

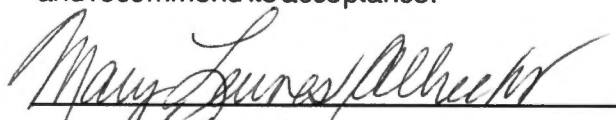
To the Graduate Council:

I am submitting herewith a thesis written by Linda L. Gombert entitled "Disease Suppression in *Zinnia elegans* Integrating Chemical and Cultural Management Strategies." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ornamental Horticulture and Landscape Design.



Susan L. Hamilton, Major Professor

We have read this thesis
and recommend its acceptance:




Accepted for the Council:



Associate Vice Chancellor and
Dean of The Graduate School

DISEASE SUPPRESSION IN *ZINNIA ELEGANS*
INTEGRATING CHEMICAL AND CULTURAL
MANAGEMENT STRATEGIES

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Linda Luann Gombert
December 1998

~~ZG-VetMed~~

Thesis

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DEDICATION

This thesis is dedicated to my family

Germaine M. Gombert

Gerald E. and Norma Gombert

Melisa M. Gombert

Jonathan, Yvonne and Holley Gombert

who have each given to me,
in their own special ways,
encouragement and support
so that I could reach my educational goals.

ACKNOWLEDGMENTS

I would like to thank Dr. Susan Hamilton for her help with my research and for having more faith in my abilities than I sometimes had. Your unflagging encouragement was more valuable than you know.

I thank Dr. Mary Lewnes Albrecht, Dr. Mark Windham and Mr. Hugh Conlon for serving on my academic committee and for all their help and advice. I thank Dr. Arnold Saxton of Statistical and Computing Services for his invaluable assistance with data analysis and interpretation. I thank Dr. Joanne Logan of the Department of Plant and Soil Science for valuable information and advice. I also thank the secretaries, Angie Berry, Sandy Kitts, Joy Newvine, Kathy Johnson and Janice Crockett for always having a kind word, a sense of humor and willingness of help me out of whatever jam I had gotten myself into.

I thank all my fellow "residents" of the graduate office, some of whom have moved on to bigger and better things, and some of whom are still plugging along. Greg, Ted, Lisa, Joel, Millie, Pam, Jenny, Jason, what would I have done without you guys? And I also thank James Newburn and his fearless crew for all their help when it came time to put thousands of little plants into the ground. Without the help of James, Leah, Scott, Mark, Chris, Stephanie and, especially, Cherie Cordell (who gave up her 4th of July holiday to help me), this research would have been very difficult to complete.

And, although I'm sure they won't be reading this, I want to express my appreciation to my little green parrot-friend, Arrow, and to all my other feathered and furry companions, who reminded me daily to find joy in simple things like taking a nap in a spot of sunlight (even if it is in the middle of the kitchen floor and people are trying to cook), screaming just because you can and savoring every nuance of flavor in an olive you've stolen from someone else's piece of pizza.

And most of all, I thank my family, especially Mom and Melisa. Mom, you don't know how much I appreciate all the digging and grubbing and sweating and logging and measuring and counting you helped me with. Aren't you glad I didn't decide to become a swamp biologist? And Melisa, without you, I would be homeless. You provided me and all my little critters a place to live where we always felt welcome, as well as other forms of support too vast in range and scope to even calculate. I could not have gotten through this without the help of the Gombert Girls.

ABSTRACT

Zinnia elegans Jacq. is prized for its large flowers, wide diversity in flower color, plant form and ease of culture. Many cultivars of *Z. elegans* have been developed by plant breeders since the plant's introduction to culture in Europe around 1796. In the last twenty years, however, zinnias have become more widely known for their disease problems than for their garden attributes. The overall objective of this research was to determine whether cultivar selection and cultural practices during commercial production as well as in the landscape can affect the development and suppression of three pathogens: *Alternaria zinniae* Pape, *Erysiphe cichoracearum* DC ex Merat, and *Xanthomonas campestris* pv. *zinniae* (syn. *X. nigromaculans* f. sp. *zinniae* Hopkins and Dowson) on the popular bedding plant and cutflower, *Zinnia elegans*. This research consisted of three studies: 1) field cultivar trials, 2) pregermination seed treatment, and 3) field irrigation practices.

The objective of the field cultivar trials study was to determine if any of the 57 cultivars of zinnia grown under uniform field conditions showed resistance to foliar pathogens. At week 4, all cultivars showed signs of being infected with *Alternaria* blight and bacterial leaf and flower spot, but disease severity was low enough to make them acceptable in the landscape. Powdery mildew was not a factor at week 4. At week 10, eleven cultivars were judged acceptable in the landscape with regard to all three pathogens. By week 17, none of the 57 cultivars tested was considered acceptable in the landscape due to disease severity from one or more pathogens.

In the pre-germination seed treatment study, seeds of seventeen cultivars of zinnia were treated with one of eight treatments and planted in 16.5 cm diameter (1180 cc) plastic pots containing soilless growing medium, placed on greenhouse benches, and allowed to grow until plants reached flowering stage. The objective of this study was to determine the effect of seven commercial greenhouse disinfectants, fungicides and biological control agents on seed germination and disease suppression during greenhouse production. It was found that pre-germination had no effect on plant height, number of buds and flowers, long-term survival of plants in the study, or disease incidence or

severity for the three diseases studied. Pre-germination seed treatment did have a significant negative effect on germination percentage for some treatments.

In the irrigation field practices study, seventeen cultivars of zinnia were subjected to either sub-irrigation, overhead-sprinkler irrigation or natural rainfall to determine if irrigation method affects disease incidence and severity of foliar disease. It was found that regardless of irrigation method, all cultivars were rendered unacceptable in the landscape by either *Alternaria* blight and/or bacterial leaf and flower spot by week 6 of the study. While watering regime had little consequence in disease severity, overhead irrigation produced greater disease severity than drip irrigation or the control for *Alternaria* blight and bacterial leaf and flower spot. For powdery mildew, drip irrigation produced greater disease severity than overhead irrigation or the control.

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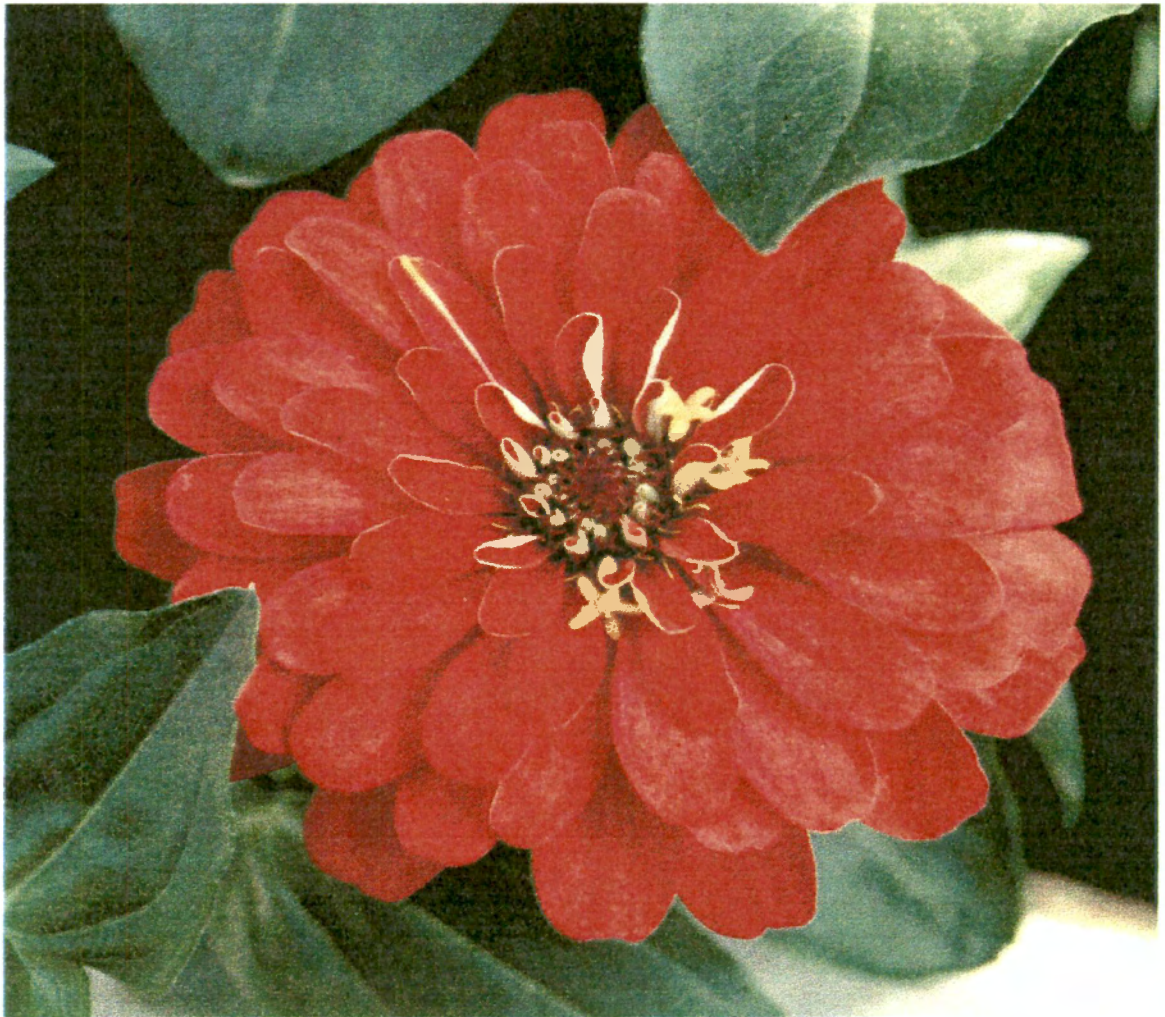
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PART 1
INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

The occurrence of various fungal and bacterial diseases in *Zinnia elegans* Jacq. is well documented (Terry-Lewandowski and Stimart, 1983; Stimart et al., 1987; Spooner et al., 1991). Alternaria blight (*Alternaria zinniae* Pape) and powdery mildew (*Erysiphe cichoracearum* DC ex Merat) are two fungal diseases affecting commercial zinnia production as well as their landscape performance (Terry-Lewandowski and Stimart, 1983). Bacterial leaf and flower spot, incited by *Xanthomonas campestris* pv. *zinniae* (syn. *X. nigromaculans* f. sp. *zinniae* Hopkins and Dowson), is also a serious problem in commercial zinnia production (Jones and Strider, 1979). Considerable economic loss to growers and landscape contractors occurs because of these three diseases. Disease problems are so prevalent that many greenhouse growers will no longer produce this bedding plant and landscape contractors no longer select it for landscape use (Terry-Lewandowski and Stimart, 1983; Stimart et al., 1987; Spooner et al., 1991).

While the epidemiology of these pathogens has been extensively studied, little research has been done to determine what cultural practices reduce incidence of foliar pathogens on *Z. elegans* and what cultivars of *Z. elegans* are resistant to these pathogens. This study sought to identify chemical and cultural practices, for both the greenhouse and landscape industries, which may suppress disease problems and aid in revitalizing the use and popularity of this once favorite garden flower.

The overall objective of this research was to determine whether cultivar selection and cultural practices during commercial production as well as in the landscape can affect the development and suppression of three pathogens: *Alternaria zinniae*, *Erysiphe cichoracearum*, and *Xanthomonas campestris* pv. *zinniae* on the bedding plant and cutflower, *Zinnia elegans*. This research consisted of three studies: 1) field cultivar trials, 2) pre-germination seed treatment, and 3) field irrigation practices.

REVIEW OF KEY LITERATURE

The genus *Zinnia* L. (Asteraceae: Heliantheae) consists of approximately eleven species of annual or perennial herbaceous plants and low-growing shrubs. All are endemic to the western hemisphere, mainly Mexico (McVaugh, 1984; Torres, 1963). *Zinnia*

elegans is the most widely cultivated species and has been an important bedding plant for several generations. It is prized for its large flowers, diversity in flower color, plant form and ease of culture (Srivastava, 1986). Many cultivars of *Z. elegans* have been developed by plant breeders since the plant's introduction to culture in Europe around 1796 (Sharma and Metcalf, 1968). A total of thirty-six *Zinnia elegans* cultivars were named All-America Selections winners between 1935 and 1988 (Whitmore, 1988). No other garden annual, flower or vegetable, has received as many AAS awards (Stimart et al., 1987).

Recent gardening trends, including the desire to attract wildlife and the rise in popularity of the home cutting garden, should ensure a place for zinnias in the American garden. The large, colorful flowerheads attract butterflies and bees, and the seed heads are a ready food source for birds (Meyer, 1996). Growth forms and flower colors can be found which suit many landscape situations. Tall cultivars (>100 cm), such as 'State Fair' and 'Giant Dahlia Bluepoint' may be used for back-of-the-border color or as cut flower specimens. Dwarf cultivars (<100 cm) such as 'Peter Pan' are suitable for season-long foreground color. In fact, cultivars may be obtained which range in height from less than 10 cm tall to more than 100 cm (Stimart et al., 1987).

In the last twenty years, however, zinnias have become more widely known for their disease problems than for their garden attributes. Growers are finding it increasingly difficult to produce a salable crop and homeowners are turning away from this once-popular bedding plant because of the almost-guaranteed incidence of alternaria blight (*Alternaria zinniae*), powdery mildew (*Erysiphe cichoracearum*) and/or bacterial leaf and flower spot (*Xanthomonas campestris* pv. *zinniae*). During warm, rainy or humid weather, these organisms may spread rapidly through an entire crop, leaving plants unsightly and of little ornamental value (Terry-Lewandowski and Stimart, 1983; Stimart et al., 1987; Spooner et al., 1991).

Alternaria Blight

Alternaria blight on zinnia, incited by *Alternaria zinniae*, was first reported in the United States at Cornell University in 1934. From 1936 to 1940, the disease appears to have spread rapidly in various parts of the United States. Today it is one of the three epiphytotics associated with zinnia. *Alternaria* blight has been reported to occur throughout the United States and in at least 15 countries (Lipschultz, 1965).

Alternaria zinniae is a member of the class form Deuteromycotina, the imperfect fungi, order Moniliales, and form family Dematiaceae. It is parasitic and saprophytic on plant material (Lipschultz, 1965).

Alternaria zinniae first manifests itself on zinnia as small spots on foliage which grow rapidly to form irregular blotches. Spots may be 2 to 10 mm in diameter, are reddish-brown and when they appear on the top surface of leaves, may have grayish-white centers. On the lower surfaces of leaves there is no clear differentiation of the spots' margins and centers. Infected leaves become brown and dry as the spots increase in size and number. On flowers, *A. zinniae* appears on the petal tissues of the ray flowers as 1 to 2 mm brown spots which may have grayish-white centers. Sporulation often causes massive secondary infection, rendering the flowers worthless as garden specimens or cut flowers (Dimock and Osborn, 1943).

Numerous small reddish spots, sometimes with grayish-white centers may appear in internodal areas of infected stems. The spots may elongate longitudinally, but are rarely more than 1 mm across. Spots may coalesce, forming large lesions which girdle the stems as the fungus grows inward. Dark brown to black sunken cankers are common on the base of infected plants. Affected plants often wilt, whether basal cankers completely girdle the stem or not. The root systems of such plants often appear healthy (Dimock and Osborn, 1943).

Root infection may also occur. While it is least conspicuous when infecting the roots of plants, *A. zinniae* is perhaps most serious in this stage because it is not amenable to control by relatively simple measures which might be employed to control infection of stems, foliage or flowers. Cortical tissues of infected roots become dark gray,

rot completely, and slough off, resulting in the wilting and ultimate death of affected plants. Secondary organisms usually follow quickly, making isolation of the pathogen difficult (Dimock and Osborn, 1943).

