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A GREENHOUSE EVALUATION OF ENVIRO RAINDROPS

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EXECUTIVE SUMMARY

Enviro RainDrops™ (ERD) is a surfactant containing hygroscopic/hydrotropic agents. When mixed with irrigation water, ERD affects the interaction between the water and soil particles. We conducted a preliminary laboratory test to determine the effect of ERD on the amount of water retained in a clay soil or a sandy loam soil and a comprehensive greenhouse study to determine how ERD affected the availability of water to Impatiens plants (*Impatiens walleriana*).

The laboratory test showed that ERD increased the amount of water drained from a clay soil, but allowed more water to be retained in a sandy loam soil. Sandy soils drain easily and dry quickly, so treatments that increase the amount of water retained in a sandy soil are beneficial. Clay soils have large water holding capacities, but the fine pore structure prevents water from moving easily through the soil. Excess water in a clay soil can prevent adequate root zone aeration. Irrigation water treated with ERD could penetrate more deeply into a clay soil and help avoid prolonged periods of saturated soil in the root zone.

In the greenhouse study, ERD mixed with irrigation water at twice the recommended rate delayed the onset of wilting in Impatiens plants by 20 to 28 hours in the clay soil, and by 40 hours in a sandy loam soil. This was equivalent to extending the amount of time before irrigation was needed by 14% in the clay soil and by 35% in the sandy loam soil. Enviro Raindrops™ appeared to slow the evapotranspirative loss of water from the soil, but the ability of Enviro Raindrops™ to delay the onset of wilting in Impatiens plants was not explained entirely by conservation of soil moisture. In this study, Enviro Raindrops™ was tested on soils that do not typically repel water. There may be greater benefits to using Enviro Raindrops™ on soils that are classified as hydrophobic or water repellent.

A Greenhouse Evaluation of Enviro Raindrops

INTRODUCTION

Water repellency is a common phenomenon in many soils throughout the world. It can significantly affect infiltration, evaporation, water holding capacity and other soil-water interactions (DeBano and Dekker, 2000; Wallis and Horne, 1992). Soil wetting or hydrophobicity can be difficult to predict and depends on such factors as relative humidity (Doerr et al., 2002), temperature (Bachmann et al., 2002), water content, texture (Dekker et al., 2001; Jonge et al., 1999) and prior soil management practices (Hallet et al., 2001). Given these uncertainties, irrigation managers may wish to use practices that increase the probability that irrigation water will infiltrate the soil and become available to plants.

Surfactants are commonly used for a variety of activities related to agriculture, horticulture and turf. Surfactants lower the surface tension of water and this can have a significant effect on soil-water interactions when surfactants are added to irrigation water. Surfactants increase the infiltration of water into hydrophobic soils and allow them to rewet more easily (Feng et al., 2002). In soils that are not hydrophobic, surfactants have little effect on infiltration or can even decrease the rate of infiltration (Pelishek et al., 1962) or the volumetric water content (Karagunduz et al., 2001). Surfactants added to agricultural irrigation water produced mixed results in terms of increased soybean yields (McCauley, 1993), but golf course managers have successfully used surfactants to alleviate localized dry spots in putting greens (Cisar et al., 2000; Kostka, 2000; and Nektarios et al., 2002).

While there are many reports based on laboratory research that describe the effects of surfactants on soil-water interactions, there is little data showing how the use of surfactants affects water availability to plants. Feng et al. (2002) concluded that even though surfactants can mitigate problems associated with water repellent soils, the utility of using surfactants in managing water repellent systems should be determined using empirical observations. Enviro Specialists, Inc. (Fort Worth, Texas) markets a surfactant/hydrotrope trademarked as Enviro Raindrops™ (ERD). It was proposed that ERD would increase water availability to plants and reduce the amount of water required for irrigation. The objective of our study was to use visual plant wilting symptoms to evaluate the product's ability to maintain plant available water in soil during extended post-application periods when no additional water was supplied.

MATERIALS AND METHODS

Preliminary laboratory experiment: A laboratory procedure was carried out to determine how the addition of Enviro Raindrops™ (ERD) to water would affect the initial retention of water in soil following drainage or excess water. Sixty grams of a clay soil or a sandy loam soil were placed in Buchner funnels and wetted with 80 mL of water containing 0X, 1X, or 2X the recommended rate of Enviro Raindrops™. Soils were allowed to drain for 24 hours. Excess water draining from the soils was captured and quantified.

Greenhouse Experimental Design: A greenhouse study was designed that would use visual plant wilting symptoms and soil dry-down weights to evaluate the ability of ERD to maintain plant available water in soil during extended post-application dry-down periods, when no additional water was supplied. The greenhouse study consisted of 4 water treatments: 1) control (tap water); 2) 100% the recommended rate of Enviro Raindrops™ (3.9 mL L^{-1}); 3) 200 % Enviro Raindrops™ (7.8 mL L^{-1}); and 4) micronutrients to match the 100% Enviro Raindrops™ rate. The water treatments were applied to 2 soil types: 1) Houston Black clay, and 2) sandy loam. Impatiens (*Impatiens walleriana*) were chosen as a water stress indicator plant because they exhibit very visible wilting symptoms as available water becomes limiting in the soil, but recover quickly once moisture is replenished (Fig. 1).

Procedure: Clay soil and sandy loam soil were placed in 6-inch greenhouse pots (1.1 kg clay soil per pot and 1.3 kg sandy loam per pot). Each treatment was replicated 12 times (i.e., 12 pots per treatment). Impatiens cuttings were placed in a rooting bed until they developed sufficient roots for transplanting. Then, one seedling was transplanted into each pot. All pots were fertilized equally, which resulted in fertilizer rates of 216 mg kg^{-1} N, 95 mg kg^{-1} P and 180 mg kg^{-1} K for the clay soil and 183 mg kg^{-1} N, 81 mg kg^{-1} P and 152 mg kg^{-1} K for the sandy loam soil. The Impatiens plants were allowed to develop root and foliage growth for approximately 8 weeks before starting water treatments. Then the pots were treated with plain tap water or the same water mixed with Enviro Raindrops™ (ERD) at one times (1X) or two times (2X) the recommended rate. A fourth treatment consisted of micronutrients (without surfactant) applied at the 1X ERD rate. After applying the water treatments, pots received no additional water so that we could observe the effects of ERD on the amount of water available to Impatiens plants. We conducted three dry-down tests in the greenhouse, but the data collected for each test was slightly different. In every dry-down test, pots were weighed daily and the plants were observed for signs of wilting. In addition to pot weights, data collection consisted of one or both of the following. Upon observing initial signs of wilting, each plant was rated on a scale of 1 to 3 with 1=no wilting, 2=leaves starting to droop, and 3=wilting leaves and stems. This rating technique was most effective for the sandy loam soil which usually exhibited a rapid onset of wilting symptoms. Starting with the second dry-down test, we also recorded the number of days between application of the treatment and signs of first wilting. The specific details of each dry-down test are described below.

The first dry down was conducted for 72 hours, which was only long enough for Impatiens plants growing in the sandy loam to exhibit wilting symptoms. Plants growing in the clay soil did not exhibit wilting symptoms during the first dry-down test. All plants were rated for degree of wilting and then water was applied to all pots for both soils.

The second dry down test was continued for 102 hours for the sandy loam soil, after which all plants were rated for degree of wilting and water was re-applied to every pot. The second dry down test was continued for 272 hours for the clay soil, but individual pots were watered sooner if wilting became severe. The number of days to first wilting was recorded for each plant.

The third dry down test was continued for 168 hours for both soils, although individual pots were watered sooner if wilting became severe. We did not rate the wilting symptoms during the third dry down test, but instead recorded the number of days till first wilting for all plants growing in both soils.

