM. Wind speed was adjusted via a variable resistor and measured with a HoldPeak® HP-866B anemometer.

The spray stakes used were the "Spot-Spitter" tall model (DS12LGN-100) manufactured by Primerus® Products, LLC. This model is rated to deliver 0.09 gallons per minute (gpm) at 15 psi and 0.12 gpm at 25 psi. Water pressure was regulated using Senninger® pressure regulators (Models PRLG153F3M and PRLG253F3M), capable of maintaining consistent flow rates within a range of 0.5 to 8.0 gpm. Pressure accuracy was verified using a glycerin-filled pressure gauge (Merrill® Manufacturing, Storm Lake, IA) with a margin of error of ± 3.0%.

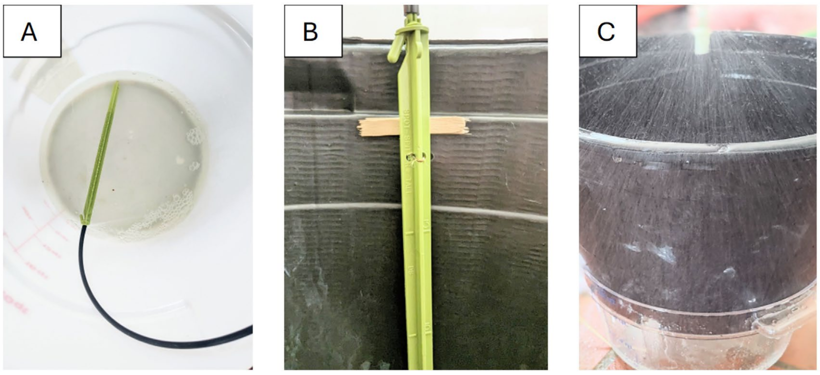

**Figure 2.** Spray stake height setup used in the experiment. (A) Spray stake positioned at 0 inches above the container rim. (B) Measurement of spray stake height with reference scale. (C) Active spray pattern demonstrating water distribution during testing. Stake heights were tested at 0, 1, and 2 inches above the container rim to evaluate the influence of elevation on irrigation water capture efficiency under various wind conditions.

Spray stakes (**Figure 2**) were mounted vertically in #7 trade-sized nursery containers (Custom-Tainer 2800C, Nursery Supplies, Inc.) with a capacity of 6.1 gallons, a height of 11.5 inches, and a top diameter of 14 inches. The containers were made from high-density polyethylene (HDPE). Stake heights were measured relative to the container rim at 0, 1, and 2 inches, with the control configuration simulating ideal water delivery into the container with no wind or stake elevation effects. Wind direction was also considered as a variable: prevailing wind (spray direction facing away from the wind apparatus) referred to airflow moving in the same direction as the water spray, while opposing wind (spray direction facing toward the wind apparatus) moved against the direction of the spray. These conditions were simulated to evaluate the influence of wind alignment on water volume capture.

Statistical analysis was performed using an analysis of variance (ANOVA) in the Statistical Analysis Systems® software (SAS), Version SAS2025, with a 3 (wind speed) × 2 (water pressure) × 4 (spray stake position) factorial design. Significance was determined at the 0.05 probability level.

## 3. Results and Discussion

Initially, irrigation water output volume at 15 and 25 psi determined that spray stakes pressurized at 15 psi (pounds per square inch) delivered 0.09 gpm (gallons per minute), while those pressurized at 25 psi delivered 0.12 gpm. These volumes are consistent with the manufacturer's specifications. There were significant differences between water pressure (15 and 25 psi) and wind direction (prevailing and opposing) treatments on water volume capture in nursery containers (**Figures 3-6**).

### 3.1. Water Pressure (15 psi)

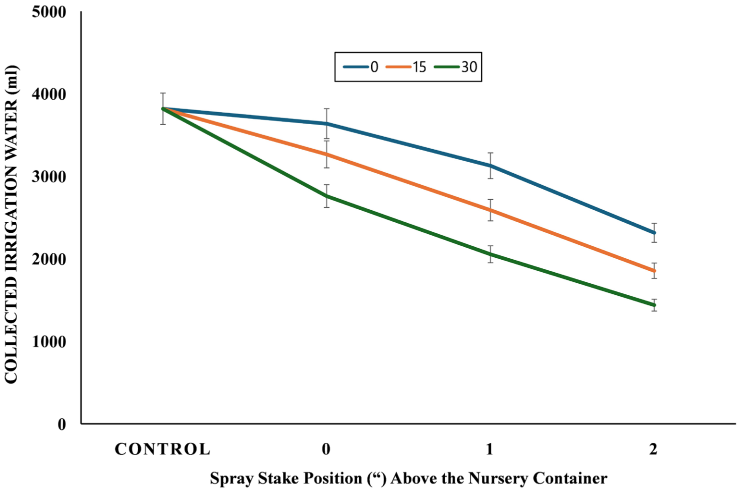

**Figure 3.** Collected irrigation water (ml) from a Primerus® "Spot-Spitter" spray stake positioned at three heights (0, 1, and 2 inches) above the rim of a #7 nursery container under prevailing wind speeds of 0, 15, and 30 mph. Irrigation was conducted over 10 minutes at 15 psi. Each data point represents the mean of eight replications (n = 8). Error bars indicate standard error (± SE).