The pathogen may be seed-borne (Dimock and Osborn, 1943; Chou and Wu, 1995; Sohi et al., 1980; Neergaard, 1979) and can reduce germination of infected seeds (Srivastava and Gupta, 1983a; Sohi et al., 1980). The pathogen has been found in varying frequencies in the seeds of over 20 species of plants, mostly Compositae, including *Z. elegans* and *Z. haageana* (Neergaard, 1979). Sohi et al. (1980) found that *Z. elegans* seeds inoculated with *Alternaria zinniae* showed significant pre-emergence mortality (53%) when compared with seedlings of non-inoculated seeds. Wu and Yang (1992) reported that the percentage of seed infected with *Alternaria zinniae* was negatively correlated with the percentage of germination. Germinated seedlings from inoculated seeds showed brownish black lesions in the cotyledonary stage and had a mortality rate of 37% (Sohi et al., 1980).

Infected seedlings may appear symptomless until the plant reaches flowering stage (Neergaard, 1979). High relative humidity is conducive to disease development and heavy dews often bring an explosion of symptoms on plants which previously appeared healthy (Lipschultz, 1965).

Seeds become infected when senescent flowers absorb dew at night and remain wet the next day. The pathogen grows through the petals into attached seeds. Infected seeds give rise to diseased seedlings which serve as hosts to a large number of spores. Air-borne spores infect leaves, stems and flowers of other plants (Franklin and Goodwin, 1981). The primary inoculum is believed to survive in the soil from the previous season's infected seedlings. *A. zinniae* is known to live for five years in infested seeds (Lipschultz, 1965).

It has been reported that up to 37% of seeds and 29% of seedlings may intrinsically show symptoms of the disease (Srivastava and Gupta, 1984). Soaking or dusting seeds with fungicides may decrease incidence of disease (Srivastava and Gupta, 1983b; Dimock and Osborn, 1943), although there is evidence that the pathogen may also exist within the pericarp and/or embryo (Srivastava and Gupta, 1984). Srivastava

(1986) reported finding conidia and mycelium of *A. zinniae* in the xylem tissue of *Z. elegans* embryos (Srivastava and Gupta, 1984; Srivastava, 1986). Wu and Yang (1992) reported increased germination from infected seeds treated with various fungicides and *Bacillus* sp. strains, when compared to those which were not treated.

Heat treatment, particularly the soaking of seeds in hot water, has been used to kill plant pathogenic fungi, including *Alternaria* spp. with mixed success. The major problem associated with the use of moist-heat treatment is a severe decrease in seed viability. Franklin and Goodwin (1981) found that a water temperature of approximately 55°C for a period of 30 minutes was appropriate for killing *A. zinniae*. However, germination percentages ranged from 5% to 30%, depending upon exact temperature used. Lower temperatures, which might have promoted higher germination percentages, failed to kill the fungus. Another disadvantage of hot water treatment is that seeds absorb a large amount of water, resulting in leakage of soluble materials (Franklin and Goodwin, 1981).

Control of alternaria blight on plants can be accomplished with varying degrees of success by using fungicides, including Chipco 26019™, Daconil 2787™, Manzate 200™, and various combinations (Powell and Anderson, 1981; Pecknold and Hoffman, 1981). However, during times of heavy rainfall and humid conditions, fungicides may be ineffective.

Powdery Mildew

Powdery mildew, incited by the fungus *Erysiphe cichoracearum*, is one of the three severe epiphytotics to threaten commercial seed and bedding plant production of *Zinnia elegans*. Fungi causing powdery mildews belong to the family Erysiphaceae, which are obligate parasites, and therefore, are unable to grow on artificial medium (Andersen, 1971).

While powdery mildew infection may render the plant's appearance as unsightly, it is usually not fatal (Powell and Lindquist, 1992). Infected plants take on the appearance of having been dusted with flour. All aboveground portions of plants may be attacked, particularly young leaves and shoots. Severe powdery mildew infection in zinnia may result in curling yellow leaves and stunted growth. Infected flower buds become discolored and dwarfed and may die. In extreme cases, flower distortion and death may

occur (Powell and Lindquist, 1992; Lucas et al., 1985).

Infection is initiated by barrel-shaped conidia or ascospores which germinate shortly after inoculation. A short germ tube grows from a corner of the spore and produces an appressorium. A haustorium develops on the end of the penetration peg and expands into the lumen of the cell. Nutrient absorption occurs through the haustoria, which also serve to attach the parasite to the host. Hyphae grow from the appressoria and from the conidia, forming a mycelial network on the leaf surface. Shortly after inoculation, conidiophores begin to form at right angles to the leaf surface, appearing as a white, powdery film on the host. When environmental disease development conditions are optimal, secondary conidia appear within 48 hours (Powell and Lindquist, 1992). Mature conidia are disseminated by wind (Andersen, 1971).

The method of dissemination of *E. cichoracearum* on zinnia is unclear. The pathogen has been found on seed of *Z. elegans*, but seed transmission has not been positively established (Neergaard, 1979). Many powdery mildews overwinter as ascocarps in buds, but since *Z. elegans* is an annual, this scenario seems unlikely. It is thought that it may overwinter as ascocarps in soil or possibly, on seed (Andersen, 1971; Spencer, 1978; Baker and Locke, 1946).

Environmental conditions which favor the development of powdery mildew may seem contradictory: while rainfall may "trigger" an epidemic, the disease often explodes when weather is hot and dry. Germination of conidia is favored in conditions of high relative humidity (98-99% seems optimal), but free water may actually inhibit conidia germination. Free water causes poor hyphal growth and conidiophores are damaged by impacting raindrops. However, showers can stimulate powdery mildews by raising relative humidity. In situations where days are warm and dry, heavy night-time dews are still possible, leading to increased infection. In microclimate situations where night-time relative humidity is higher (for example, near the coast, vs. a few miles inland), powdery mildew infection may be more severe (Spencer, 1978). Wind and rain help spread the disease throughout the crop (Powell and Lindquist, 1992).

Most powdery mildews will not thrive at temperatures above 30°C. Plant parts which are directly exposed to full sunlight are not as seriously affected by powdery

mildew because they develop temperatures are above the optimum for powdery mildew growth or survival. Shaded foliage or leaves deep within the canopy are more likely to be infected by powdery mildew (Powell and Lindquist, 1992).

In greenhouse crops, air movement helps with both the spread and prevention of powdery mildew. Air circulation is necessary to allow leaf surfaces to dry, but a pattern of disease will often appear which corresponds with the flow of air within a greenhouse. Control of relative humidity is necessary to prevent leaf surfaces from remaining damp. Proper use of heat and venting systems is also imperative in order to prevent moisture condensation in the greenhouse (Powell and Lindquist, 1992).

Erysiphe cichoracearum has a wide host range, including cucurbits, potatoes, phlox, lettuce, and zinnias. Within the species, specific races of the fungus are restricted in the plants they will parasitize. For instance, the fungus which causes powdery mildew on cucurbits only infects Cucurbitaceae. A mildew isolate which has been found on *Phlox drummondii* Hook and cultivated perennial phlox has only been found to infect those specific hosts. The race which infects zinnia is known to infect other Asteraceae, as well as one species each of the Solanaceae and Boraginaceae families (Andersen, 1971).

Although numerous attempts at breeding *Z. elegans* for resistance to *E. cichoracearum* have been made, little success has been achieved (Terry-Lewandowski and Stimart, 1983). Husain and Akram (1995) cultivar-tested 54 *Z. elegans* cultivars for resistance to *E. cichoracearum* and found only three which could be classified as "resistant." *Zinnia angustifolia*, a related species, has been shown to exhibit moderate to complete resistance to *E. cichoracearum*. Interspecific hybrids between *Z. elegans* and *Z. angustifolia* exhibit excellent resistance to the pathogen (Boyle and Stimart, 1982). The major problem with these hybrids, however, is that they are currently available in a limited range of colors and growth habits (B. Corr, Pan American Seed Co., West Chicago, Ill., *personal communication*). It may be several years before *Z. marylandica*, as one hybrid has been named, (Spooner et al., 1991) becomes a comparable substitute for *Z. elegans* in landscape and cutflower use.

Control of powdery mildew may be achieved with varying degrees of success by using fungicides such as Manzate 200™, Banrot 40W™, Dithane M-45™, Daconil

2787™, and various combinations (Strider, 1979a; Powell and Anderson, 1981). "Non-traditional" remedies, such as horticultural oil/sodium bicarbonate (baking soda) solutions in water have been reported to be moderately effective in controlling powdery mildew infections. Powdery mildew infections may also be controlled with 2% horticultural oil solution or 2% insecticidal soap solution, at 14-day intervals. The general consensus among growers, however, is that prevention is far more easily accomplished than curing an infection once the pathogen becomes established. Once established, under environmental conditions conducive to development, the pathogen may spread more rapidly than it can be controlled. Preventive spraying with fungicides is common (Meyer, 1996).

Bacterial Leaf and Flower Spot

Bacterial leaf and flower spot of zinnia, incited by the bacterium *Xanthomonas campestris* pv. *zinniae*, was first observed in the United States in 1972 in Columbus, Ohio (Sleesman et al., 1973) and in North Carolina (Strider, 1973). The first incidence of what is now suspected to be the same disease was originally observed in Italy in 1929, and was first described from plants in southern Rhodesia in 1949 (Hopkins and Dowson, 1949). Today, *Xanthomonas campestris* pv. *zinniae* is one of the three epiphytotics affecting zinnia seed and plant production as well as use of zinnia in the landscape (Terry-Lewandowski and Stimart, 1983; Strider, 1976).

Symptoms of bacterial leaf and flower spot disease begin as small yellow spots on foliage which develop pin-point necrosis in the center within two days. The spots are angular to irregularly circular, reddish-brown to dark brown and 1 to 4 mm in diameter. They are surrounded by a prominent yellow halo. Lesions are readily distinguishable from those of alternaria blight, which are larger, reddish-brown to purple, lacking a yellow halo, and often have gray centers. Microscopic examination of lesions reveals oozing, water-soaked margins (Sleesman et al., 1973). On flowers, spotting appears as irregular necrotic lesions on petals (Jones, 1977).

During warm, humid and rainy weather, the bacterium is capable of spreading rapidly through an entire crop, rendering plants unsightly and of little ornamental value

(Jones and Strider, 1979). Jones (1977) reported that temperature regimes of around 29 to 31°C days and 21 to 23°C night were most conducive to development of severe disease symptoms in *Z. elegans*. Higher and lower temperatures slow progression of the disease. Jones (1977) also reported a direct correlation between disease severity and amount of time that foliage remained wet prior to and after inoculation with the pathogen. Strider (1979b) reported that during extended dry periods, symptoms do not tend to develop on new foliage.

Strider (1973) showed that the pathogen is seed-borne and suggested that soaking seeds for two minutes in 10% Clorox solution (.52% sodium hypochlorite) may prevent disease development. *X. campestris* pv. *zinniae* has been detected in two-year-old seeds stored in paper bags at room temperature and in four-year-old seeds in hermetically sealed foil. The pathogen has also been found to remain virulent for at least 14 months in dried infected leaves. This strongly suggests that the organism can overwinter in zinnia debris in the greenhouse or in the field (Strider, 1979b).

Strider (1979b) also described a "deceptive" feature of this pathogen. Typical disease symptoms might disappear for a period of time after initial infection of cotyledons (primary infection) and reappear when disease conditions are right. Severely infected cotyledons may fall off plants or infected seedlings may die within two weeks of emergence, leaving only apparently healthy seedlings in the seedbed. However, the pathogen has not disappeared and when disease conditions are right, the disease may suddenly reappear and become rampant. Strider (1979b) also noted that primary infection symptoms on cotyledons may be atypical of symptoms normally associated with this disease on older, more mature plants. Primary symptoms may be less distinctive and smaller or they may be so numerous on cotyledons, stems and leaves that tissues collapse rapidly, precluding the development of typical symptoms. Seedlings that become diseased during germination and emergence but do not die remain severely stunted and unproductive.

Soaking seeds in a 20% Clorox™ solution (1.04% sodium hypochlorite) has been shown to eradicate *X. campestris* pv. *zinniae* without significant loss to germination percentage. Lower concentrations of Clorox, while having a marked effect on the

pathogen's survival, do not produce disease-free seedlings. Heat treatment of seeds (soaking seeds for 30 minutes at temperatures of 51 to 53°C) appears to be less effective in eliminating the pathogen and has a more significant negative effect on seed germination percentage (Strider, 1979c).

Captan™, a fungicide, has an inhibitory effect on *X. campestris* pv. *zinniae*. A slurry of Captan, 360 g a.i./L is recommended as a seed treatment for protection against both bacterial leaf and flower spot and against various fungal damping-off pathogens which occur during seed emergence (Strider, 1980). Strider (1981) also reported that Captan 80W was an effective foliar control of this pathogen (as well as for *Alternaria zinniae* and *Erysiphe cichoracearum*) when applied at rates of 3 lbs/100 gal and 12 lbs/100 gal. Jindal and Meeta (1990), however, found that Captan failed to give control of bacterial leaf and flower spot when applied as a foliar spray.

Kishun et al. (1979) found that three sprays of streptocycline or agrimycin-100 (streptomycin sulfate 15% + oxytetracycline 1.5%) were effective in controlling bacterial leaf and flower spot on zinnia plants. Jindal and Meeta (1988) reported that bacterial leaf and flower spot on zinnia can be controlled by the application of streptocycline at a concentration of 0.01%.

Virtually all cultivars of *Z. elegans* which have been tested have been shown to be at least moderately susceptible to *X. campestris* pv. *zinniae*. Two other species of zinnia, *Z. angustifolia* and *Z. haageana*, appear to exhibit good to total resistance to the pathogen (Jones, 1977; Terry-Lewandowski and Stimart, 1983). Efforts were made to cross *Z. elegans* with *Z. angustifolia* in the mid-1980s in the hope that an interspecific hybrid would possess better resistance to *X. campestris* pv. *zinniae*, as well as to the other two epiphytotic pathogens previously discussed. Although successful hybridization of *Z. elegans* x *Z. angustifolia* has been achieved, the resulting hybrids are currently available in a limited range of colors and growth forms, and are therefore generally not comparable substitutes for *Z. elegans*.

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PART 2
FIELD CULTIVAR TRIAL

ABSTRACT

Fifty-seven cultivars of *Zinnia elegans* were studied under uniform field conditions for 17 weeks to determine their resistance or susceptibility to *Alternaria* blight, powdery mildew and bacterial leaf and flower spot. A disease severity scale was developed and plants were judged for acceptability/unacceptability in the landscape based upon this scale. At week 4, all cultivars were found to be acceptable when evaluated for all the pathogens studied. At week 10, eleven cultivars were found to be acceptable when evaluated for the pathogens studied, while the other 46 cultivars showed disease severity beyond an acceptable level for at least one of the pathogens. At week 17, all 57 cultivars were found to be unacceptable in the landscape. Ten cultivars had been killed by one or more pathogens by week 17. Only two cultivars showed any tolerance to any of the pathogens (powdery mildew) at week 17.

INTRODUCTION

Zinnia elegans Jacq. has long been an important bedding plant. However, considerable economic loss occurs to growers and landscape contractors using zinnia because of the diseases *alternaria* blight (*Alternaria zinniae* Pape), powdery mildew (*Erysiphe cichoracearum* DC ex Merat) and bacterial leaf & flower spot [*Xanthomonas campestris* pv. *zinniae* (syn. *X. nigromaculans* f. sp. *zinniae* Hopkins & Dowson)]. *Alternaria* blight and powdery mildew are two common fungal diseases affecting commercial zinnia production as well as their landscape performance (Terry-Lewandowski and Stimart, 1983). Bacterial leaf & flower spot is also a serious problem in commercial zinnia production (Jones and Strider, 1979).