At the end of the dry down tests, all plants were harvested by excising the main stem about 1 cm above the soil surface. Plants were washed three times in deionized water, placed in paper bags, and dried at 60 C. Dry weights were determined for each plant, and the plant tissue was ground to pass a 2 mm sieve and analyzed for total nitrogen, phosphorus, potassium, iron, copper and zinc.

RESULTS AND DISCUSSION

Preliminary laboratory experiment

Enviro Raindrops™ (ERD) increased the amount of water that drained from a clay soil but decreased the amount of drainage from a sandy loam soil (Fig. 2). Other researchers have shown that addition of a surfactant to a soil that is not water repellant can either increase or decrease water infiltration (Pelishek et al., 1962). The laboratory test suggested that ERD would increase the amount of plant available water in the sandy loam soil, but decrease it in the clay soil. However, clay textured soils have a large total water holding capacity and tend to tightly bind water in their small pores. Much of this water is unavailable to plants. Inadequate or slow drainage is also a common problem in clay-textured soils, so it is conceivable that ERD-treated irrigation water would drain more quickly from a clay soil and help remove excess moisture that prevented adequate root zone aeration. Another benefit might be a deeper penetration of ERD-treated irrigation water into the root zone. On the other had, sandy-textured soils tend to drain too easily, so treatments that increase the amount of water retained in the soil should be favorable for plant growth. Overall, the laboratory drainage results provided information on how ERD-treated water would interact with different soils, but the results were not sufficient to predict how ERD would affect the amount of plant available water in either the clay or sandy loam soils.

Greenhouse Experiment

Results are presented for each of the dry down tests separately because the type of data collected for each of these tests was slightly different. Some of the data for the second and third dry-down tests on the clay soil is combined into one figure. No dry-down data is presented for the 1X micronutrient treatment, because it contained no surfactant and essentially behaved the same as the control. Finally, plant yields and tissue analyses are presented for all treatments including the 1X micronutrient treatment.

First Greenhouse Dry-down test

During the four days following application of water containing Enviro Raindrops™ (ERD), there were no differences in the dry down rates among the three water treatments applied to the clay soil (Fig. 3A). Clay soils are fine textured and conserve water for longer periods of time than courser textured soils due to a greater volume of pore space. Fig. 3B shows that compared to the clay soil, the sandy loam soil tended to dry quickly. More importantly, the addition of ERD at the recommended rate (1X) and twice the recommended rate (2X) resulted in greater amounts of soil moisture for extended periods of time.

The benefit of reduced water evaporation from the sandy loam soil can be seen in Fig. 4. Impatiens plants growing in the sandy loam soil treated with 1X and 2X the recommended rate of ERD showed fewer signs of wilting than the control after water had been withheld for four days. There were no benefits on the clay soil because there was sufficient soil moisture in all pots after four days due to the clay soil's high water holding capacity.

Second Dry-down test

Clay soil: Between approximately 36 to 144 hours after water application to the clay soil, the 2X rate of Enviro Raindrops™, and to a lesser extent, the 1X rate, increased the amount of water retained in the soil (Fig 5A). After 144 hours (6 days), there was little difference in soil water content among the three treatments. However, it was not until after 144 hours that the 2X and 1X rates of ERD decreased the number of wilted Impatiens plants in the clay soil (Fig. 6).

Sandy loam soil: The 1X and 2X rates of ERD reduced water loss from the sandy loam soil up to 72 hours (3 days) after application (Fig. 5B). There was little difference among treatments beyond 72 hours. Impatiens plants growing in the sandy loam soil were rated for degree of wilting 102 hours after application of water. Plants that were irrigated with the 2X rate of ERD, and to a lesser extent the 1X rate, exhibited less wilting than plants irrigated with normal water (Fig. 7).

Third Dry-down test

Clay soil: Similar to the second dry-down test, the 1X and 2X Enviro Raindrops™ treatments reduced water loss from the clay soil between 24 and 96 hours after water application (Fig. 8A). The 2X rate of ERD reduced the number of wilted plants from 96 to 168 hours after water application (Fig. 9A).

Sandy loam soil: The third dry-down test with the sandy loam soil was also similar to the second dry-down test. The 2X rate, and to a lesser extent the 1X rate, reduced water loss from the soil up to 72 hours after application, but after that, there was little difference among treatments (Fig. 8B). After 72 hours, the 2X and 1X rates of ERD reduced the number of wilted plants in the sandy loam soil (Fig. 9B).

Effectiveness of Enviro Raindrops™

The three dry down tests provided evidence that addition of Enviro Raindrops™ to irrigation water temporarily reduced the amount of wilting in Impatiens plants in both a clay soil and a sandy loam soil. Furthermore, the effectiveness appeared to increase with rate of application. To explore this trend further, linear regression was used to determine the relationship between ERD application rate and the amount of time till plants started to wilt (hours to first wilting).

Clay soil: For the clay soil, data from the second and third dry-down tests showed that the amount of time before Impatiens plants started to wilt was significantly increased with increasing application rate of ERD up to twice the recommended application rate (Fig. 10). The relationship was stronger for the third dry-down test than the second, which suggests that environmental factors also influence the effectiveness of ERD. Daytime temperatures in the greenhouse for the third dry down test were generally warmer than those for the second test. It is important to note that although there was a statistically significant relationship between the application rate of ERD and hours to first wilting, the correlation coefficients (r^2-values), although statistically significant, were very low. This demonstrates that even though ERD increased the amount of time before plants started to wilt, other factors such as temperature, soil type and total soil water content were more important for determining when Impatiens plants became stressed. The 2X rate of ERD delayed the onset of wilting by only 20 to 28 hours, or approximately one day, for Impatiens plants growing in the clay soil based on two dry-down tests. This was equivalent to a 14% increase in the time plants could survive before additional irrigation was needed.

Sandy loam soil: The relationship between application rate of Enviro Raindrops™ and onset of wilting was much stronger (r^2=0.315) for the sandy loam soil (Fig. 11). Only data from the third dry down test was available for this analysis. For the third dry-down test, the 2X rate of ERD delayed the onset of wilting by 40 hours, or approximately 2 days. This was equivalent to a 35% increase in the time plants could survive before additional irrigation was needed.

Overall Impatiens Growth

Except for the various water treatments, all Impatiens plants were treated equally. They all received a generous application of nitrogen, phosphorus and potassium fertilizer shortly after transplanting followed by adequate watering up to the initiation of the Enviro Raindrops™ water treatments. The objective was to have a homogenous population of flowering Impatiens plants at the time we started applying the water treatments. Therefore, any differences in plant growth, as determined by above-ground yield, could be attributed to the water treatments. In reality, the Impatiens plants were at a fairly advanced stage of development at the time the water treatments were started. Although the Impatiens plants were at a fairly advanced stage of development at the time the water treatments were started, additional growth was possible. However, the plants were placed under considerable stress during the dry-down tests, so there was little accumulative growth during that period.

The only significant difference in Impatiens aboveground biomass production was between the clay soil and the sandy loam soil. Impatiens plants growing in the clay soil produced more biomass than those growing in the sandy loam soil (Fig. 12). This was probably due to the natural fertility levels of each soil. Due to the design of the experiment, every plant became water stressed on several occasions. Therefore, even though ERD prolonged the period of time before Impatiens plants became stressed, the frequency and duration of this stress inhibited plant growth and prevented potential differences among treatments.

Impatiens Tissue Composition

Soil moisture is an integral component of nutrient uptake by plants. Adequate soil moisture is critical for plants to extract and transport nutrients from the soil to aboveground stems, leaves and flowers. Therefore, it was important to consider the effect of Enviro Raindrops™ on the nutrient concentrations in Impatiens tissue. The macronutrients, which consist primarily of nitrogen, phosphorus and potassium, were not affected by the ERD-treated water treatments (Fig.