At 15 psi, spray stakes positioned at 0 inches without wind (0 mph) delivered the highest volume of irrigation water to nursery containers across all treatments (**Figure 3**). As spray stake height increased to 1 and 2 inches, captured water volumes declined significantly under all wind speeds. Under prevailing wind conditions, irrigation efficiency decreased progressively with both wind speed and spray stake elevation, resulting in an 18% reduction at 1 inch and a 39% reduction at 2 inches compared to the control.

In contrast, under opposing wind conditions (**Figure 4**), water captured at the 0 inch stake position remained similar across 0, 15, and 30 mph wind speeds. Interestingly, the 2 inch stake position combined with 15 mph opposing wind delivered a greater water volume than at 0 or 30 mph, likely due to wind redirecting spray into the nursery container. However, across all treatments, the highest water losses were observed at the 2 inch position with 30 mph wind, where water volume was reduced by over 70% compared to the control. Overall, increasing spray stake height consistently reduced irrigation water volume capture under both wind directions.

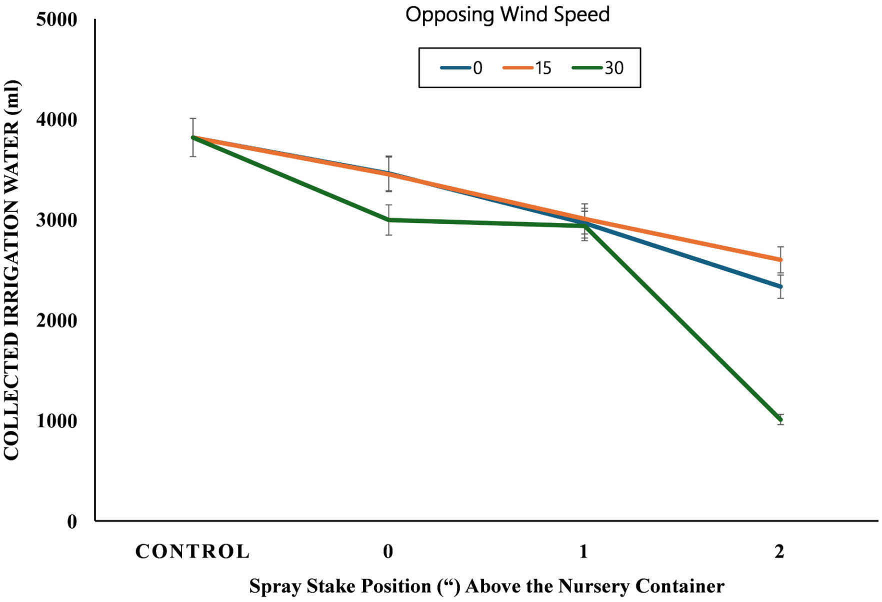

**Figure 4.** Collected irrigation water (ml) from a Primerus® “Spot-Spitter” spray stake positioned at three heights (0, 1, and 2 inches) above the rim of a #7 nursery container, under opposing wind speeds of 0, 15, and 30 mph. Irrigation was applied at 15 psi for ten minutes. Each point represents the mean of eight replications (n = 8). Error bars represent the standard error (± SE).

### 3.2. Water Pressure (25 psi)

At 25 psi, spray stakes positioned at 0 inches consistently delivered the highest irrigation volumes under prevailing wind speeds of 0 and 15 mph (**Figure 5**). However, under a 30 mph wind speed, a significant decline in captured water volume was observed across all stake heights, with a reduction of nearly 50% at the 2 inch position compared to the control. Captured water volume decreased with increasing spray stake height, particularly under higher wind speeds, indicating increased susceptibility to spray distortion and overspray.

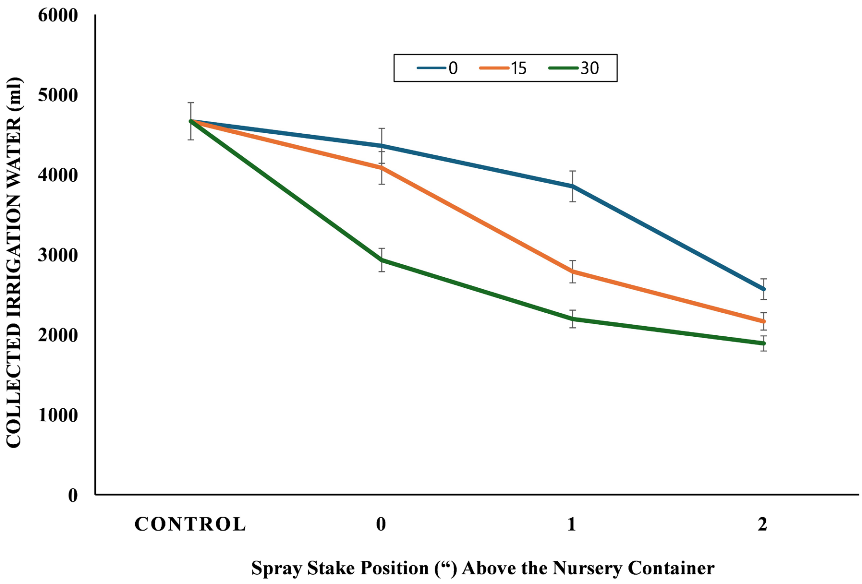

**Figure 5.** Collected irrigation water (ml) from a Primerus® "Spot-Spitter" spray stake positioned at three heights (0, 1, and 2 inches) above the rim of a #7 nursery container, under prevailing wind speeds of 0, 15, and 30 mph. Irrigation was conducted at 25 psi for ten minutes. Each data point represents the mean of eight replications (n = 8). Error bars indicate the standard error (± SE) at the 0.05 level.