During warm, rainy or humid weather, these organisms may spread rapidly through an entire crop, leaving plants unsightly and of little ornamental value (Terry-Lewandowski and Stimart, 1983; Stimart et al., 1987; Spooner et al., 1991). Disease problems are so prevalent that many greenhouse growers will no longer produce this once-popular bedding plant and landscape contractors no longer select it for landscape use.

While the epidemiology of these pathogens has been extensively studied, little research has been done to determine what cultivars of *Z. elegans* are less susceptible to these pathogens. The overall objective of this research was to determine whether cultivar selection can affect the development and suppression of three pathogens: *Alternaria zinniae*, *Erysiphe cichoracearum*, and *Xanthomonas campestris* pv. *zinniae* on the bedding plant and cutflower, *Zinnia elegans*.

MATERIALS AND METHODS

Plant Materials and Culture

Seed from fifty-seven cultivars of *Zinnia elegans* were obtained from various commercial seed suppliers in the spring of 1997 (Table 1). Seeds were sown on 3 and 5 June 1997 in germination row-type flats (TLC Polyform, Plymouth, Minn.) in a commercial germination mix (Berger's BM2 Germination Mix, Que., Canada) and placed under intermittent mist on benches in the University of Tennessee propagation greenhouse. Seed flats were placed on bench-bottom heat, at temperatures of 18.0°C nights, 26.7°C days, and a relative humidity of 70%.

When seedlings had produced their first set of true leaves (16 June) they were transplanted into 70 ml, 1803 cell-pack inserts (T.O. Plastics, Minneapolis, Minn.) containing a soilless bedding plant growing medium (Pro-Mix BX, Premier Horticulture, Inc., Red Hill, Pa.). Plants were grown in a bedding plant greenhouse where temperatures averaged 18.0°C night and 26.7°C day and relative humidity was 60-65%.

Plants were irrigated with a hose and water breaker and fertilized using Peter's™ water-soluble fertilizer 15.0N–7.0P–14.1K (Scotts-Sierra Horticultural Products Company, Maysville, Ohio) at each irrigation. Fertilizer was applied at 200 mg·liter⁻¹ from date of transplanting into cell-packs until plants were transplanted into the field.

On 30 June, when plants had produced several sets of true leaves, they were pinched to two nodes and transplanted into experimental field plots where they were grown under uniform conditions for the duration of the experiment. The experimental

Table 1. Cultivars of *Zinnia elegans* used in cultivar trial research study and their sources.

Cultivar name	Source	Cultivar name	Source	Cultivar name	Source
Dasher Series		Oklahoma Series		Small World Series	
Orange	Ball ¹	Salmon	Benary	Cherry	Vaughan's ⁵
Scarlet	Ball	White	Benary	Pink	Vaughan's
Pink	Ball	Golden Yellow	Benary	Sun Series	
Dreamland Series		Pink	Benary	Golden	Vaughan's
Coral	Ball	Scarlet	Benary	Red	Vaughan's
Ivory	Ball	Peter Pan Series		Misc. Cultivars	
Rose	Ball	Cream	Goldsmith ⁴	Dahlia Flowered Mix	Park
Scarlet	Ball	Flame	Goldsmith	Liliput Mix	Vaughan's
Pink	Ball	Orange	Goldsmith	Pulcino Mix	Ball
Red	Ball	Princess	Goldsmith	Pumila Mix	Park
Yellow	Park ²	Scarlet	Goldsmith	Splendor Pink	Ball
Giant Dahlia Bluepoint Series		White	Goldsmith	State Fair Mix	Ball
Crimson Monarch	Benary ³	Gold	Goldsmith	Sunbow Mix	Johnny's ⁶
Dream	Benary	Pink	Goldsmith	Thumbilina Mix	Vaughan's
Eldorado	Benary	Plum	Goldsmith		
Exquisite	Benary	Ruffles Series			
Golden State	Benary	Cherry	Park		
Hallo	Benary	Pink	Park		
Polar Bear	Benary	Yellow	Park		
Purple Prince	Benary	Short Stuff Series			
Scarlet Flame	Benary	Coral	Goldsmith		
Bright Pink	Benary	Deep Red	Goldsmith		
Golden Dawn	Benary	Gold	Goldsmith		
Meteor	Benary	Orange	Goldsmith		
		Scarlet	Goldsmith		
		White	Goldsmith		

¹ Ball Seed Co., West Chicago, Illinois.

² Park Seed Co., Greenwood, South Carolina.

³ Ernst Benary, Hann, Germany.

⁴ Goldsmith Seeds, Inc., Gilroy, California.

⁵ Vaughan's Seed Co., Downers Grove, Illinois.

⁶ Johnny's Selected Seeds, Albion, Maine.

plots were irrigated with sub-irrigation soaker hoses as needed. Due to adequate nutrient levels in the field soil, no additional fertilizer was administered.

Experimental Design

The experimental design for this study was a modified randomized complete block. Prior to being planted in experimental field plots, the cultivar trials were divided into three height categories: tall cutflower types (76 cm or taller), medium height (38–76 cm), and short bedding plant types (under 38 cm) (Table 2). This was done to eliminate skewed data from a short cultivar being “shaded” by an adjacent tall cultivar. Cultivars were randomized within their respective height categories. Four repetitions of each cultivar were used in the study. A repetition consisted of three plants of the same cultivar. This totaled twelve plants of each cultivar being used in the the study. All plants were planted on 30.5 cm centers with each repetition being planted three plants deep in the 1.83 m wide beds.

Table 2. Height categories of *Zinnia elegans* cultivars used in cultivar trial.

Series	Average height (cm)	Height category
Short Stuff Series	22.86	Short
Thumbilina Mix	22.86	Short
Dreamland Series	26.67	Short
Dasher Series	27.94	Short
Peter Pan Series	27.94	Short
Pulcino Mix	34.29	Short
Small World Series	40.64	Medium
Liliput Mix	60.40	Medium
Pumila Mix	70.00	Medium
Splendor Pink	70.00	Medium
Sun Series	70.60	Medium
Ruffles Series	73.10	Medium
Sunbow Mix	73.10	Medium
State Fair Mix	83.82	Tall
Oklahoma Series	88.90	Tall
Dahlia Flowered Mix	106.68	Tall
Giant Dahlia Bluepoint Series	114.30	Tall

Experimental field plots consisted of three adjacent beds each 30.50 meters long x 1.83 meters wide. The beds contained fertile, well-drained soil of Huntington silt loam (USDA 1955), mulched with shredded hardwood bark.

A pair of sub-irrigation soaker hoses ("ooze tubes") (Aquapore Moisture Systems, Inc., Phoenix, Ariz.) ran the length of each bed, spaced approximately 0.60 meters apart and connected to a central water line, allowing irrigation to be administered to all treatment beds simultaneously. Irrigation was administered on an "as needed" basis, as determined by visual inspection of plants for signs of wilting.

Data Collected

Plants were evaluated at 4 (26 July), 10 (3 Sept.) and 17 week (22 Oct. 1997) after transplanting into the field for incidence and severity of disease as each of these factors pertained to *Alternaria* blight, powdery mildew and bacterial leaf and flower spot. Data were collected on the center plant; the two outer plants served as guard plants. The following disease severity rating scale was used to evaluate each disease:

- 0.0 = no disease apparent
- 1.0 = $\leq$ 2% affected by disease
- 2.0 = $\leq$ 10% affected by disease
- 3.0 = $\leq$ 25% affected by disease
- 4.0 = $\leq$ 50% affected by disease
- 5.0 = $>$ 50% affected by disease
- 6.0 = plant dead (killed by disease).

Disease data were analyzed using mixed model analysis of variance (SAS Inst., Cary, N.C.). The model tested the factorial effects of cultivar and treatment and had repeated measures over weeks. The statistical mean for the foliage damage rating for each cultivar was used to determine its resistance or susceptibility to each of the three pathogens. Cultivars having a disease severity rating ≤ 2.0 ($\leq 10\%$ of plant foliage showing signs and/or symptoms of disease) were judged acceptable in a landscape situation. Those cultivars having a disease severity rating > 2.0 were judged unacceptable in a landscape situation.

RESULTS

Alternaria Blight

Week 4 incidence and severity for cultivars. At evaluation week 4 (25 July), incidence of Alternaria blight was found to be significantly different among cultivars. Incidence of Alternaria blight among cultivars ranged from 0.0% to 83.3%. Two cultivars, 'Dreamland Scarlet' and 'Peter Pan Cream' showed no incidence of Alternaria blight. Alternaria blight severity was below the landscape acceptability threshold for all cultivars, despite significant differences found in the statistical analysis. Alternaria blight severity ratings ranged from 0.0 to 1.3, resulting in all cultivars being judged acceptable in the landscape when evaluated for susceptibility to Alternaria blight.

Week 4 incidence and severity for series. At evaluation week 4, incidence of Alternaria blight was found to be significantly different among series although all series showed incidence of the disease. Incidence of Alternaria blight among series ranged from 23.6% to 83.3%. Alternaria blight severity was found to be not significantly different among series. All series showed disease severity ratings below 2.0, resulting in all series being judged acceptable in the landscape when evaluated for susceptibility to Alternaria blight. Disease severity ratings ranged from 0.2 to 1.0.

Week 10 incidence and severity for cultivars. At week 10 (3 Sept.), incidence of Alternaria blight was not significantly different among cultivars. All 57 cultivars showed some incidence of Alternaria blight, although severity varied significantly among cultivars. Disease severity ratings ranged from 0.3 to 3.3. Disease severity ratings in 43 of the 57 cultivars evaluated was ≤ 2.0 and those cultivars were judged acceptable in the landscape when evaluated for susceptibility to Alternaria blight (Table 3). Six cultivars, 'Giant Dahlia Bluepoint Golden Dawn,' 'Liliput mix,' 'Peter Pan Cream,' 'Ruffles Pink,' 'Ruffles Yellow,' and 'Short Stuff White,' were only minimally affected, demonstrating disease severity ratings ≤ 1.0 .

Week 10 incidence and severity for series. At week 10, incidence of Alternaria blight was not significantly different among series. All series showed some incidence of Alternaria blight, although severity varied significantly among series. Disease severity

Table 3. Disease severity ratings for Alternaria blight, powdery mildew and bacterial leaf and flower spot at weeks 10 and 17.

Series Name / Cultivar	Disease Severity Rating ^{z, y}					
	Alternaria Blight		Powdery Mildew		Bacterial Leaf & Flower Spot	
	Week 10	Week 17	Week 10	Week 17	Week 10	Week 17
Dasher Series						
Orange	2.3 abcde	4.5 defg	0.0 c	3.3 cdef	2.5 bcde	4.5 cdefg
Scarlet	2.5 abcd	5.5 abc	0.0 c	4.0 abcde	3.0 abc	5.0 abcde
Pink	1.8 cdefg	4.3 efg	0.0 c	2.8 ef	2.3 cde	4.0 efg
Dreamland Series						
Coral	2.0 bcdef	5.8 ab	0.3 bc	5.2 abc	2.3 cde	5.8 ab
Ivory	1.8 cdefg	6.0 a	0.0 c	--x	2.0 de	6.0 a
Rose	2.0 bcdef	6.0 a	0.0 c	--	2.3 cde	6.0 a
Scarlet	2.0 bcdef	5.0 bcde	0.0 c	4.4 abc	2.0 de	4.8 bcdef
Pink	2.3 abcde	6.0 a	0.0 c	--	2.3 cde	6.0 a
Red	2.5 abcd	6.0 a	0.0 c	--	2.5 bcde	6.0 a
Yellow	1.3 efghi	6.0 a	0.0 c	--	2.8 abcd	6.0 a
Giant Dahlia Bluepoint Series						
Crimson Monarch	1.3 efghi	5.0 bcde	0.3 bc	4.3 abcd	2.8 abcd	4.5 cdefg
Dream	1.8 cdefg	4.8 cdef	0.0 c	5.0 a	2.5 bcde	5.0 abcde
Eldorado	2.0 bcdef	5.5 abc	0.0 c	5.0 a	2.0 de	5.3 abcd
Exquisite	1.8 cdefg	4.5 defg	0.3 bc	4.8 ab	2.3 cde	5.0 abcde
Golden State	3.3 a	4.5 defg	0.05 c	5.0 a	3.5 a	5.0 abcde
Hallo	1.3 efghi	4.5 defg	0.0 c	4.3 abcd	3.0 abc	4.3 defg
Polar Bear	1.0 fghi	4.3 efg	0.3 bc	4.5 abc	2.3 cde	4.5 cdefg
Purple Prince	1.5 defgh	4.5 defg	0.0 c	4.5 abc	2.8 abcd	4.5 cdefg
Scarlet Flame	1.8 cdefg	5.0 bcde	0.0 c	5.0 a	2.0 de	5.0 abcde
Bright Pink	1.3 efghi	4.8 cdef	0.0 c	4.8 ab	2.5 bcde	4.3 defg
Golden Dawn	0.8 ghi	4.8 cdef	0.5 bc	3.0 def	2.3 cde	4.3 defg
Meteor	1.5 defgh	5.3 abcd	0.0 c	5.1 a	2.5 bcde	5.3 abcd
Oklahoma Series						
Salmon	2.0 bcdef	4.5 defg	0.3 bc	4.5 abc	2.0 de	4.5 cdefg
White	1.0 fghi	3.8 gh	0.0 c	4.3 abcd	2.3 cde	3.8 fg
Golden Yellow	2.0 bcdef	4.5 defg	0.3 bc	4.8 ab	2.3 cde	4.3 defg
Pink	1.5 defgh	4.3 efg	0.3 bc	4.5 abc	2.5 bcde	4.5 cdefg
Scarlet	1.8 cdefg	4.5 defg	0.0 c	4.0 abcde	2.5 bcde	4.5 cdefg
Peter Pan Series						
Cream	1.0 fghi	6.0 a	0.0 c	--	3.3 ab	6.0 a
Flame	2.3 abcde	6.0 a	0.0 c	--	2.5 bcde	6.0 a
Orange	2.5 abcd	5.0 bcde	0.5 bc	4.1 abcde	2.5 bcde	5.0 abcde
Princess	2.8 abc	5.5 abc	0.0 c	3.1 cdef	3.0 abc	4.8 bcdef
Scarlet	3.0 ab	5.3 abcd	0.0 c	4.4 abc	2.8 abcd	4.8 bcdef
White	1.3 efghi	5.3 abcd	0.0 c	2.1 f	2.3 cde	5.0 abcde
Gold	1.3 efghi	6.0 a	1.5 a	--	2.5 bcde	6.0 a
Pink	2.5 abcd	5.5 abc	0.0 c	4.9 ab	2.8 abcd	5.5 abc
Plum	2.5 abcd	6.0 a	0.0 c	--	2.5 bcde	6.0 a

Table 3. Disease severity ratings for Alternaria blight, powdery mildew and bacterial leaf and flower spot at weeks 10 and 17, continued.