13). In the case of nitrogen, there was a high degree of variability in the data and there were no significant differences between soils or among treatments. There were significant differences between soils for tissue P and K, but there were no significant differences among treatments.

Since Enviro Raindrops™ contained a mixture of micronutrients in addition to a surfactant, we examined the effect of the treatments on Impatiens tissue concentrations of Fe, Cu, and Zn (Fig. 14). The "Micronutrients 1X" treatment was included to determine the effect of adding micronutrients in the absence of a surfactant. Impatiens tissue concentrations of Fe and Cu were not affected by soil type or water treatment, whereas tissue Zn concentrations were affected by soil type, but not water treatment.

The absence of significant difference in Impatiens tissue nutrient concentrations is related to overall growth. Very little Impatiens growth occurred after the treatments were initiated because the plants had already reached a fairly advanced stage of development when the treatments were started and the subsequent stressful conditions of the test prevented significant additional accumulative growth. Once the water treatments were initiated, the plants were maintained under drought stress for a large portion of the time. Therefore, very little growth and nutrient accumulation occurred during the 2 to 3 months that the plants were being exposed to the various water treatments. It is possible that use of Enviro Raindrops™ over the entire life cycle of the plant under more favorable plant growing conditions would result in differences in micronutrient uptake.

Summary

A greenhouse study using Impatiens plants as water stress indicators demonstrated that Enviro Raindrops™ had a quantifiable effect on the plant available water content of a clay soil and a sandy loam soil. Under the greenhouse conditions of this study, Enviro Raindrops™ mixed with irrigation water increased the period of time Impatiens plants remained wilt-free by 14% in a clay soil, and by 35% in a sandy loam soil. Enviro Raindrops™ appeared to slow the evapotranspirative loss of water from the soil, although the magnitude of this effect was relatively small. The ability of Enviro Raindrops™ to delay the onset of wilting in Impatiens plants was not explained entirely by an increase in the total water content of the soil. In our study, Enviro Raindrops™ was tested on two soils that are not typically hydrophobic. There may be greater benefits to using Enviro Raindrops™ on soils that are classified as hydrophobic or water repellent.

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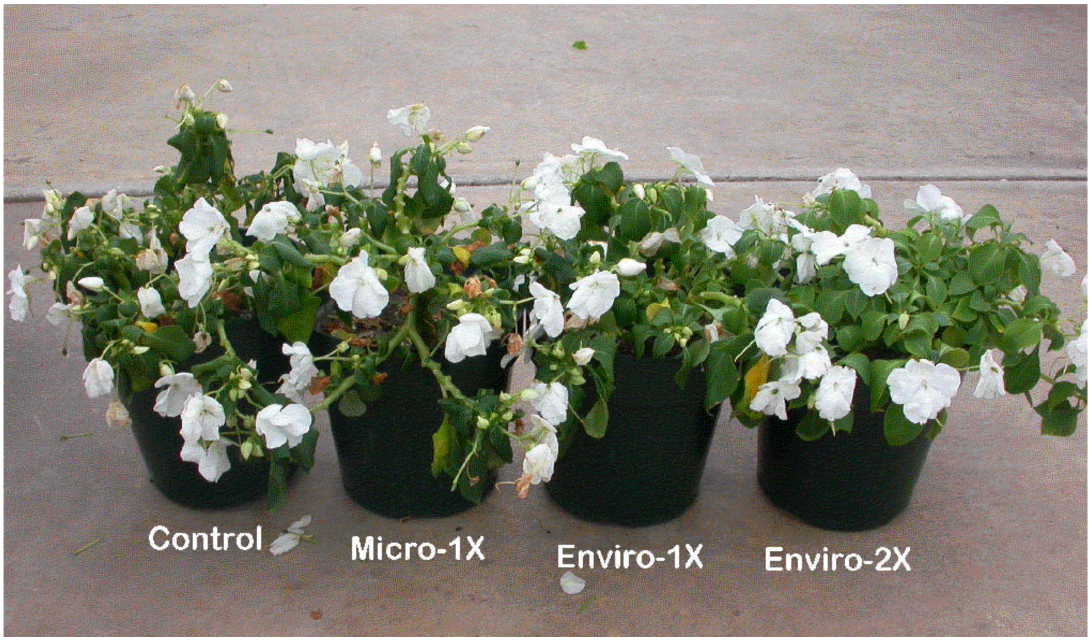


Fig. 1. Impatiens (*Impatiens walleriana*) exhibiting various stages of wilting ranging from severely wilted for the Control and Micro-1X treatments on the left, to initial onset of wilting for the Enviro-1X treatment, to absence of wilting for the Enviro-2X treatment.

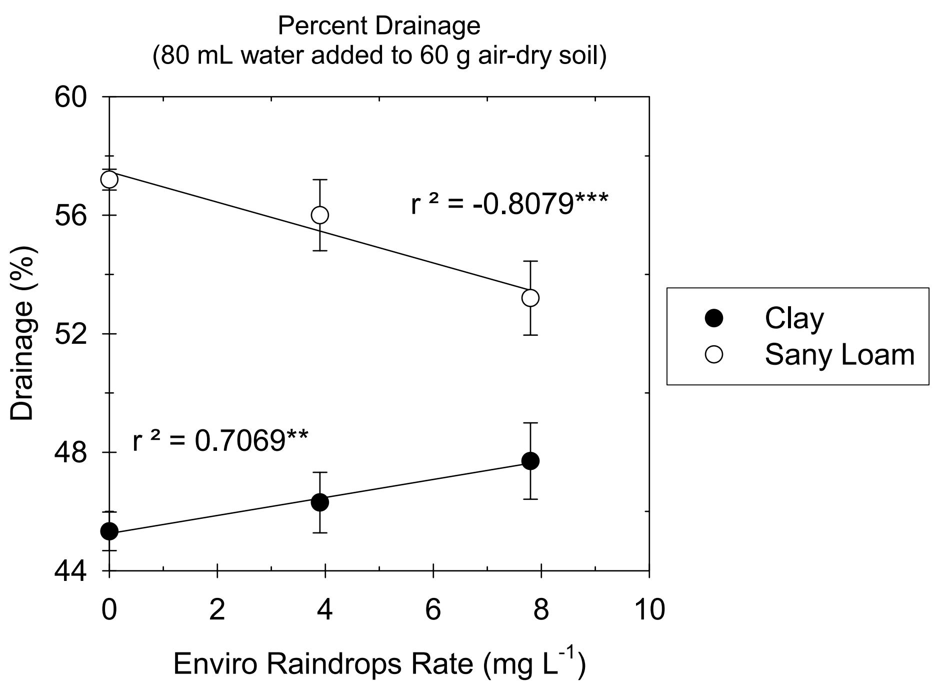
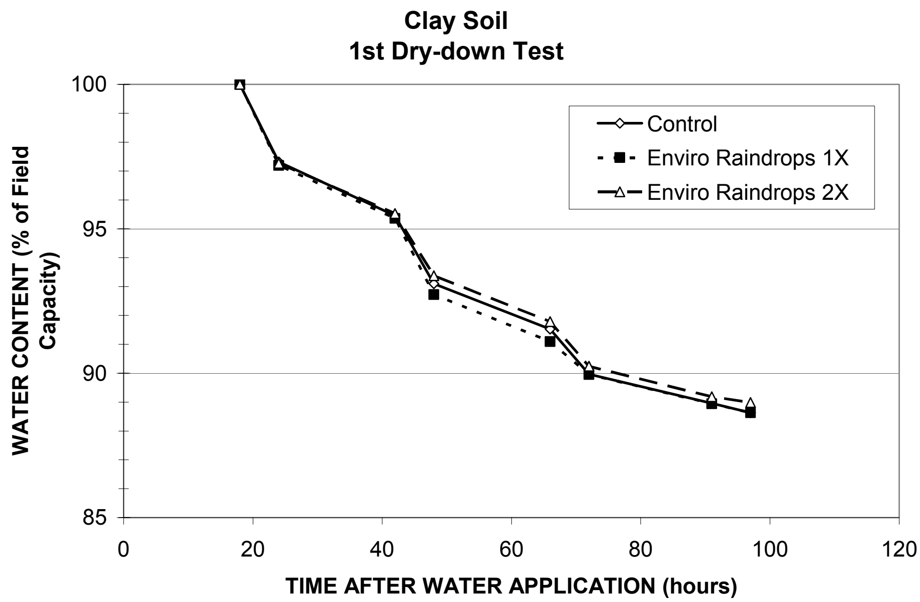
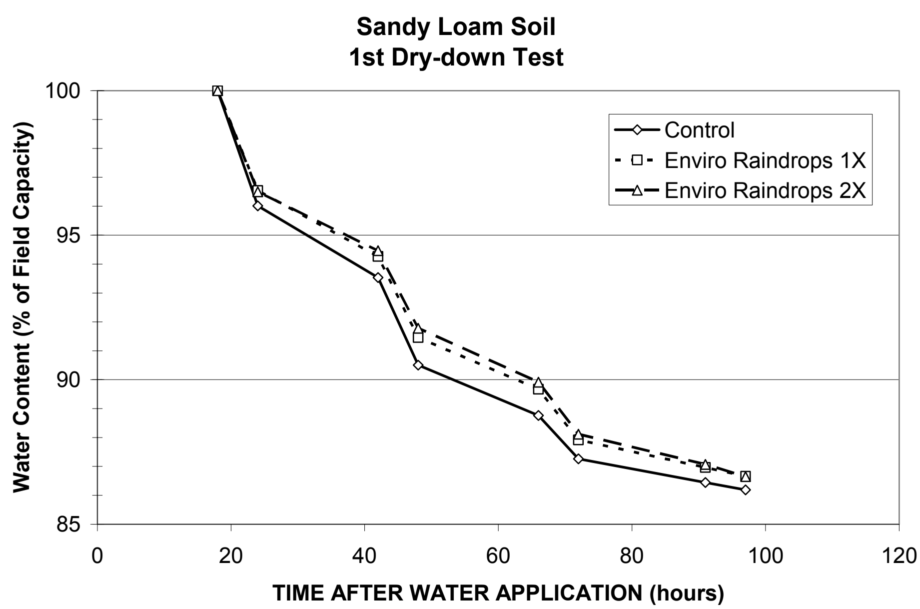