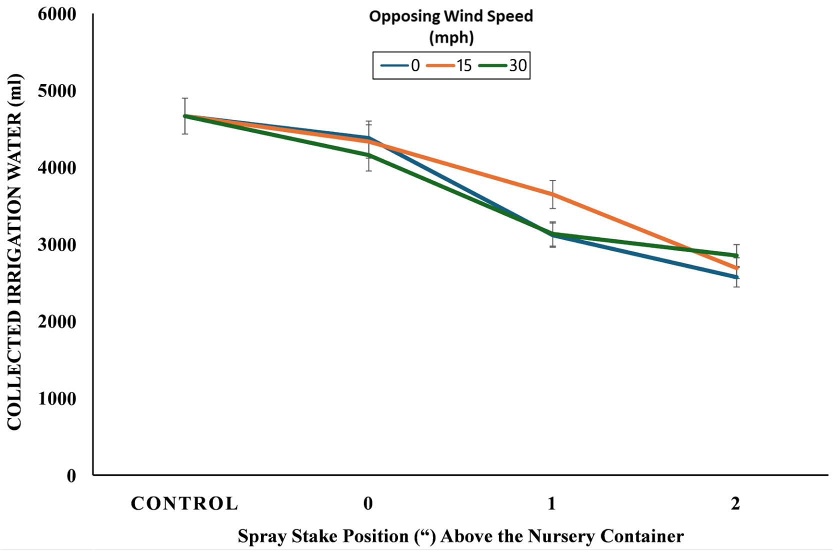

**Figure 6.** Collected irrigation water (ml) from a Primerus® "Spot-Spitter" spray stake positioned at three heights (0, 1, and 2 inches) above the rim of a #7 nursery container, under opposing wind speeds of 0, 15, and 30 mph. Irrigation was applied at 25 psi for ten minutes. Each point represents the mean of eight replications (n = 8). Error bars represent standard error (± SE) at the 0.05 significance level.

Under opposing wind conditions (**Figure 6**), spray stakes at 0 inches maintained a similar captured water volume across all wind speeds (0, 15, and 30 mph) and were comparable to the control. Interestingly, the 15 mph opposing wind speed treatment resulted in the highest captured water volume at the 1 inch position, suggesting that moderate opposing wind may redirect spray more effectively into the container. This was only partially true at the 2 inch position, where the water volume captured was less at 0 and 15 mph yet greater at the 30 mph opposing wind speed, likely due to wind redirecting spray into the nursery container. Generally speaking, elevated stake positions were consistently less effective with the exception of the 2 inch position at 25 psi and 30 mph wind speed.

## 4. Conclusions

Increasing water pressure enhances the total captured water volume delivered by spray stakes in nursery container production in the absence of wind. Wind direction and speed significantly affect captured water volume, improving coverage of nursery irrigation systems. Prevailing winds and higher speeds (15 and 30 mph) can also reduce nursery irrigation coverage. Lower spray stake positioning (0 and 1 inch above the container rim) generally results in improved water coverage, especially under opposing wind conditions. Notably, the 2 inch spray stake position operated at 15 psi and exposed to 30 mph opposing wind speed configuration produced the most drastic reduction in water volume, likely due to wind energy disrupting the spray pattern.

Spray stakes positioned at 2 inches were particularly vulnerable to overspray and wind distortion under high prevailing wind speeds. Therefore, positioning stakes as low as possible, ideally at or just below the container rim, and orienting them opposite to the prevailing wind direction are recommended to reduce water loss. These adjustments are especially critical in environments prone to high or gusty winds. Additional protective strategies may include physical shielding of the stake or modifying the container rim design to minimize spray drift. This often negates any perceived economic benefit, thus preventing the adoption of more sustainable irrigation systems. The results of this experiment, however, showed that through simple management practices, sometimes as simple as adjusting the orientation of a spray stake, it is possible to improve irrigation efficiency and achieve economic advantages without disadvantages in irrigation system design or additional or higher-than-average costs.

The conclusion of this study offers a valuable solution to this very problem. It is possible to increase container water delivery and thus reduce overall water irrigation costs. The findings of this study suggest that nursery managers can improve container micro-irrigation coverage with no additional costs by merely placing the irrigation spray stakes at a lower height, as well as orienting the irrigation spray pattern to oppose a prevailing wind. Nurseries can reduce offsite irrigation runoff while increasing the sustainability and profitability of the business operation.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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