Series Name / Cultivar	Disease Severity Rating ^{Z, Y}					
	Alternaria Blight		Powdery Mildew		Bacterial Leaf & Flower Spot	
	Week 10	Week 17	Week 10	Week 17	Week 10	Week 17
Ruffles Series						
Cherry	1.8 cdefg	4.3 defg	0.5 bc	4.3 abcd	2.8 abcd	5.3 abcd
Pink	0.5 hi	3.3 h	0.3 bc	3.5 bodef	1.8 e	3.5 g
Yellow	0.3 i	4.3 efg	0.5 bc	4.8 ab	2.0 de	4.5 cdefg
Short Stuff Series						
Coral	2.3 abode	4.3 efg	0.0 c	4.1 abcde	2.8 abcd	4.5 cdefg
Deep Red	1.5 defgh	5.5 abc	0.0 c	4.4 abcd	2.5 bode	5.5 abc
Gold	1.3 efghi	6.0 a	0.0 c	--	2.8 abcd	6.0 a
Orange	1.8 cdefg	5.3 abcd	0.0 c	2.1 f	3.3 ab	4.8 bodef
Scarlet	2.0 bodef	5.5 abc	0.0 c	3.0 cdef	2.8 abcd	5.5 abc
White	1.0 fg hi	5.7 ab	0.0 c	5.2 abc	2.3 cde	5.8 ab
Small World Series						
Cherry	1.8 cdefg	5.0 bode	0.5 bc	4.0 abcde	2.3 cde	5.0 abcde
Pink	1.8 cdefg	5.0 bode	0.0 c	4.3 abcd	2.5 bode	4.3 defg
Sun Series						
Golden	1.5 defgh	5.3 abcd	0.5 bc	5.0 a	2.3 cde	5.3 abcd
Red	1.5 defgh	5.5 abc	0.5 bc	5.0 a	2.3 cde	5.5 abc
Misc. Cultivars						
Dahlia Flowered Mix	2.5 abcd	5.5 abc	0.5 bc	5.0 ab	2.5 bode	5.5 abc
Liliput Mix	0.8 ghi	4.8 cdef	0.8 b	4.7 ab	2.0 de	4.8 bodef
Pulcino Mix	1.8 cdefg	4.8 cdef	0.0 c	3.8 abcde	3.0 abc	3.5 g
Pumila Mix	2.0 bodef	4.8 cdef	0.3 bc	4.3 abcd	2.0 de	3.8 fg
Splendor Pink	2.3 abcde	4.8 cdef	0.5 bc	4.5 abc	2.3 cde	5.0 abcde
State Fair Mix	2.0 bodef	4.8 cdef	0.0 c	4.3 abcd	2.5 bode	4.5 cdefg
Sunbow Mix	2.0 bodef	4.0 fgh	0.5 bc	4.3 abcd	2.0 de	4.5 cdefg
Thumbilina Mix	1.8 cdefg	4.3 efg	0.0 c	4.3 abcd	2.0 de	3.8 fg

^ZDisease severity rating scale: 0.0 = no disease apparent
 1.0 = ≤ 2% affected by disease
 2.0 = ≤ 10% affected by disease
 3.0 = ≤ 25% affected by disease
 4.0 = ≤ 50% affected by disease
 5.0 = > 50% affected by disease
 6.0 = plant dead (killed by disease).

^Y Means followed by the same letters are not significantly different using least square means test at $P \leq 0.05$.

^X Plant dead from Alternaria blight and/or bacterial leaf and flower spot, therefore no disease rating for powdery mildew was possible at this date.

ratings for series ranged from a low of 0.8 for the Ruffles series to a high of 2.2 for the Dasher series. All three cultivars in the Ruffles series had disease severity ratings ≤ 2.0 , making the Ruffles series the best-performing series for tolerance to *Alternaria* blight. Only the Dasher and Peter Pan series, with mean foliage damage ratings of 2.2 and 2.1, respectively, were found to be susceptible to *Alternaria* blight at week 10.

Week 17 incidence and severity for cultivars. At week 17 (22 Oct.), incidence of *Alternaria* blight was not significantly different among cultivars nor among series. Virtually all plants exhibited severe disease damage. Disease severity ratings for cultivars at week 17 ranged from 3.3 to 6.0. Fifty-five of the 57 cultivars tested exhibited disease severity ratings between 4.0 and 6.0. Ten cultivars ('Dreamland Ivory,' 'Dreamland Rose,' 'Dreamland Pink,' 'Dreamland Red,' 'Dreamland Yellow,' 'Peter Pan Cream,' 'Peter Pan Flame,' 'Peter Pan Gold,' 'Peter Pan Plum,' 'Short Stuff Gold') were dead, most likely killed by a combination of *Alternaria* blight and bacterial leaf and flower spot. Only two cultivars, 'Oklahoma White' and 'Ruffles Pink,' exhibited disease severity ratings below 4.0 and those ratings were too high for those plants to be acceptable in the landscape when evaluated for susceptibility to *Alternaria* blight. Therefore, although significant differences in severity of *Alternaria* blight among cultivars were shown in the ANOVA and separation of means, all cultivars were found to be susceptible to the pathogen at week 17.

Week 17 incidence and severity for series. At week 17, incidence of *Alternaria* blight was not significantly different among series. Disease severity ratings for series at week 17 ranged from 3.9 for the Ruffles series to 5.8 for the Dreamland series, resulting in all series being rated unacceptable at that date when evaluated for susceptibility to *Alternaria* blight.

Powdery Mildew

Week 4 incidence and severity for cultivars and series. Powdery mildew incidence was virtually non-existent at week 4 (25 July) and was not significantly different among either cultivars or series. Because the pathogen was not observed in the experimental crop at week 4, disease severity ratings for all cultivars and series remained at 0.0, well below the landscape acceptability threshold for powdery mildew at week 4.

Week 10 incidence and severity for cultivars and series. Powdery mildew incidence was minimal at week 10 (3 Sept.) and was not significantly different among either cultivars or series. Disease severity ratings for cultivars for powdery mildew at week 10 ranged from 0.0 to 1.5, below the landscape acceptability threshold for powdery mildew. Thirty-six cultivars showed no apparent signs of the disease at week 10. All series exhibited disease severity ratings ≤ 1.0 at week 10, also well below the landscape acceptability threshold. Disease severity ratings for series ranged from 0.0 to 0.8.

Week 17 incidence and severity for cultivars. At week 17 (22 Oct.), powdery mildew was rampant. Despite the significant differences in incidence and severity among cultivars shown by statistical analysis, virtually all surviving plants were severely damaged by the pathogen. Disease severity ratings for 45 of the 47 surviving cultivars ranged from 2.8 to 5.2, resulting in those cultivars being judged unacceptable in the landscape. The two best-performing cultivars were 'Peter Pan White' and 'Short Stuff Orange.' Both of these cultivars had a mean disease severity rating of 2.1, showing them to be less susceptible to powdery mildew at week 17 than the other 55 cultivars tested.

Week 17 incidence and severity for series. At week 17 all series were found to have disease severity ratings which resulted in them being rated unacceptable, despite significant differences found in the statistical analysis. Mean disease severity ratings for series ranged from 3.3 to 5.0.

Bacterial Leaf and Flower Spot

Week 4 incidence and severity for cultivars. At week 4 (25 July), incidence of bacterial leaf and flower spot was found to be not significantly different among cultivars. All cultivars showed some incidence of the pathogen. Incidence ranged from 50% to 100% of plants within a cultivar being affected. At week 4, bacterial leaf and flower spot severity was also found to be not significantly different among cultivars. Disease severity ratings ranged from 0.5 to 2.0, resulting in all cultivars being judged acceptable in the landscape at week 4 when evaluated for susceptibility to bacterial leaf and flower spot.

Week 4 incidence and severity for series. At week 4, incidence of bacterial leaf and flower spot was found to be not significantly different among series. All series showed some incidence of the pathogen. Incidence ranged from 62.5% to 100% of plants

some incidence of the pathogen. Incidence ranged from 62.5% to 100% of plants within a series being affected by the pathogen. At week 4, bacterial leaf and flower spot severity was also found to be not significantly different among series. Disease severity ratings ranged from 0.5 to 1.5, resulting in all cultivars being judged acceptable in the landscape when evaluated for susceptibility to bacterial leaf and flower spot.

Week 10 incidence and severity for cultivars. At week 10 (3 Sept.), all cultivars were infected with bacterial leaf and flower spot. Disease severity ratings for Bacterial leaf and flower spot ranged from 1.8 to 3.5. Eleven cultivars demonstrated less susceptibility to bacterial leaf and flower spot by having disease severity ratings ≤ 2.0 . These cultivars were 'Giant Dahlia Bluepoint Eldorado,' 'Giant Dahlia Bluepoint Scarlet Flame,' 'Liliput mix,' 'Oklahoma Salmon,' 'Pumila mix,' 'Sunbow mix,' 'Thumbilina mix,' 'Dreamland Ivory,' 'Dreamland Scarlet,' 'Ruffles Pink,' and 'Ruffles Yellow.' 'Ruffles Pink,' with a disease severity rating of 1.8, showed the least severe disease damage.

Week 10 incidence and severity for series. At week 10 all series were found to have disease severity ratings too high to be acceptable in the landscape when evaluated for bacterial leaf and flower spot, in spite of significant F-values found in the ANOVA and separation of means. Disease severity ratings for series ranged from 2.2 for the Ruffles series to 2.7 for the Short Stuff series. The Ruffles series, with a disease severity rating of 2.2 was the best-performing series for tolerance to bacterial leaf and flower spot.

Week 17 incidence and severity for cultivars and series. At week 17 (22 Oct.), all cultivars showed serious disease damage. Disease severity ratings ranged from 3.5 to 6.0. Ten cultivars ('Dreamland Ivory,' 'Dreamland Rose,' 'Dreamland Pink,' 'Dreamland Red,' 'Dreamland Yellow,' 'Peter Pan Cream,' 'Peter Pan Flame,' 'Peter Pan Gold,' 'Peter Pan Plum,' 'Short Stuff Gold') were dead, most likely from a combination of bacterial leaf and flower spot and Alternaria blight. The two cultivars demonstrating the lowest disease severity ratings, 'Ruffles Pink' and 'Pulcino mix,' both with ratings of 3.5, were still far too severely damaged to be acceptable in a landscape situation. Disease severity ratings for series, all of which were judged unacceptable, ranged from 4.3 to 5.8.

DISCUSSION

All three pathogens are known to be seed-borne (Neergaard, 1979; Andersen, 1971; Strider, 1973), but it is impossible to determine the source of the initial inoculants in this study. The spring of 1997 saw abnormally high rainfall, and primary inoculum may have been present in the soil before the experimental crop was planted. Once the crop was in place, plants were quickly attacked by the pathogens. It is safe to postulate that once a pathogen had infected one (or a few) individual host(s), it multiplied rapidly due to environmental conditions conducive to its development, spreading quickly throughout the experimental crop.

Plants grown from "clean" seed are not immune to infection from nearby plants which are infected with a pathogen when environmental conditions favor disease. Monoculture situations, such as that encountered in this cultivar trial, provide ideal conditions for pathogens to spread because of the close proximity of one host plant to another. Had the crop been divided into several separate, smaller lots or alternated with blocks of non-host plants, rather than clustered together, disease problems may have been limited to isolated plots, rather than widespread throughout the entire crop. It is suggested that further research be conducted in this area. Contractors and gardeners who continue to use zinnia in the landscape should consider using it in small pocket plantings, rather than using the plant in masses.

While all cultivars proved to be susceptible to all three pathogens, it is important to note that the summer of 1997 manifested atypically high disease pressures. Maximum daily relative humidity readings $\geq 95\%$ were recorded for 69 of the 114 days of the study. Heavy dews, which allow all three pathogens to flourish, are likely to have occurred on those dates. There were a greater than normal number of days with significant rainfall ($\geq .254$ cm) for the months of August, September and October, providing more opportunities for pathogens to spread by splashing rain (Figure 1). However, total rainfall for the months of July, August and September was less than normal, possibly stressing plants, allowing them to be more easily invaded by splashing pathogens (Figure 2). October, on the other hand, was much wetter than normal. By the end of the study, more

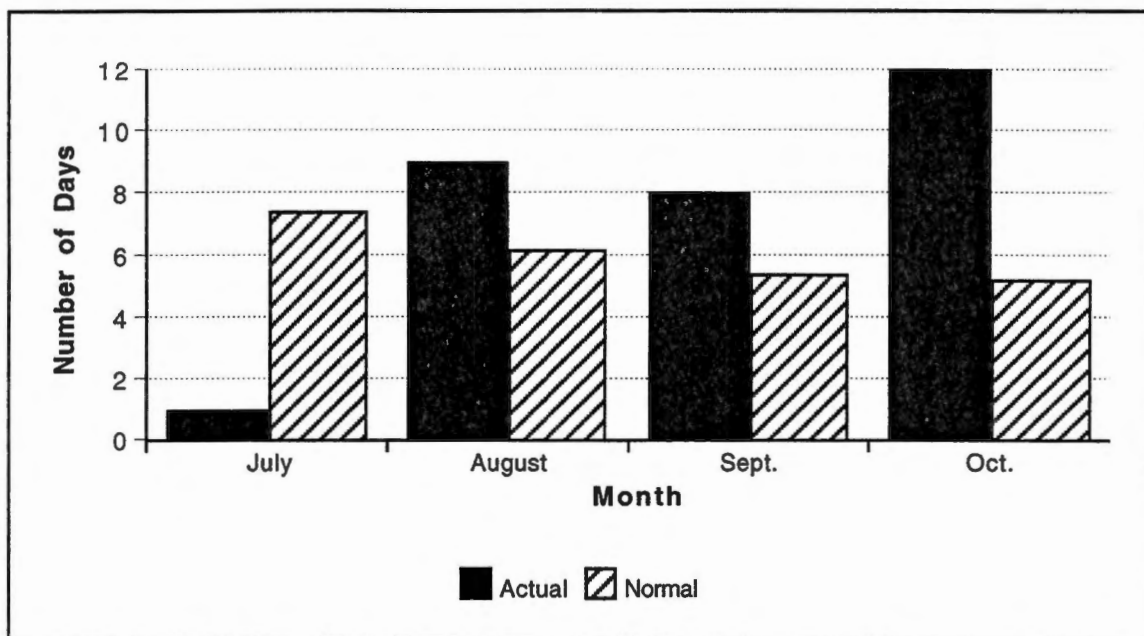


Figure 1. Total number of days with significant rainfall ($\geq .254$ cm) over the period of the experiment. Actual number of days is calculated from measurements taken in the field. Normal number of days were provided by University of Tennessee Department of Plant and Soil Sciences.

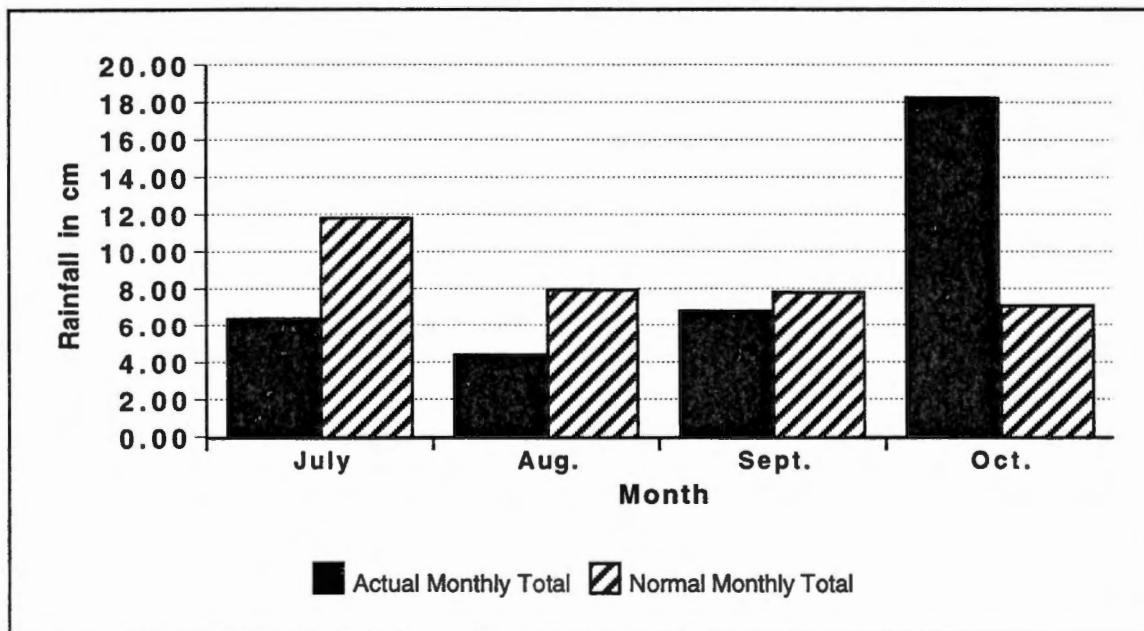


Figure 2. Actual monthly rainfall totals versus normal monthly rainfall totals over the period of the experiment. Actual totals were measured in the field. Normal totals were provided by University of Tennessee Department of Plant and Soil Sciences.

than twice the normal monthly rainfall total had been recorded.