Fig. 2. Effect of Enviro Raindrops™ applied at 1X or 2X the recommended application rate on the quantity of water draining from a clay or sandy loam soil. Correlations were significant at the 0.01 (**) or 0.001 (***) level of probability.



(A)



(B)

Fig. 3. Effect of Enviro Raindrops™ on dry-down of (A) a clay soil and (B) a sandy loam soil when applied at the recommended (1X) and twice (2X) the recommended rate.

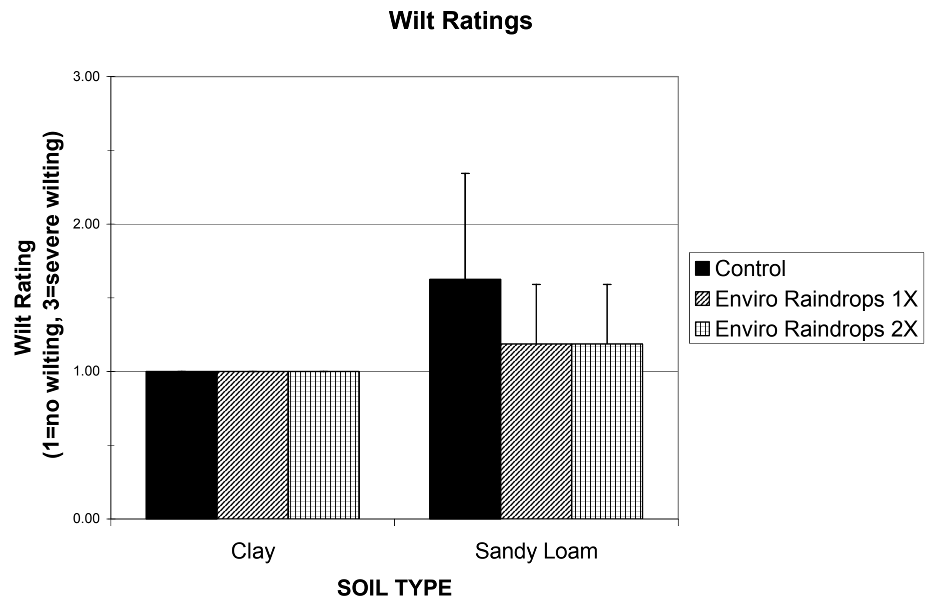
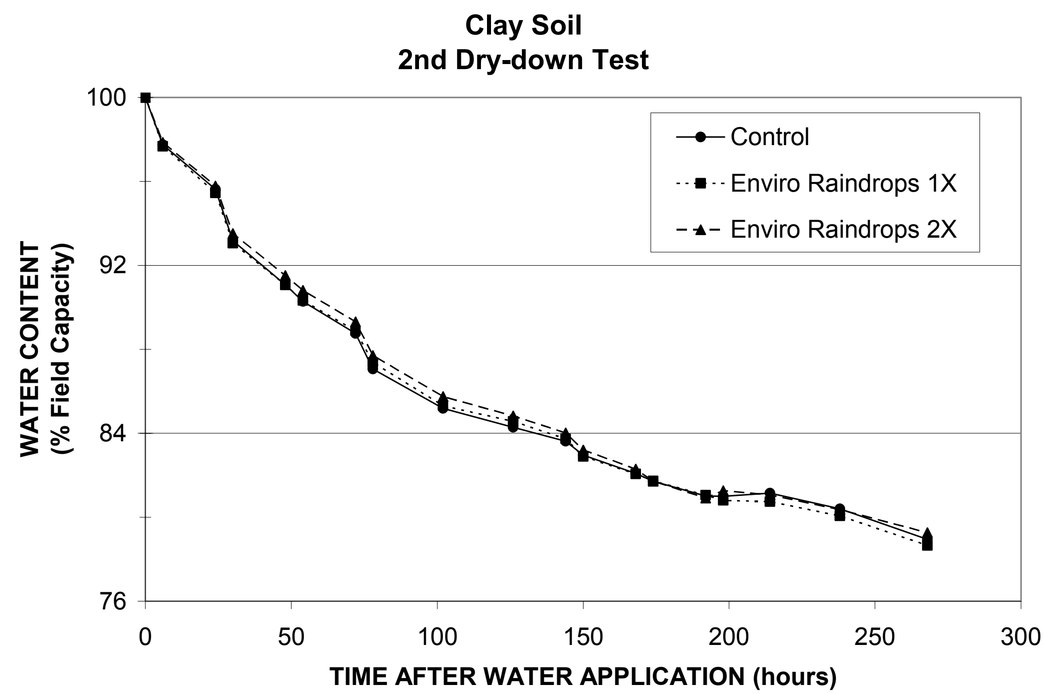
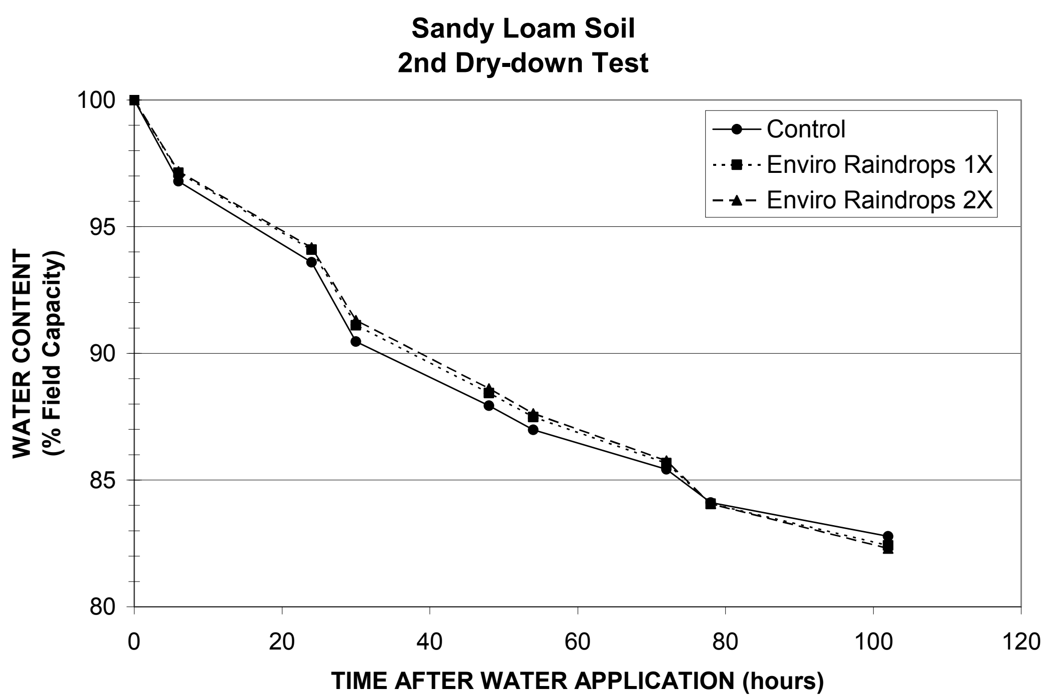


Fig. 4. Effect of 1X and 2X rates of Enviro Raindrops™ on degree of wilting of Impatiens plants in a clay soil or sandy loam soil after four days in greenhouse pots with no additional water application.



(A)



(B)

Fig. 5. Effect of water treatments on the drying rate of a (A) clay and (B) sandy loam soil during the second dry-down test.

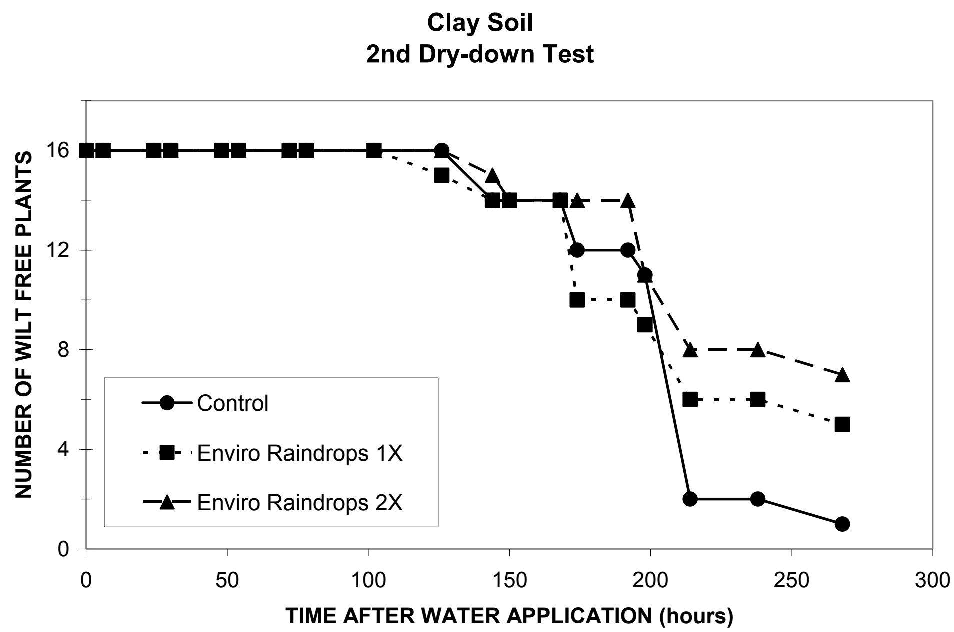


Fig. 6. Effect of water treatments and time after application on the number of wilt-free Impatiens plants in a clay soil during the second dry-down test.

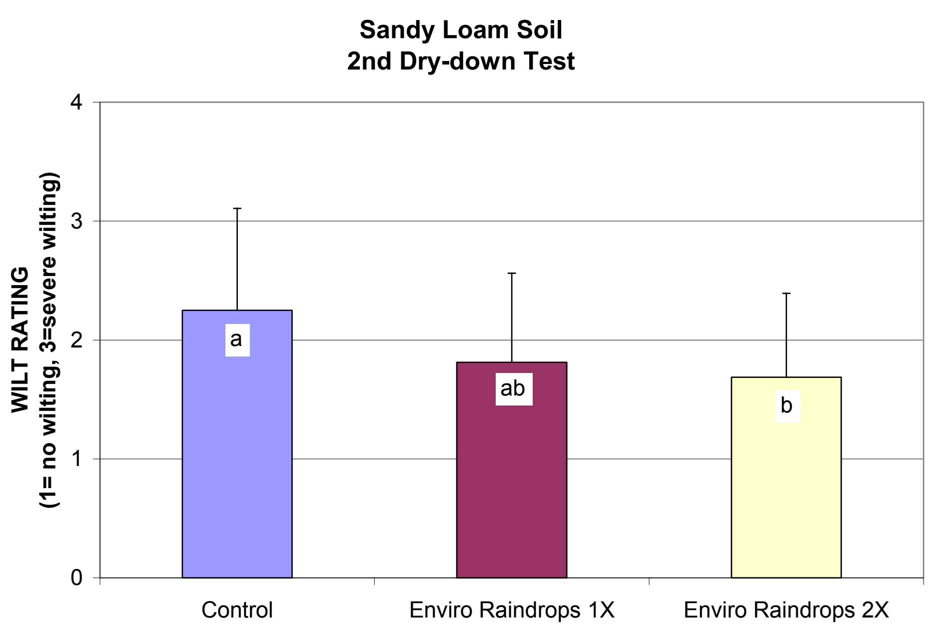
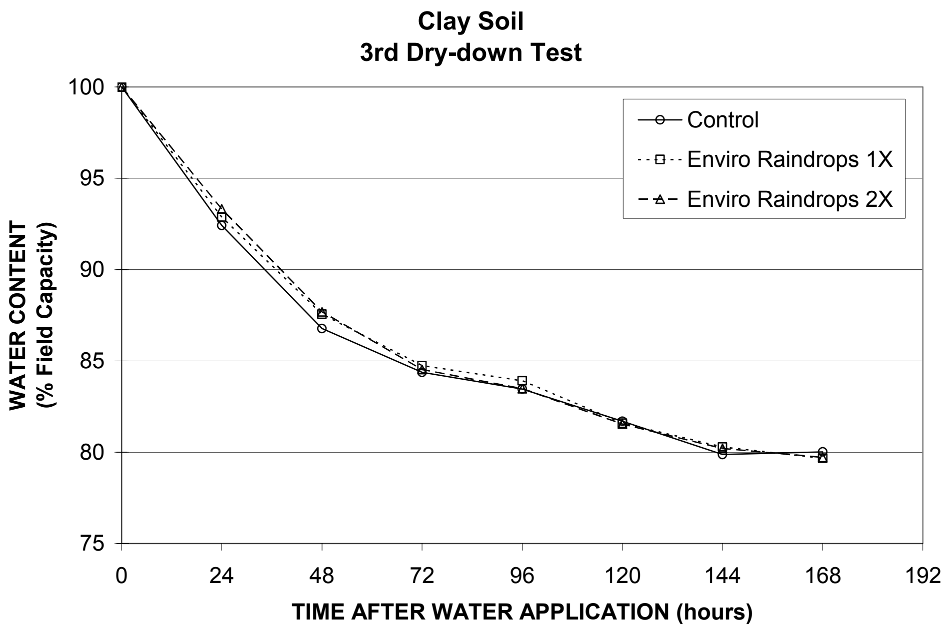
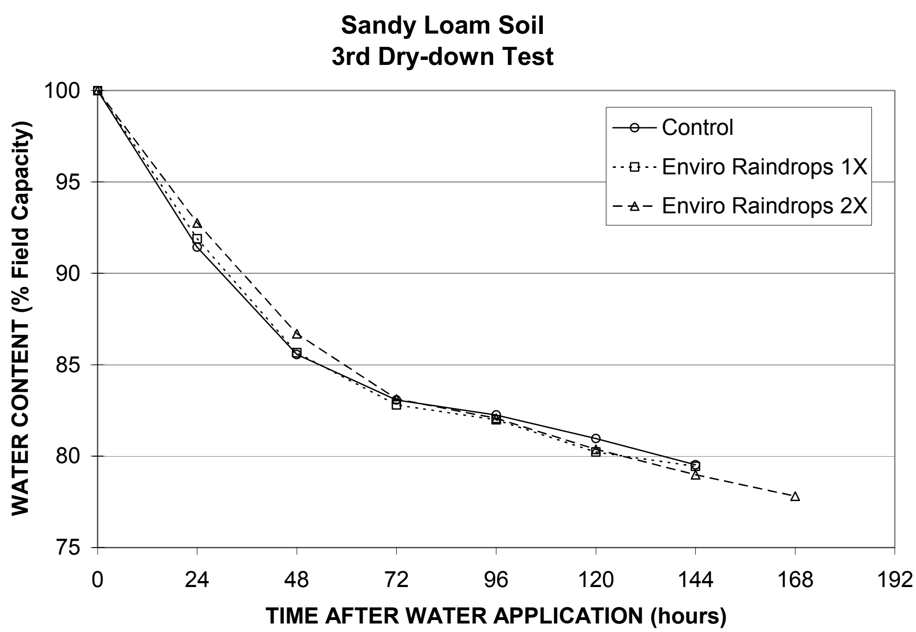