Daily high temperatures for most of the study fell into the optimum range for development of bacterial leaf and flower spot (Jones, 1977) (Figure 3). Additionally, daily low temperatures were below normal for weeks 11–14, falling into the optimal temperature range for powdery mildew development (Powell and Lindquist, 1992).

The time period included by this experiment may have played a role in the incidence and severity of disease encountered in this study. While a normal bedding plant crop would be planted during the first two weeks of May, the plants in this study were not planted until the last week of June, by which time daily high temperatures were high enough to cause significant metabolic stress to the young plants, possibly resulting in higher incidence and severity of disease than might have occurred had the crop been established by this date.

The method in which the seeds were sown may have also played a role in the spread of disease for this experiment. Personal experience among some researchers has shown that direct seeding of zinnia seeds into cell-pack inserts, rather than first sowing them in germination row flats, results in lower incidence of some fungal diseases (M. Albrecht, University of Tennessee Department of Ornamental Horticulture and Landscape Design, Knoxville, Tenn., *personal communication*). Additional research into disease incidence in direct-sown versus transplanted zinnia seedlings is suggested.

In Tennessee, it is common landscape practice to plant warm season annuals such as zinnia in the landscape in early- to mid-May with the expectation that they will flower and remain attractive until late October. This time period, 22 to 24 weeks, is considerably longer than the 17 weeks that this study encompassed. It is not profitable for landscape contractors to replace warm-season annuals in mid-September, and then return to the same site 4 to 8 weeks later in order to replace those plants with cool-season annuals for fall and winter color. None of the cultivars tested in this study proved to be acceptable plants for season-long color in a landscape situation.

However, some of those cultivars which remained resistant to the pathogens for 10 weeks may be acceptable for cut-flower crops. In cut-flower production, plants are

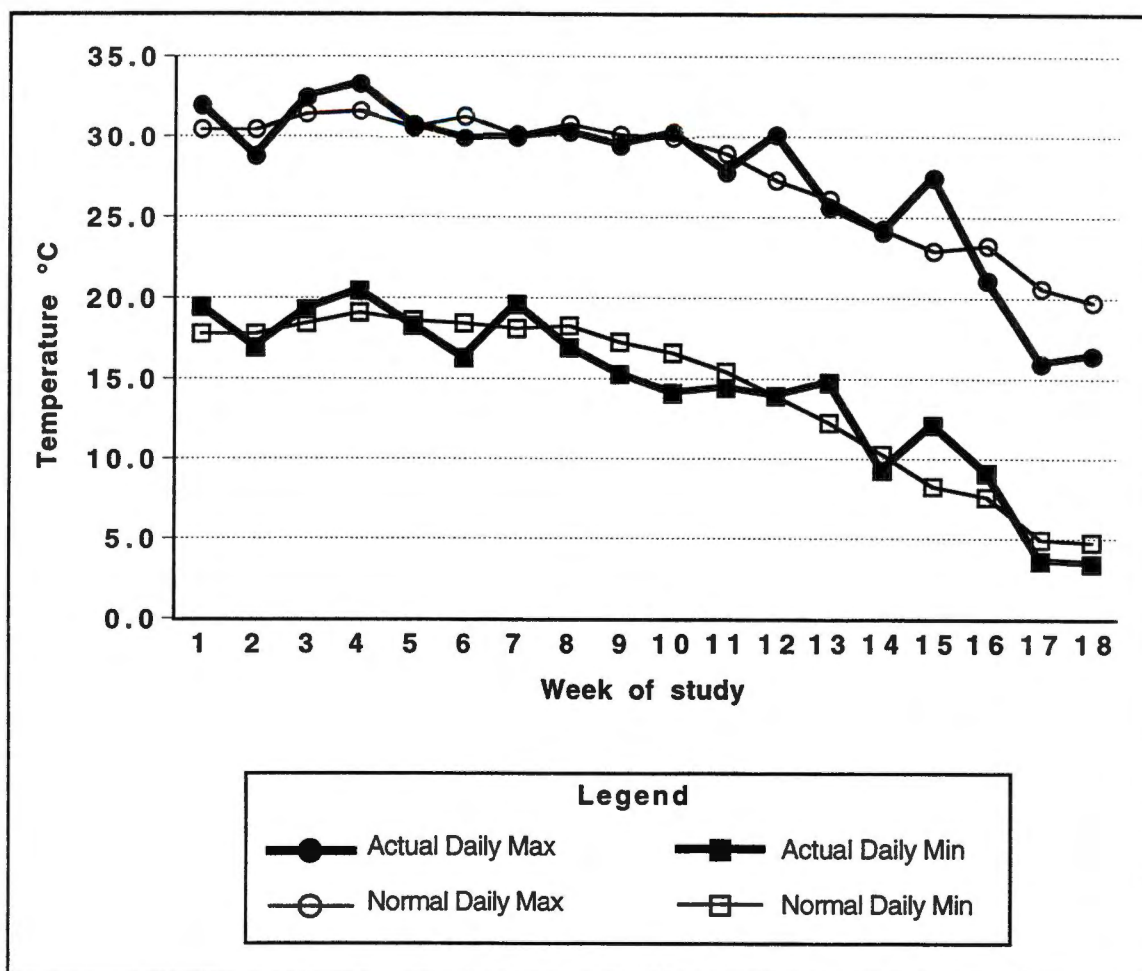


Figure 3. Actual daily minimum and maximum temperatures versus normal daily minimum and maximum temperatures over period of cultivar trial study. Information provided by University of Tennessee Department of Plant and Soil Sciences.

regularly pruned back and new growth is continually emerging. In this scenario, under environmental conditions which do not heavily favor pathogens, growers may be able to produce a salable crop. Of the eleven cultivars judged resistant to all three pathogens at week 10, three were short bedding plant types which would not be suitable for cut-flower production. Five were medium-height cultivars with an average height range of 60–73 cm. These could possibly be used in cut-flower production successfully. The three tall cultivars would be good choices for cut-flower production. It is suggested that further research be conducted in this area.

By week 17, all 57 cultivars tested were found to be susceptible to *Alternaria* blight and bacterial leaf and flower spot. Ten cultivars had been killed by either one or a combination of both pathogens. In the case of these ten cultivars, powdery mildew was never afforded the opportunity to become a problem. For 45 of the remaining 47 cultivars, powdery mildew infection by week 17 was severe. However, two cultivars, 'Peter Pan White' and 'Short Stuff Orange,' demonstrated some resistance to powdery mildew. While it might be tempting to tout the powdery mildew resistance of these two cultivars, it should be noted that both were severely affected by the other two pathogens.

Because many growers and homeowners alike rely on several seed sources, it is impossible to guarantee that any cultivar is safe from contamination by other infected plants. It is therefore recommended that seed producers work to develop pathogen-free seed strains.

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PART 3
PRE-GERMINATION SEED TREATMENT

ABSTRACT

Seventeen cultivars of *Zinnia elegans*, representing six series, were evaluated under greenhouse conditions to determine the effect of eight different pre-germination seed treatments on disease incidence and severity for three diseases: Alternaria blight, bacterial leaf and flower spot, and powdery mildew. Seeds of each cultivar were subjected to eight different treatments prior to sowing. Pre-germination seed treatment was found to have no effect on plant height, number of buds and flowers, or long-term survival of plants. Pre-germination seed treatment did have an effect on germination percentage. Pre-germination seed treatment had no effect on incidence or severity for the three diseases studied as disease was minimal. Cultivar was found to have an effect on powdery mildew incidence and severity and long-term survival of plants.

INTRODUCTION

Zinnia elegans Jacq. has long been an important bedding plant. However, considerable economic loss occurs to growers and landscape contractors using zinnia because of the diseases alternaria blight (*Alternaria zinniae* Pape), powdery mildew (*Erysiphe cichoracearum* DC ex Merat) and bacterial leaf & flower spot [*Xanthomonas campestris* pv. *zinniae* (syn. *X. nigromaculans* f. sp. *zinniae* Hopkins & Dowson)]. Alternaria blight and powdery mildew are two common fungal diseases affecting commercial zinnia production as well as their landscape performance (Terry-Lewandowski and Stimart, 1983). Bacterial leaf & flower spot is also a serious problem in commercial zinnia production (Jones and Strider, 1979).

During warm, rainy or humid weather, these organisms may spread rapidly through an entire crop, leaving plants unsightly and of little ornamental value (Terry-Lewandowski and Stimart, 1983; Stimart et al., 1987; Spooner et al., 1991). Disease problems are so prevalent that many greenhouse growers will no longer produce this once-popular bedding plant and landscape contractors no longer select it for landscape use.

While the epidemiology of these three pathogens has been extensively studied, relatively little research has been done to determine if treatment of seed prior to sowing has an affect on susceptibility of zinnia to the three pathogens discussed. The overall

objective of this research was to determine if pre-germination seed treatment can affect the development and suppression of three pathogens: *Alternaria zinniae*, *Erysiphe cichoracearum*, and *Xanthomonas campestris* pv. *zinniae* on the bedding plant and cutflower, *Zinnia elegans*.

MATERIALS AND METHODS

Plant Materials and Culture

Seed from seventeen cultivars of *Zinnia elegans* were obtained from various commercial seed suppliers in the spring of 1997 (Table 1). Twenty seeds of each cultivar were subjected to one of eight treatments and sown directly into standard 16.5 cm diameter (1180 ml) (Dillen Products, Middlefield, Ohio) plastic pots containing soilless growing medium (Pro-Mix BX, Premier Horticulture, Inc., Red Hill, Pa.) on 13 and 14 Aug. 1997.

When seedlings had produced their second to third sets of true leaves (23 days after sowing, 6 Sept.), they were pinched to two nodes. Plants were grown in a University of Tennessee bedding plant greenhouse where temperatures averaged 20.0°C night and 29.5°C day and relative humidity was 55-60%.

Plants were irrigated with a hose and water breaker and fertilized using Peter's™ water-soluble fertilizer 15N-7.0P-14.1K (Scotts-Sierra Horticultural Products Company, Marysville, Ohio) at each irrigation. Fertilizer was applied at 200 mg·liter⁻¹ from when plants had produced their first sets of true leaves through the duration of the study.

The study ended on 8 Oct. 1997, when the plants in the study were considered to be in marketable condition (54 days after seeds were sown). "Marketable condition" was defined as the date when approximately half the buds on the plants in the greenhouse crop were open and plants would therefore be more likely to be purchased by consumers of bedding plants at a typical garden center.

Table 1. Cultivars of *Zinnia elegans* used in pre-germination seed treatment study and their sources.

Cultivar name	Source
Dreamland Series	
Pink	Ball ¹
Red	Ball
Yellow	Park ²
Giant Dahlia Bluepoint Series	
Bright Pink	Benary ³
Golden Dawn	Benary
Meteor	Benary
Oklahoma Series	
Golden Yellow	Benary
Pink	Benary
Scarlet	Benary
Peter Pan Series	
Gold	Goldsmith ⁴
Pink	Goldsmith
Plum	Goldsmith
Short Stuff Series	
Coral	Goldsmith
Gold	Goldsmith
Scarlet	Goldsmith
Small World Series	
Cherry	Vaughans ⁵
Pink	Vaughan's

¹ Ball Seed Co., West Chicago, Illinois.

² Park Seed Co., Greenwood, South Carolina.

³ Ernst Benary, Hann, Germany.

⁴ Goldsmith Seeds, Inc., Gilroy, California.

⁵ Vaughan's Seed Co., Downers Grove, Illinois.

Experimental Design

The experimental design for this study was a modified completely randomized design. Plants were divided into two height categories: tall cutflower types (over 70 cm), and short types (less than 70 cm) (Table 2). Plants were placed randomly on greenhouse benches within their respective height categories. There were four repetitions of eight treatments. Each repetition consisted of one 16.5 cm pot containing five directly sown seeds. Plants in the "short" height group were spaced on 26.1 cm centers, while those in the "tall" height group were spaced on 30.5 cm centers.

Treatments

1. *Control*. Seeds were sown directly into pots without being subjected to any treatment.

2. *Bleach*. Seeds were soaked for 30 minutes in a 25% bleach solution (Clorox Company, Oakland, Calif.) (1.30% sodium hypochlorite) prior to planting.

Table 2. Height categorization of *Zinnia elegans* cultivars used in pre-germination seed treatment study.

Series name	Average height (cm)	Height category
Short Stuff Series	22.9	Short
Dreamland Series	26.7	Short
Peter Pan Series	27.9	Short
Small World Series	40.6	Short
Oklahoma Series	88.9	Tall
Giant Dahlia Bluepoint Series	114.3	Tall

3. *Triathlon* (Olympic Horticultural Products, Mainland, Pa.) [n-alkyl (60% C14, 30% C16, 5% C12, 5% C18) dimethyl benzyl ammonium chlorides; n-alkyl (50% C12, 30% C14, 17% C16, 3% C18) dimethyl ethylbenzyl ammonium chlorides; n-alkyl (50% C12, 30% C14, 17% C16, 3% C18) dimethyl benzyl ammonium chlorides]. Seeds were soaked for five minutes in a solution of 4 ml Triathlon per liter of water prior to planting. The concentration of Triathlon used in this study was mixed as specified in the label instructions for seed treatment.

4. *Hot Water*. Seeds were soaked for 30 minutes in distilled water which was heated to 51.7°C prior.

5. *Thiram* (Gustafson, Inc., Plano, Texas) [Tetramethylthiuram disulfide (50%)]. Seeds were placed into a plastic resealable sandwich bag along with a small amount (approximately 2.0 g) of thiram powder. The bag was sealed and shaken. The bag was then allowed to sit for approximately five minutes, allowing the dust to settle. Seeds were then removed and immediately sown in pots.

6. *RootShield* (BioWorks, Inc., Geneva, N.Y.) (*Trichoderma harzianum* Rifai strain T-22). Seeds were placed into a plastic resealable sandwich bag along with a small amount (approximately 2.0 g) of RootShield powder. The bag was sealed and shaken. The bag was then allowed to sit for approximately five minutes, allowing the dust to settle. Seeds were then removed and immediately sown in pots.

7. *Kodiak* (Gustafson, Inc., Plano, Texas) (*Bacillus subtilis* (Ehrenberg) Cohn. isolate GBO3). Seeds were placed into a plastic resealable sandwich bag along with a small amount (approximately 2.0 g) of Kodiak powder. The bag was sealed and shaken. The bag was then allowed to sit for approximately five minutes, allowing the dust to settle. Seeds were then removed and immediately sown in pots.

8. *Metalaxyl* (Gustafson, Inc., Plano, Texas) [*N*-(2,6-dimethylphenyl)-*N*-(methoxyacetyl) alanine methyl ester]. Seeds were placed into a plastic resealable sandwich bag along with a small amount (approximately 2.0 g) of metalaxyl powder. The bag was sealed and shaken. The bag was allowed to sit for approximately five minutes, allowing the dust to settle. Seeds were then removed and immediately sown in pots.

Data Collected

Vegetative and flowering data. Data on germination rate were taken, as well as data on number of surviving plants at the end of the study (when compared to the number which had germinated) to determine treatment effect on germination and long-term plant survival.

Plant height and number of buds and flowers were recorded at the end of the study to determine treatment effect on plant growth and flower production. Vegetative and flowering data were analyzed using mixed model analysis of variance (SAS Inst., Cary, N.C.). The model tested the factorial effects of cultivars and treatments and had repeated measures over weeks. Least square means were calculated and compared using Least Significant Difference mean separation. Disease ratings that were not normally distributed were tested using Chi-square analysis.

Disease data. Plants were evaluated at weekly intervals for 3 weeks beginning on 24 Sept. 1997, for incidence and severity of disease as these factors pertained to *Alternaria* blight, powdery mildew and bacterial leaf and flower spot. The following disease severity rating scale was used:

- 0.0 = no disease apparent
- 1.0 = $\leq$ 2% affected by disease
- 2.0 = $\leq$ 10% affected by disease
- 3.0 = $\leq$ 25% affected by disease
- 4.0 = $\leq$ 50% affected by disease
- 5.0 = $>$ 50% affected by disease
- 6.0 = plant dead (killed by disease).

Disease data were analyzed using mixed model analysis of variance (SAS Inst., Cary, N.C.). The model tested the factorial effects of cultivars and treatments and had repeated measures over weeks. Least square means were calculated and compared using Least Significant Difference mean separation. Disease ratings that were not normally distributed were tested using Chi-square analysis.

The statistical mean for the foliage damage rating for each cultivar was used to determine its susceptibility to each of the three pathogens. Cultivars having a mean disease severity rating ≤ 2.0 ($\leq 10\%$ of plant foliage showing signs and/or symptoms of

disease) were judged acceptable as greenhouse crop specimens. Those cultivars having a mean foliage damage rating >2 were judged unacceptable as greenhouse crop specimens.

RESULTS

Vegetative and Flowering Response

Height. There was no significant difference among treatments regarding height of plants at the end of the study.

Number of buds and flowers. Significant differences were found among cultivars and treatments for number of buds and flowers. However, there were interactions between cultivars and treatments, but none were consistent within series or cultivars. They were therefore interpreted to be of no practical importance.

Germination percentage. Significant differences in germination percentage were found among cultivars and among treatments (Appendix A). Statistical analysis showed that not all cultivars responded to pre-germination seed treatment in the same manner. Some cultivars were affected to a greater or lesser extent than other cultivars for any given treatment.

- Control. Mean germination percentage for plants receiving no pre-germination seed treatment was 90.3%. This number varied with cultivar and ranged from a low of 80.0% for 'Giant Dahlia Bluepoint Golden Dawn,' 'Oklahoma Pink' and 'Peter Pan Gold;' to a high of 100% for 'Peter Pan Pink,' 'Peter Pan Plum' and 'Short Stuff Gold.'

- Bleach. Mean percent germination was significantly lower than the control for plants which received the bleach treatment. Mean germination for plants receiving the bleach treatment was 74.0% although germination rate varied widely among cultivars. Germination rate for plants receiving this treatment ranged from 40.0% for 'Dreamland Yellow' to 100% for 'Dreamland Pink.' Eight of the seventeen cultivars had a significant drop in germination rate when compared with the control. These included 'Giant Dahlia Bluepoint Bright Pink,' 'Giant Dahlia Bluepoint Golden Dawn,' 'Small World Cherry,' 'Dreamland Yellow,' 'Peter Pan Pink,' 'Peter Pan Plum,' 'Short Stuff Coral' and 'Short Stuff

Scarlet.' Nine cultivars had no significant difference from the control.

- Triathlon. Mean percent germination was not significantly different from the control for plants receiving the Triathlon treatment. Mean germination rate for plants receiving Triathlon treatment was 87.1% although germination rate varied among cultivars. Germination rate for plants receiving this treatment ranged from 65.0% for 'Small World Cherry' to 100% for 'Peter Pan Gold' and 'Short Stuff Coral.'

- Hot Water. Mean percent germination was significantly lower than the control for plants receiving hot water treatment. Mean germination rate for plants receiving hot water treatment was 79.1% although germination rate varied among cultivars. Germination rate for plants receiving this treatment ranged from 40.0% for 'Small World Cherry' to 95.0% for 'Dreamland Red,' 'Peter Pan Gold' and 'Peter Pan Pink.' Three cultivars had a significant drop in germination rate compared to the control. Germination for 'Giant Dahlia Bluepoint Meteor' was 55.0% for hot water-treated plants, compared to 90.0% for the control. 'Short Stuff Gold' had a germination rate of 100% for control plants, compared to 75.0% for those receiving hot water treatment. 'Small World Cherry' had a larger drop: germination rate of 40.0% for plants treated with hot water, while germination rate for the control was 85.0%.

- Thiram. Mean percent germination was not significantly different from the control for plants receiving thiram treatment. Mean percent germination for plants receiving thiram treatment was 90.3% although germination rate varied among cultivars. Germination rate for plants receiving this treatment ranged from 75.0% for 'Giant Dahlia Bluepoint Meteor' and 'Small World Cherry' to 100% for 'Peter Pan Gold,' 'Peter Pan Pink' and 'Short Stuff Scarlet.'

- RootShield. Mean percent germination was not significantly different from the control for plants receiving RootShield treatment. Mean germination for plants receiving RootShield treatment was 92.1% although germination rate varied among cultivars. Germination rate for plants receiving this treatment ranged from 80.0% for 'Giant Dahlia Bluepoint Golden Dawn,' 'Dreamland Yellow' and 'Short Stuff Gold;' to 100% for 'Small World Pink,' 'Dreamland Pink,' 'Peter Pan Gold,' 'Peter Pan Pink' and 'Peter Pan Plum.'

- Kodiak. Mean percent germination was significantly lower than the control for plants receiving Kodiak treatment. Mean germination for plants receiving Kodiak treatment

was 80.9% although germination rate varied among cultivars. Germination for plants receiving this treatment ranged from 55.0% for 'Giant Dahlia Bluepoint Bright Pink' and 'Oklahoma Scarlet,' to 95.0% for 'Oklahoma Pink' 'Dreamland Pink,' 'Dreamland Red,' 'Peter Pan Gold,' 'Peter Pan Pink,' and 'Short Stuff Scarlet.' Four cultivars experienced a significant drop in germination percentage when subjected to treatment with Kodiak. Germination rate for 'Giant Dahlia Bluepoint Bright Pink' and 'Oklahoma Scarlet' was 55.0% for treated plants, compared to 85.0% and 95.0%, respectively, for control plants. 'Dreamland Yellow' had a 65.0% germination rate for Kodiak treated plants versus 90.0% for control plants. Germination rate for 'Short Stuff Coral' was 65.0% for plants receiving treatment with Kodiak, compared to 95.0% in control plants.

- Metalaxyl. Mean percent germination was significantly lower than the control for plants receiving metalaxyl treatment. Mean germination for plants receiving this treatment was 83.8% although germination rate varied among cultivars. Germination for plants receiving metalaxyl treatment ranged from 45.0% for 'Giant Dahlia Bluepoint Bright Pink' to 100% for 'Peter Pan Gold.' Two cultivars treated with metalaxyl had a significant drop in germination percentage compared to the control. For 'Giant Dahlia Bluepoint Bright Pink,' plants treated with metalaxyl had a germination rate of 45.0%, compared with the control which had an 85.0% germination rate. Germination rate for 'Giant Dahlia Bluepoint Meteor' was 65.0% for treated plants, versus 90.0% for control plants.

Long-Term Survival. No significant differences among treatments were found in the number of plants which survived throughout the duration of the study. However, significant differences in the number of plants which survived throughout the duration of the study were found among cultivars (Table 3). Six of seventeen cultivars experienced 100% survival rate throughout the study across all treatments. These were 'Peter Pan Gold,' 'Short Stuff Scarlet,' 'Small World Pink,' 'Short Stuff Gold,' 'Dreamland Pink,' and 'Dreamland Red.' Survival rates for the remaining eleven cultivars in the study ranged from 99.4% for 'Small World Cherry,' to 72.8% for 'Oklahoma Scarlet.'

Table 3. Long-term survival^Z percentages of 17 cultivars of *Zinnia elegans* for all treatments, plus mean. LSD=20.22. $P \leq 0.05$.

Cultivar	Control	Bleach	Triathlon	Hot water	Thiram WP	Root Shield	Kodiak	Apron WP	Mean
Giant Dahlia Bluepoint Bright Pink	83.8	97.9	85.4	87.5	93.8	62.5	93.3	100.0	88.0
Giant Dahlia Bluept. Golden Dawn	88.8	87.5	90.0	78.3	86.7	100.0	87.5	85.0	88.0
Giant Dahlia Bluepoint Meteor	88.8	100.0	56.3	91.7	70.8	87.5	82.5	95.0	84.1
Oklahoma Golden Yellow	75.0	69.2	70.8	56.3	76.3	88.8	91.7	80.0	76.0
Oklahoma Pink	93.8	93.8	75.0	85.0	95.0	61.3	62.5	77.5	80.5
Oklahoma Scarlet	85.0	73.8	73.8	67.5	66.3	75.0	79.2	70.0	73.8
Small World Cherry	95.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4
Small World Pink	100.0	95.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4
Dreamland Pink	95.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4
Dreamland Red	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Dreamland Yellow	95.0	100.0	100.0	100.0	100.0	100.0	100.0	95.0	98.8
Peter Pan Gold	100.0	100.0	100.0	100.0	100.0	100.0	100.0	95.0	99.4
Peter Pan Pink	80.0	100.0	90.0	100.0	75.0	100.0	90.0	100.0	91.9
Peter Pan Plum	100.0	100.0	100.0	100.0	95.0	100.0	100.0	95.0	98.8
Short Stuff Coral	100.0	95.0	100.0	95.0	100.0	100.0	100.0	100.0	98.8
Short Stuff Gold	100.0	95.0	100.0	100.0	100.0	100.0	100.0	95.0	98.8
Short Stuff Scarlet	100.0	100.0	95.0	100.0	95.0	100.0	100.0	100.0	98.8

^ZLong-term survival rate based upon number of plants which were alive at end of study compared to number of plants which germinated.

Disease Response

Alternaria Blight. No significant differences were found among cultivars, among treatments or among weeks for incidence or severity of *Alternaria* blight. Minimal disease incidence precluded successful mixed model analysis. Therefore, all cultivars were found to be acceptable greenhouse crop specimens when evaluated for susceptibility to *Alternaria* blight, regardless of treatment.

Bacterial leaf and flower spot. No significant differences were found among cultivars, among treatments or among weeks for incidence or severity of bacterial leaf and flower spot. Minimal disease incidence precluded successful mixed model analysis. Therefore, all cultivars were found to be acceptable greenhouse crop specimens when evaluated for susceptibility to bacterial leaf and flower spot, regardless of treatment.

Powdery mildew. No significant differences were found among treatments regarding incidence of powdery mildew. However, significant differences were found among cultivars for incidence of powdery mildew (Table 4). By the end of the study (8 Oct.), all cultivars showed some incidence of powdery mildew, although incidence varied among cultivars. Incidence ranged from 13.5% for 'Short Stuff Scarlet' to 41.9% for 'Small World Cherry.'

No significant differences were found among treatments for powdery mildew severity. However, significant differences were found among cultivars for severity of powdery mildew (Table 4). Mean disease severity ratings for powdery mildew ranged from 0.2 for 'Short Stuff Scarlet' to 0.5 for 'Small World Cherry.' In spite of the fact that there were significant differences in severity of powdery mildew among cultivars, all cultivars showed disease severity ratings <2.0 and were considered acceptable greenhouse crop specimens throughout the duration of the study when evaluated for susceptibility to powdery mildew.

It was found that interactions occurred for powdery mildew severity between cultivars and evaluation periods during this study. However, in spite of these significant differences, all cultivars showed disease severity ratings <2.0 and were considered acceptable greenhouse crop specimens when evaluated for susceptibility to powdery mildew.

Table 4. Disease incidence and severity ratings for powdery mildew for 17 cultivars of *Zinnia elegans* on 8 Oct. 1997. $P \leq 0.05$.

Cultivar	Disease incidence (%)	Disease severity rating ^{Z,Y}
Giant Dahlia Bluepoint Bright Pink	29.0	0.3 cde
Giant Dahlia Bluepoint Golden Dawn	27.1	0.3 cdef
Giant Dahlia Bluepoint Meteor	16.7	0.2 fg
Oklahoma Golden Yellow	15.6	0.2 g
Oklahoma Pink	22.9	0.2 defg
Oklahoma Scarlet	30.2	0.3 cde
Small World Cherry	41.9	0.5 a
Small World Pink	38.5	0.5 ab
Dreamland Pink	27.8	0.4 bcd
Dreamland Red	34.4	0.4 abc
Dreamland Yellow	13.7	0.2 efg
Peter Pan Gold	16.7	0.2 efg
Peter Pan Pink	25.0	0.3 bcd
Peter Pan Plum	29.2	0.4 bcd
Short Stuff Coral	14.6	0.2 g
Short Stuff Gold	14.6	0.2 g
Short Stuff Scarlet	13.5	0.2 g

^ZDisease severity rating scale: 0.0 = no disease apparent

1.0 = $\leq$ 2% affected by disease

2.0 = $\leq$ 10% affected by disease

3.0 = $\leq$ 25% affected by disease

4.0 = $\leq$ 50% affected by disease

5.0 = $>$ 50% affected by disease

6.0 = plant dead (killed by disease).

^Y Means followed by the same letters are not significantly different using least square means test at $P \leq 0.05$.

DISCUSSION

All three pathogens are known to be seed-borne (Neergaard, 1979; Andersen, 1971; Strider, 1973). However, in this study, disease problems were minimal, probably because environmental conditions did not favor spread of disease and because of the short time period that this study comprised. The method in which the seeds were sown may have played a role in the lack of disease incidence in this experiment. Personal experience among some researchers has shown that direct seeding of zinnia seeds into cell-pack inserts or plastic pots, rather than transplanting from germination row flats, results in lower incidence of some fungal diseases (M. Albrecht, University of Tennessee Department of Ornamental Horticulture and Landscape Design, Knoxville, Tenn., *personal communication*). This study evaluated the crop during greenhouse production only. Therefore, it is recommended that a similar study be done which follows the crop from germination in the greenhouse to frost in the landscape to observe changes in disease incidence and/or severity as the crop continues to mature.

Lower germination rates were expected for some treatments. Franklin and Goodwin (1981) reported success in killing *Alternaria zinniae* with hot water, but also found that germination percentage was adversely affected. This study confirms those findings, with fourteen of the seventeen cultivars tested showing a decrease in germination rate, however small. (While a statistically significant drop in germination rate occurred in only three cultivars, a drop of as little as 5.0%, which was not considered statistically significant in this study, would most likely be significant to growers.) In the case of 'Small World Cherry,' which showed the largest drop, hot water treated plants had a 40.0% germination rate, compared to 85.0% for control plants.

On the other hand, an unexpected decrease in germination rates was experienced with some treatments. While Strider (1979b) reported that soaking seeds in 20% Clorox™ solution (1.04% sodium hypochlorite) eradicated *X. campestris* pv. *zinniae* without significant loss in germination rate, this study found that a 25% Clorox™ solution (1.30% sodium hypochlorite) resulted in decreased germination rates for twelve of the seventeen cultivars tested. Although not all of these decreases in germination rate were statistically

significant, they would probably be of interest to growers. For 'Dreamland Yellow,' the most dramatic example, germination dropped from 90.0% in the control, to 40.0% for plants receiving the bleach treatment.