Fig. 7. Effect of water treatments on the degree of wilting in Impatiens plants 5 days after application of water during the second dry-down test. Columns with the same letter are not significantly different ($p \leq 0.10$).

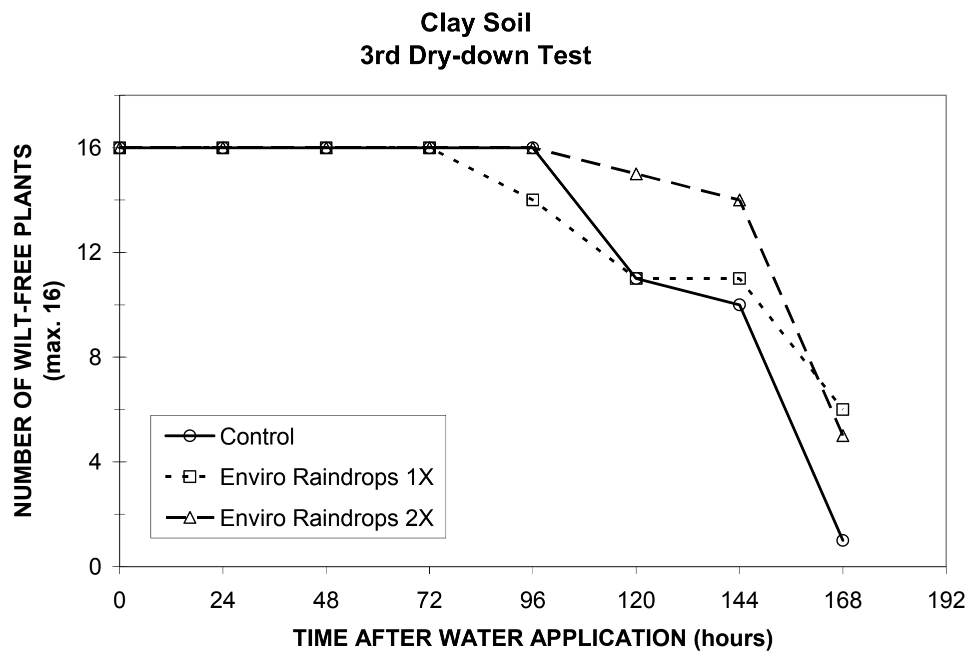


(A)

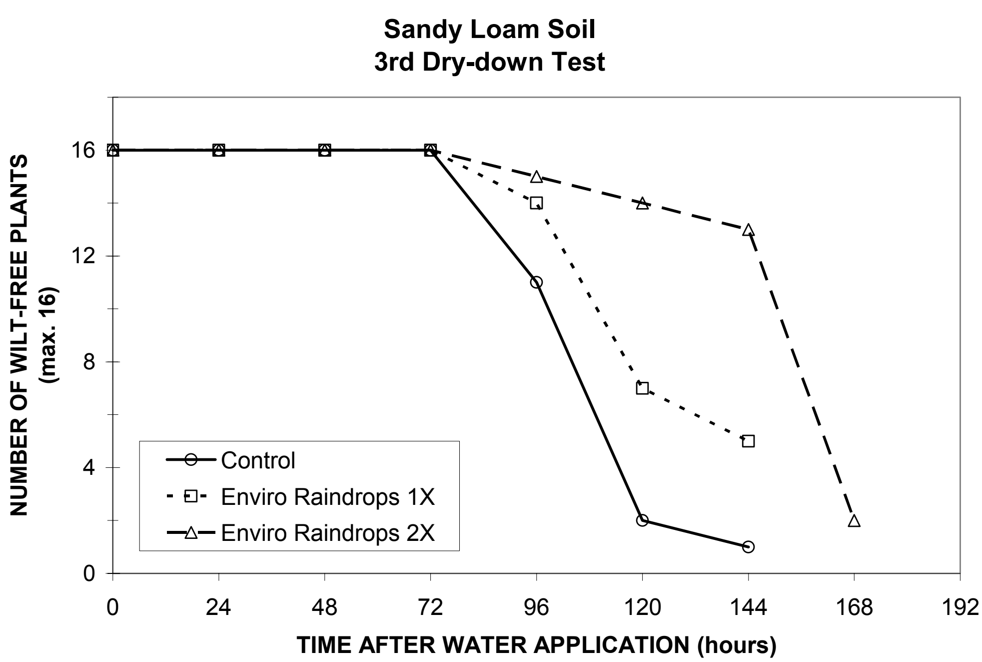


(B)

Fig. 8. Effect of water treatments on the drying rate of a (A) clay and (B) sandy loam soil during the third dry-down test.



(A)



(B)

Fig. 9. Effect of water treatments and time after application on the number of wilt-free Impatiens plants in (A) a clay soil and (B) a sandy loam soil during the third dry-down test.