Wu and Yang (1992) reported increased germination from infected seeds treated with *Bacillus* sp. strains. However, in this study, Kodiak (*Bacillus subtilis* GB03) had a detrimental effect on germination rate, with thirteen cultivars showing a drop in germination rate. While only four cultivars showed a statistically significant drop in germination percentage, a 5.0% decrease in germination rate, which was not considered statistically significant in this study, would be significant to most growers. For 'Oklahoma Scarlet,' which showed the largest decrease in germination rate, plants treated with Kodiak had 55.0% germination, compared with 95.0% germination for the control.

Metalaxyl, a systemic fungicide commonly used as a seed dressing, also had a detrimental affect on germination rate, with eleven cultivars showing a decrease in germination rate when subjected to this treatment. Again, while only two cultivars showed statistically significant drops in germination rate, growers would most likely consider even a small decrease in germination rate significant. The most dramatic example of this was seen in 'Giant Dahlia Bluepoint Pink.' Control plants for this cultivar had 85.0% germination, while those treated with metalaxyl had a germination rate of 45.0%.

Eight cultivars showed an increased germination rate when treated with Rootshield. While these increases were not considered significant in the statistical analysis, increases in germination rate for these cultivars ranged from 5.0–20.0%. Windham, et al. (1986) reported increased germination of tomato and tobacco seeds when germination medium was inoculated with various *Trichoderma* spp. isolates. It should also be noted that four cultivars in this study showed a decrease in germination rate with the Rootshield treatment (a 20.0% decrease in the case of 'Short Stuff Gold'), and five cultivars showed no change in germination rate. Further investigation in this area is recommended to determine if Rootshield could be used as a reliable germination stimulation agent for zinnia.

There were significant differences in long-term survival among cultivars. This can be largely attributed to plant height. Plants in the "short" series (Small World, Dreamland,

Peter Pan and Short Stuff) generally had survival rates $\geq 95.0\%$. The exception to this was 'Peter Pan Pink,' which had survival rates ranging from 75.0% to 100.0%, depending upon treatment. It is not known why this cultivar had higher than normal mortality rates during the study.

On the other hand, plants in the "tall" series (Giant Dahlia Bluepoint and Oklahoma) had survival rates ranging from 56.3% to 100.0%. It is suspected that this was not a function of treatment or even cultivar, but rather, the result of plants being too tall and top-heavy to remain upright. Zinnias grow very quickly, and these cultivars were approaching their maximum height by the end of the study. Plants simply fell over and broke, often taking several other plants with them in a sort of "domino effect." It was determined that these series are not suitable for greenhouse pot culture because of their excessive height.

Neergaard (1979) reported that zinnia seedlings infected with *Alternaria zinniae* may mask symptoms until plants reach flowering stage, at which time severe disease symptoms may appear. Stider (1979a) reported a similar feature of *Xanthomonas campestris* pv. *zinniae*, in which cotyledons of infected seedlings may die and fall off, leaving apparently healthy seedlings to grow on. While the pathogen may not be apparent, it is still present and when disease conditions are right, the disease may suddenly reappear and become rampant. Neither of these scenarios was observed in this study, as evidenced by the high survival rates for the short cultivars and the general absence of disease throughout the experimental greenhouse crop.

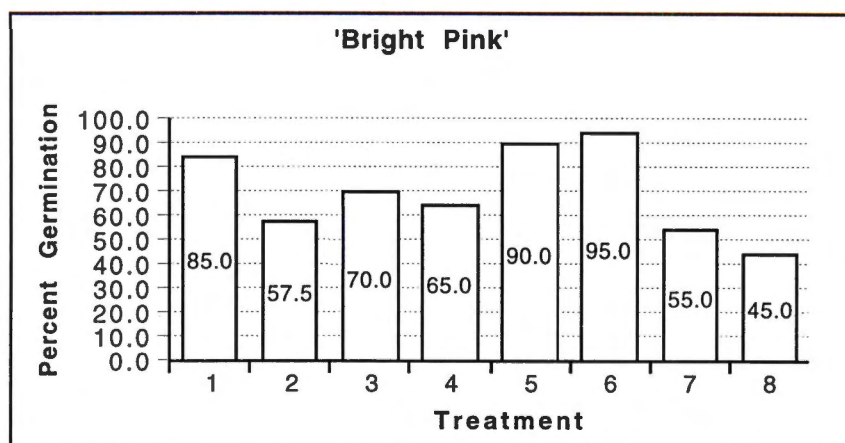
This study suggests that for short-term, greenhouse zinnia production, pre-germination seed treatment does not appear to be worth the extra time and expense to growers.

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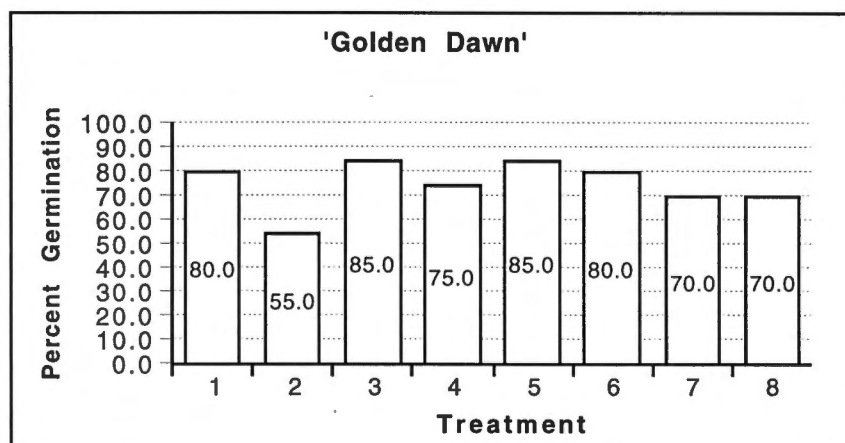
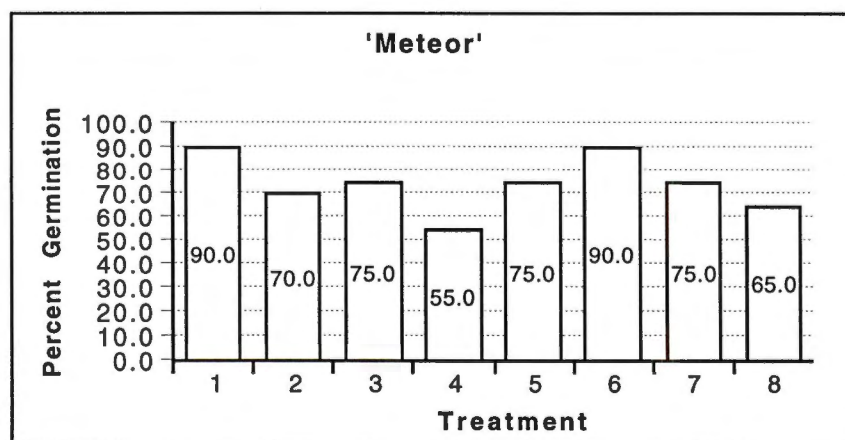
APPENDIX

GIANT DAHLIA BLUEPOINT SERIES PERCENT GERMINATION



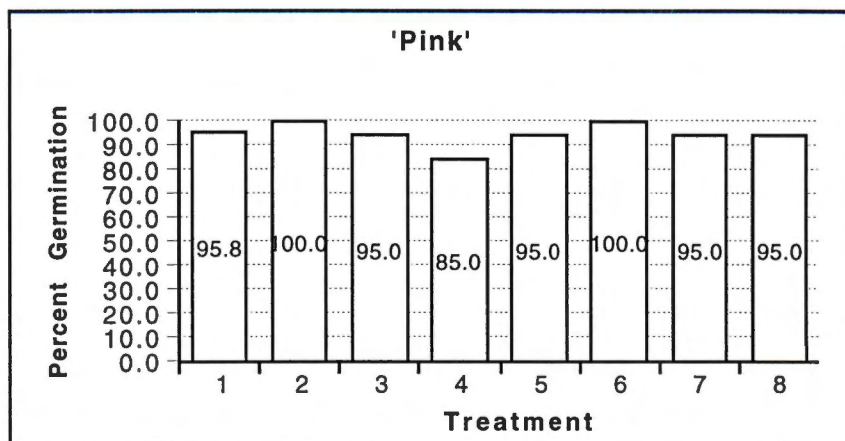
Treatments

1. Control
2. Bleach
3. Triathlon
4. Hot Water
5. Thiram WP
6. RootShield
7. Kodiak
8. Apron WP

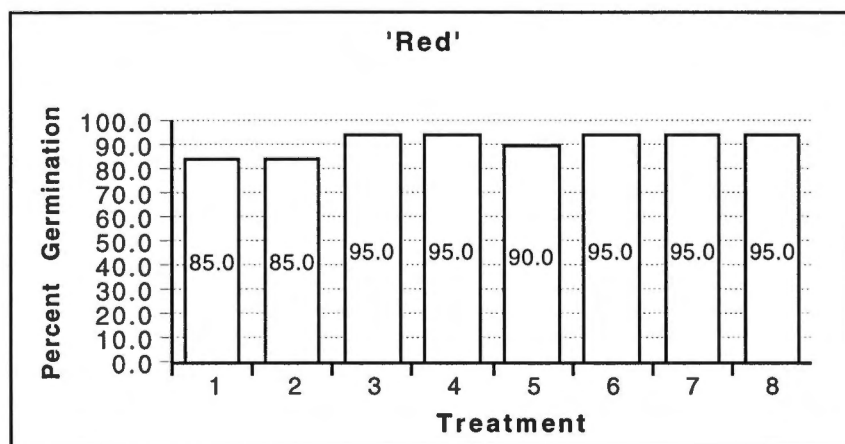
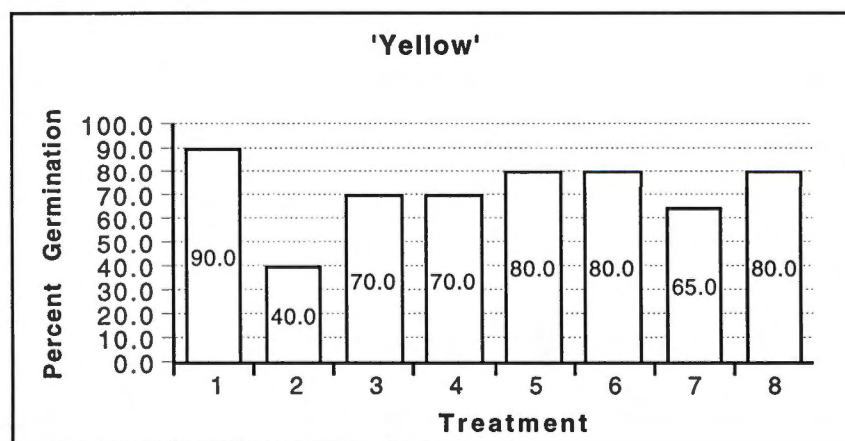


Appendix A. The effect of pre-germination seed treatments on germination rate for *Zinnia elegans* cultivars. LSD = 16.17. $P \leq 0.05$.

DREAMLAND SERIES PERCENT GERMINATION

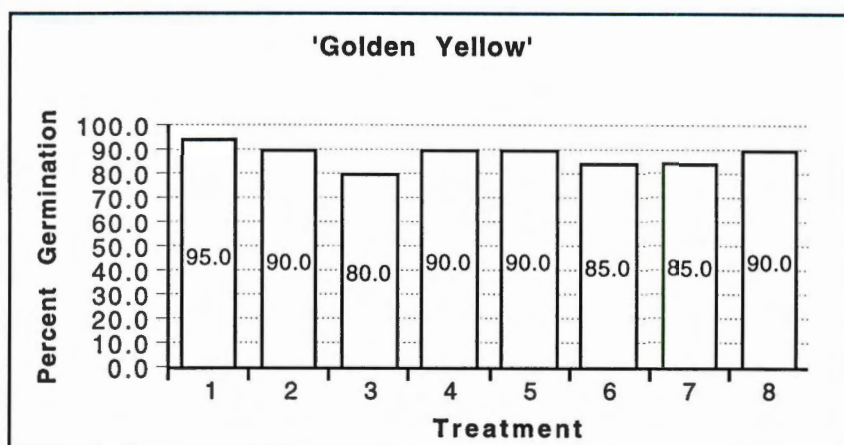
**Treatments**

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4. Hot Water
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6. RootShield
7. Kodiak
8. Apron WP

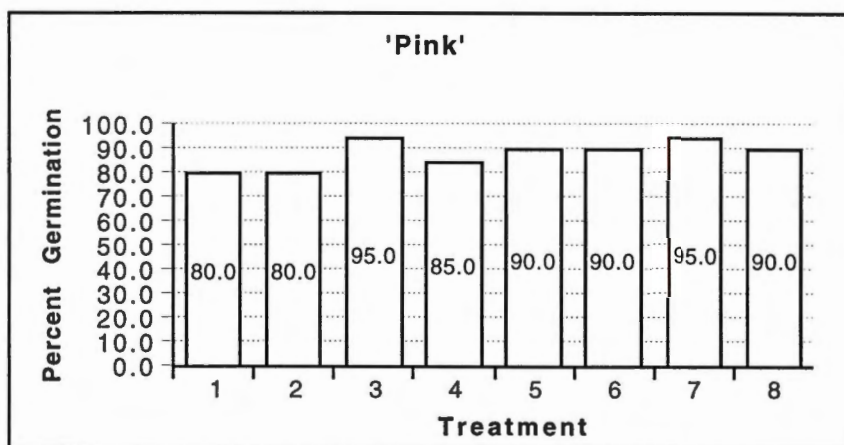
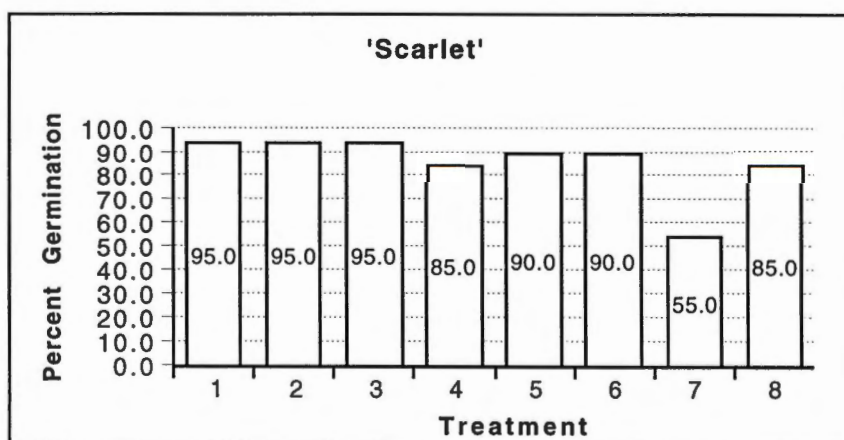


Appendix A. The effect of pre-germination seed treatments on germination rate for *Zinnia elegans* cultivars, continued. LSD = 16.17. $P \leq 0.05$.