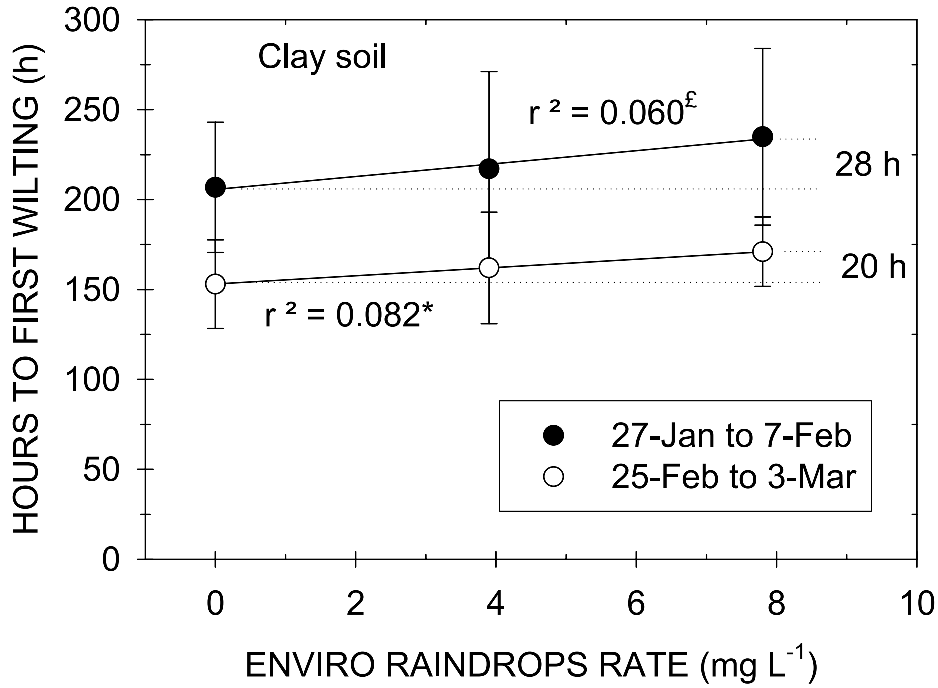


Fig. 10. Effect of Enviro Raindrops application rate on the number of hours till Impatiens plants showed first wilting symptoms during two greenhouse dry-down tests. *, [£]Significant at the 0.05 and 0.10 level of probability, respectively.

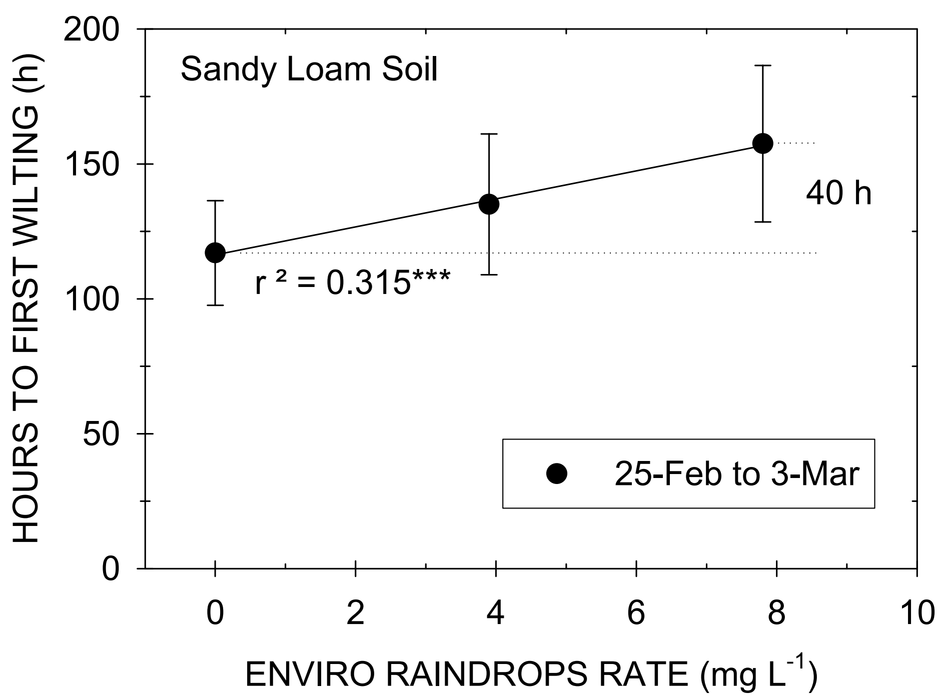


Fig. 11. Effect of Enviro Raindrops application rate on the number of hours till Impatiens plants showed first wilting symptoms during a greenhouse dry-down test. ***Significant at the 0.05 and 0.10 level of probability, respectively.

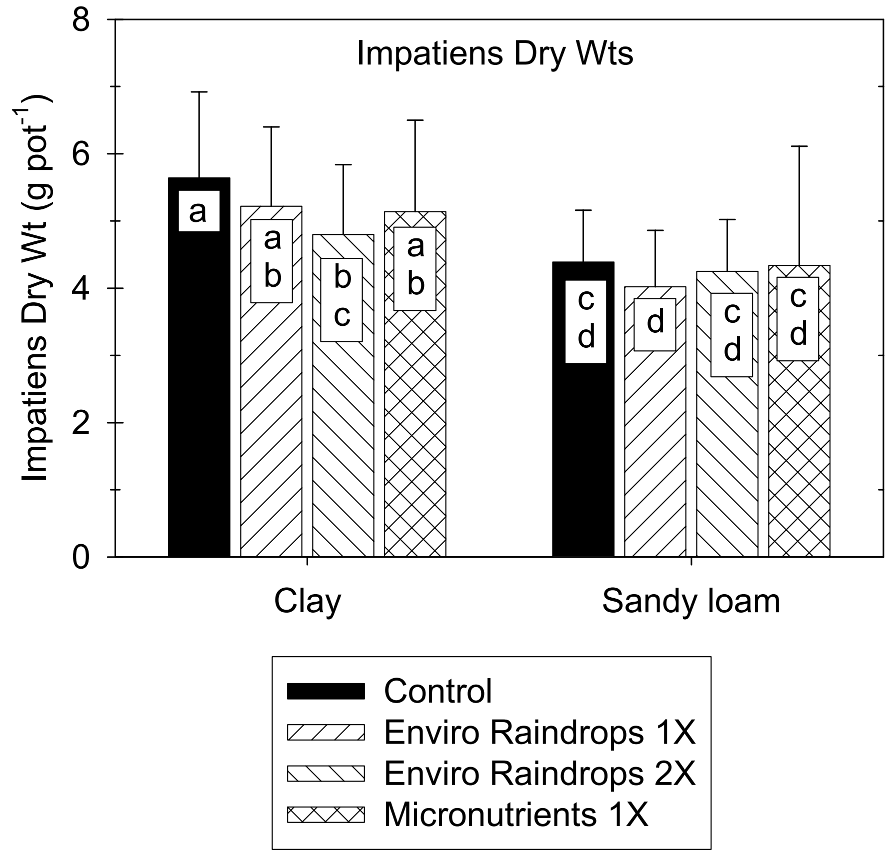


Fig. 12. Effect of Enviro Raindrops™ water treatment on the above-ground dry weights of Impatiens plants grown in a clay or sandy loam soil after four dry-down stress tests. Bars with the same letter are not statistically significant (Fisher's LSD, $p \leq 0.05$).

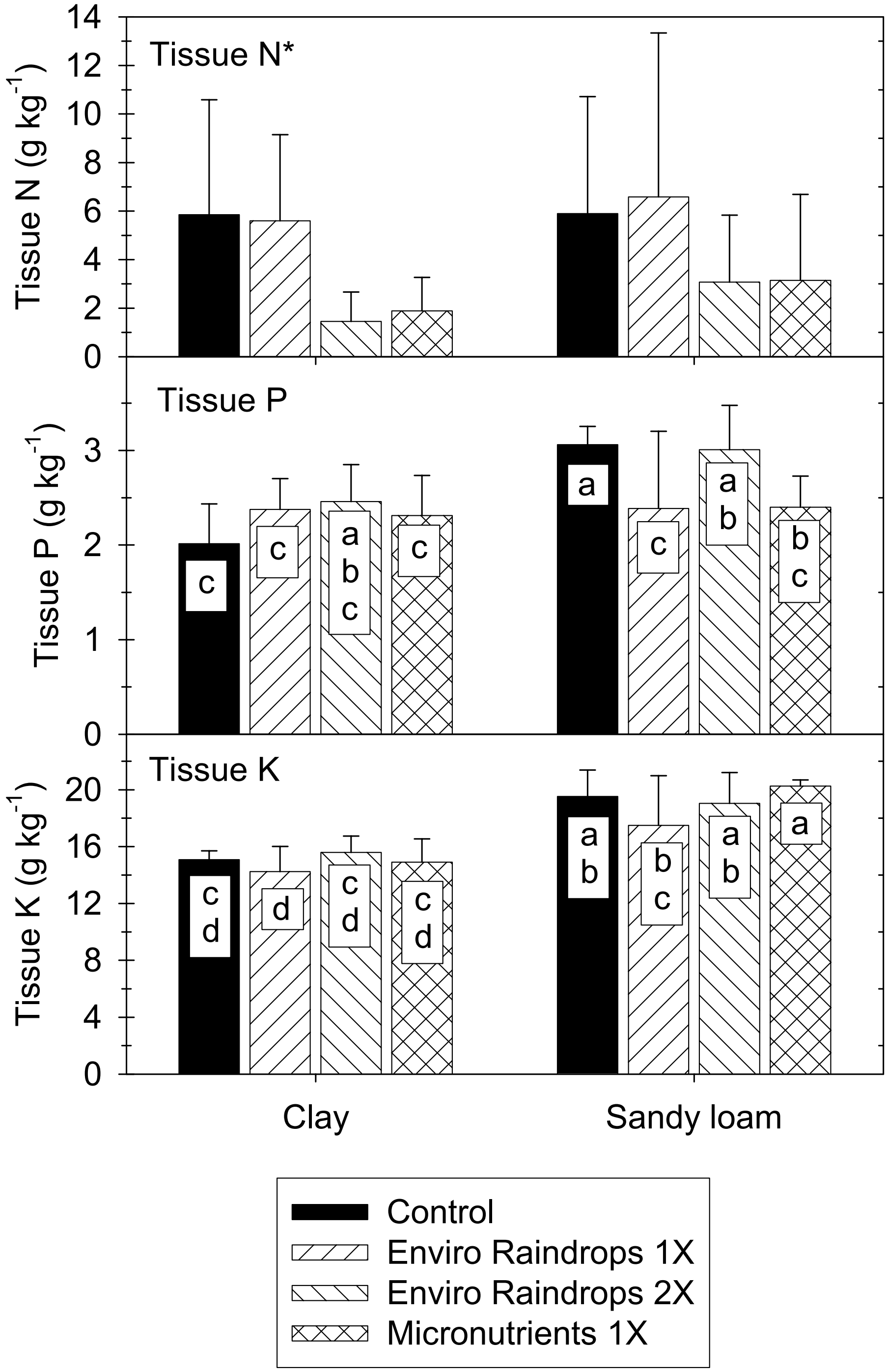


Fig. 13. Effect of Enviro Raindrops™ water treatment on the total nitrogen, phosphorus and potassium content of above-ground Impatiens tissue from plants grown in a clay or sandy loam soil after four dry-down stress tests. For each element, bars with the same letter are not statistically significant (Fisher's LSD, $p \leq 0.05$). *Absence of letters on bars indicates there were no significant differences among soils and treatments for this element.

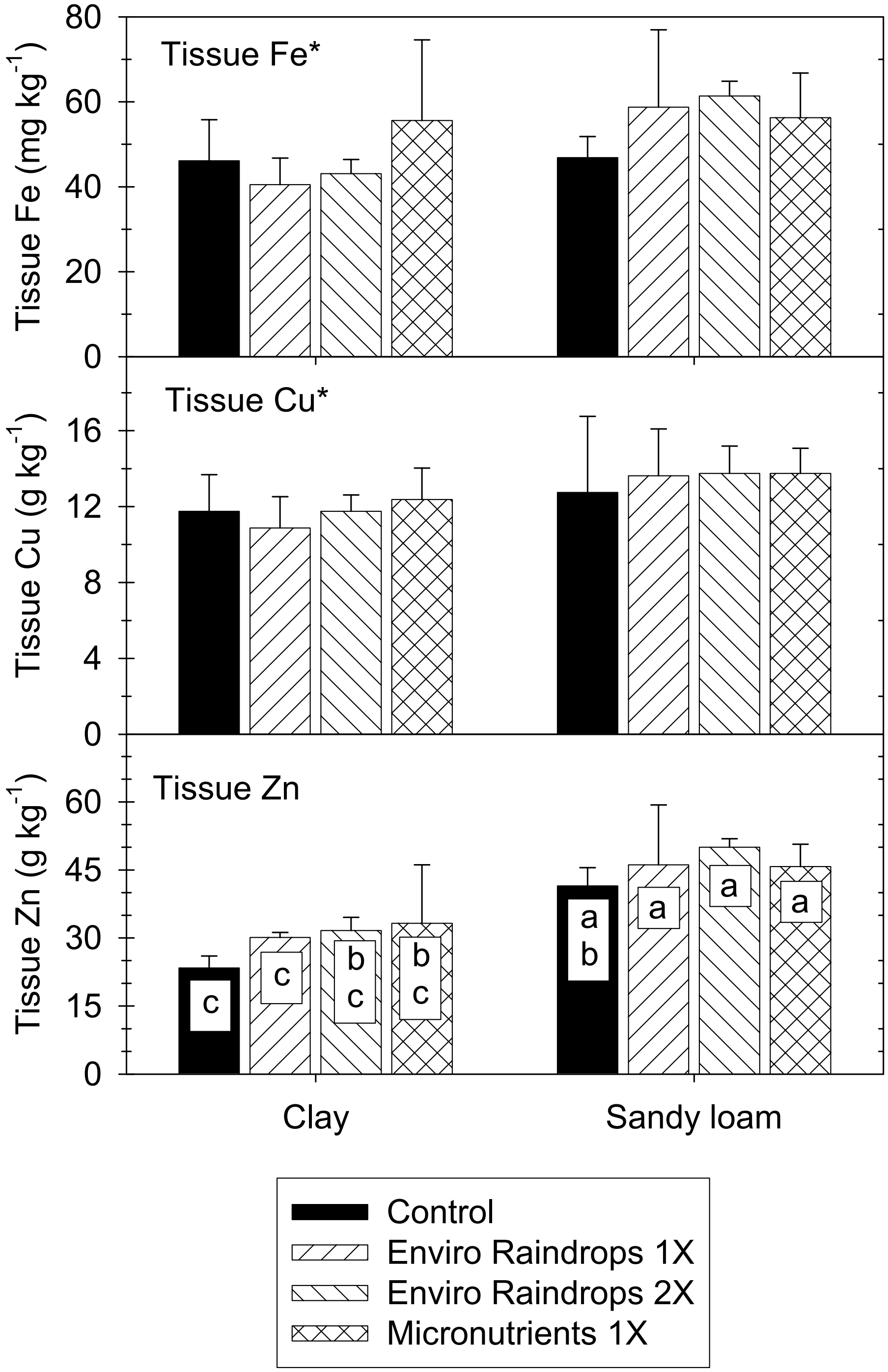


Fig. 14. Effect of Enviro Raindrops™ water treatment on the total Fe, Cu, and Zn content of above-ground Impatiens tissue from plants grown in a clay or sandy loam soil after four dry-down stress tests. For each element, bars with the same letter are not statistically significant (Fisher's LSD, $p \leq 0.05$). *Absence of letters on bars indicates there were no significant differences among soils and treatments for this element.