OKLAHOMA SERIES PERCENT GERMINATION

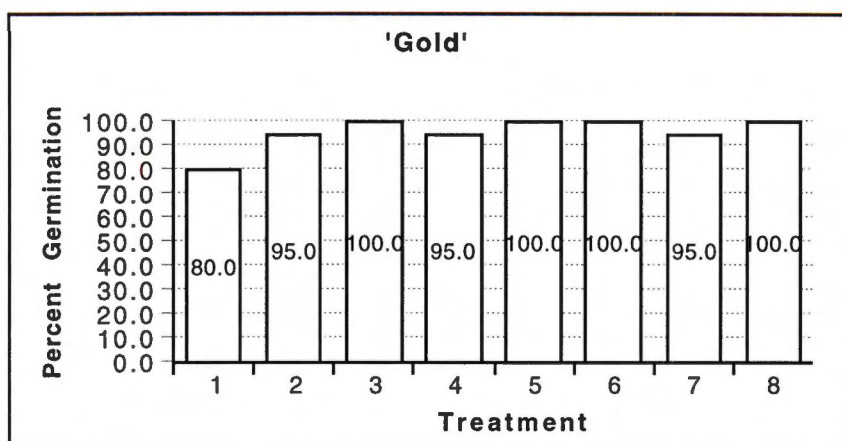
**Treatments**

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2. Bleach
3. Triathlon
4. Hot Water
5. Thiram WP
6. RootShield
7. Kodiak
8. Apron WP



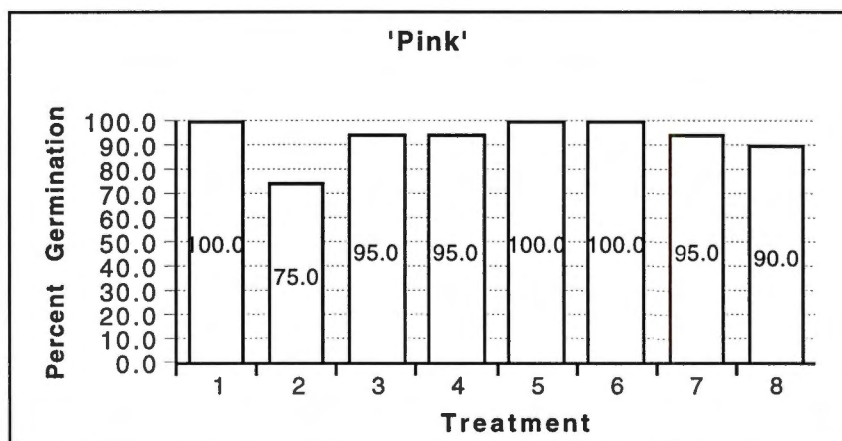
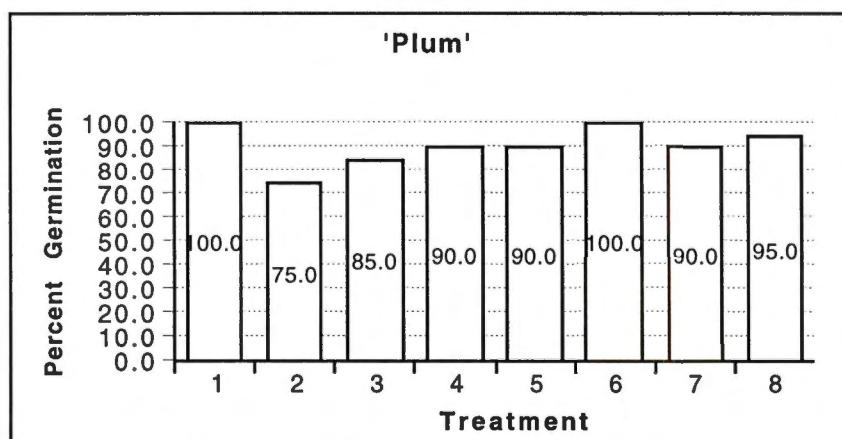
Appendix A. The effect of pre-germination seed treatments on germination rate for *Zinnia elegans* cultivars, continued. LSD = 16.17. $P \leq 0.05$.

PETER PAN SERIES PERCENT GERMINATION



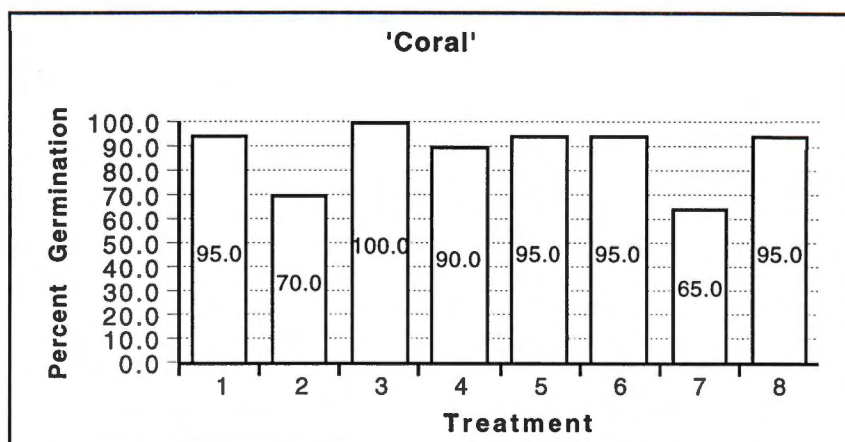
Treatments

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2. Bleach
3. Triathlon
4. Hot Water
5. Thiram WP
6. RootShield
7. Kodiak
8. Apron WP



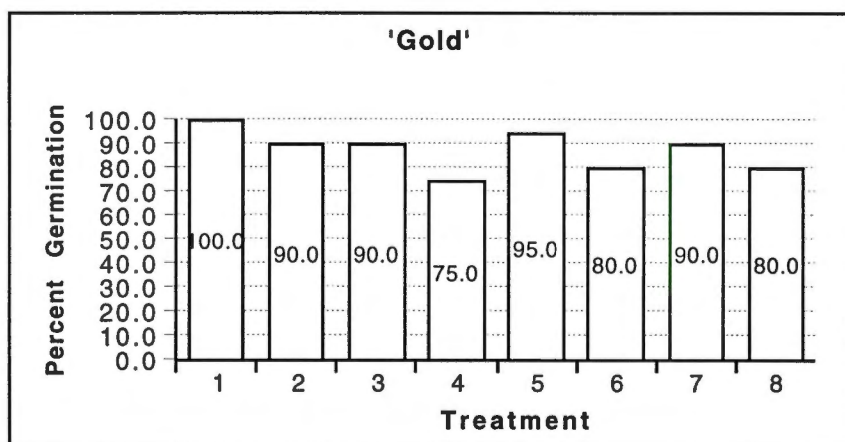
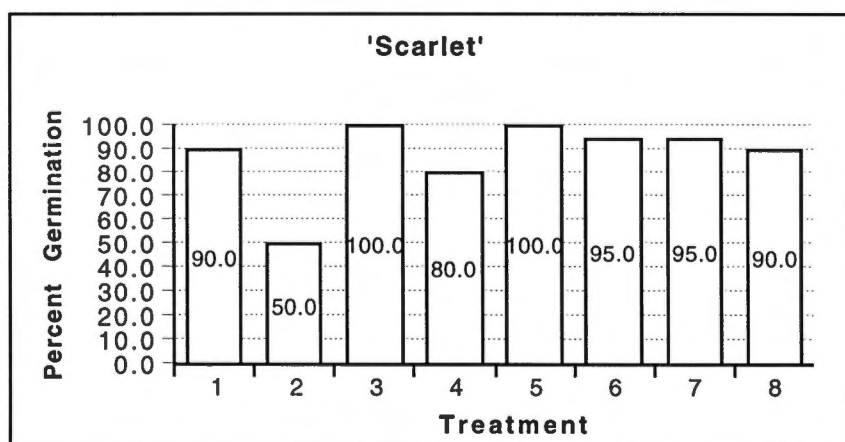
Appendix A. The effect of pre-germination seed treatments on germination rate for *Zinnia elegans* cultivars, continued. LSD = 16.17. $P \leq 0.05$.

SHORT STUFF SERIES PERCENT GERMINATION



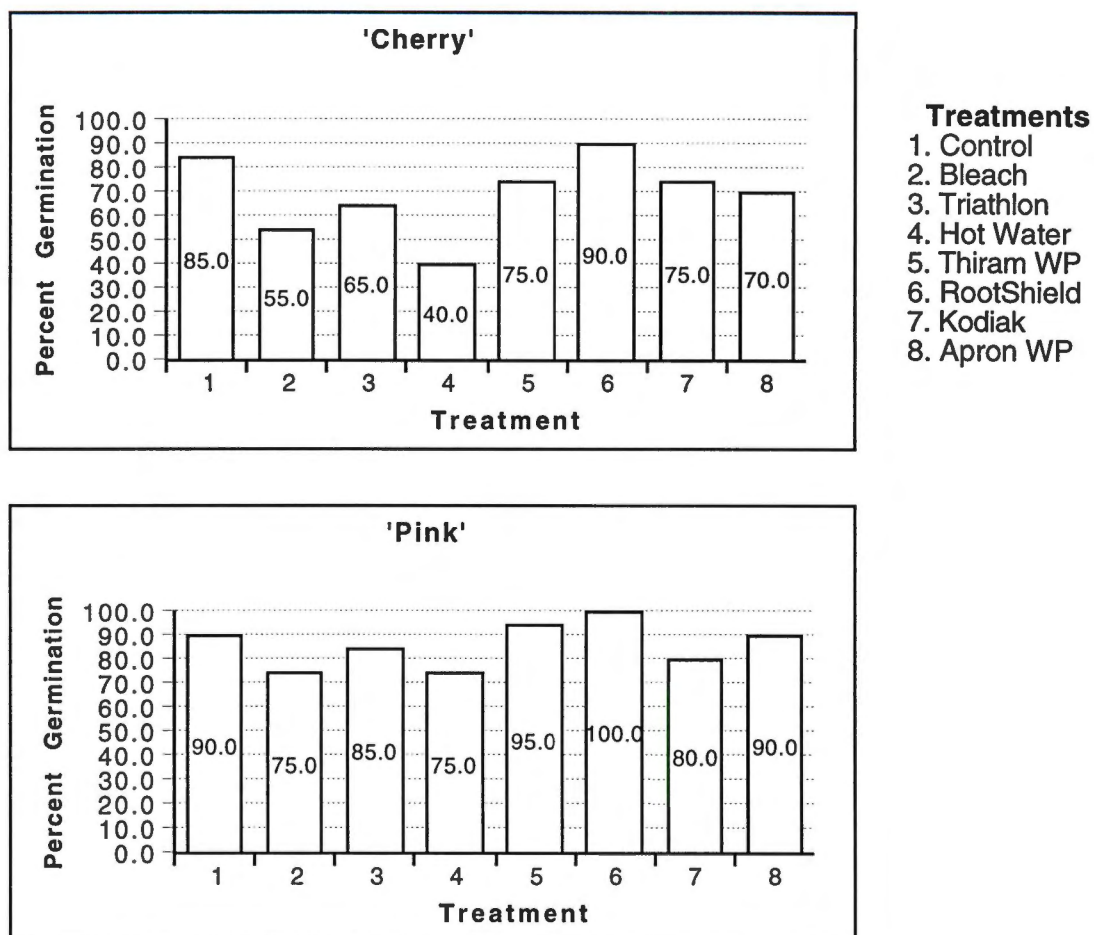
Treatments

1. Control
2. Bleach
3. Triathlon
4. Hot Water
5. Thiram WP
6. RootShield
7. Kodiak
8. Apron WP



Appendix A. The effect of pre-germination seed treatments on germination rate for *Zinnia elegans* cultivars, continued. LSD = 16.17. $P \leq 0.05$.

SMALL WORLD SERIES PERCENT GERMINATION



Appendix A. The effect of pre-germination seed treatments on germination rate for *Zinnia elegans* cultivars, continued. LSD = 16.17. $P \leq 0.05$.

PART 4
FIELD IRRIGATION PRACTICES

ABSTRACT

Seventeen cultivars of *Zinnia elegans*, representing six series, were evaluated under three different irrigation treatments to determine the effect of field irrigation method on disease incidence and severity for three diseases: Alternaria blight, bacterial leaf and flower spot, and powdery mildew. Each cultivar was grown under overhead irrigation, drip irrigation and natural rainfall. A disease severity scale was developed and plants were judged for acceptability/unacceptability based upon this scale. It was found that regardless of irrigation method, all cultivars were rendered unacceptable in the landscape by either Alternaria blight and/or bacterial leaf and flower spot by week 6 of the study. While watering regime had little consequence in disease severity, overhead irrigation produced greater disease severity than drip irrigation or the control for Alternaria blight and bacterial leaf and flower spot. For powdery mildew, drip irrigation produced greater disease severity than overhead irrigation or the control.

INTRODUCTION

Zinnia elegans Jacq. has long been an important bedding plant. However, considerable economic loss occurs to growers and landscape contractors using zinnia because of the diseases alternaria blight (*Alternaria zinniae* Pape), powdery mildew (*Erysiphe cichoracearum* DC ex Merat) and bacterial leaf & flower spot [*Xanthomonas campestris* pv. *zinniae* (syn. *X. nigromaculans* f. sp. *zinniae* Hopkins & Dowson)]. Alternaria blight and powdery mildew are two common fungal diseases affecting commercial zinnia production as well as their landscape performance (Terry-Lewandowski and Stimart, 1983). Bacterial leaf & flower spot is also a serious problem in commercial zinnia production (Jones and Strider, 1979).

During warm, rainy or humid weather, these organisms may spread rapidly through an entire crop, leaving plants unsightly and of little ornamental value. Disease problems are so prevalent that many greenhouse growers will no longer produce this once-popular bedding plant and landscape contractors no longer select it for landscape use (Terry-

Lewandowski and Stimart, 1983; Stimart et al., 1987; Spooner et al., 1991).

While the epidemiology of these pathogens has been extensively studied, relatively little research has been done to determine what cultural practices, if any, reduce the incidence of these pathogens on *Z. elegans*. The overall objective of this study was to determine whether irrigation practices in the landscape can affect the development and suppression of three pathogens: *Alternaria zinniae*, *Erysiphe cichoracearum*, and *Xanthomonas campestris* pv. *zinniae* on the bedding plant and cutflower, *Zinnia elegans*.

MATERIALS AND METHODS

Plant Materials and Culture

Seed from seventeen cultivars of *Zinnia elegans* were obtained from various commercial seed suppliers in the spring of 1997 (Table 1). Seeds were sown on 5 June 1997 in germination row-type flats (TLC Polyform, Plymouth, Minn.) in a commercial germination mix (Berger's BM2 Germination Mix, Que., Canada) and placed under intermittent mist on benches in the University of Tennessee propagation greenhouse. Seed flats were placed on bench bottom heat, at temperatures of 18.0°C nights, 26.7°C days, and a relative humidity of 70%.

When seedlings had produced their first set of true leaves (17 and 18 June), they were transplanted into 17 ml, 1803 cell-pack inserts (T.O. Plastics, Minneapolis, Minn.) containing a soilless bedding plant growing medium (Pro-Mix BX, Premier Horticulture, Inc., Red Hill, Pa.). Plants were grown in a University of Tennessee bedding plant greenhouse where temperatures averaged 18.0°C night and 26.7°C day and relative humidity was 60-65%.

Plants were irrigated with a hose and water breaker and fertilized using Peter's™ water-soluble fertilizer 15.0N–7.0P–14.1K (Scotts-Sierra Horticultural Products Company, Maysville, Ohio) at each irrigation. Fertilizer was applied at 200 mg·liter⁻¹ from first transplant date until plants were transplanted into the field.

On July 3–4, when plants had produced several sets of true leaves, they were pinched to two nodes and transplanted into experimental field plots for the duration of the

Table 1. Cultivars of *Zinnia elegans* used in irrigation study and their sources.

Cultivar name	Source
Dreamland Series	
Pink	Ball ¹
Red	Ball
Yellow	Park ²
Giant Dahlia Bluepoint Series	
Bright Pink	Benary ³
Golden Dawn	Benary
Meteor	Benary
Oklahoma Series	
Golden Yellow	Benary
Pink	Benary
Scarlet	Benary
Peter Pan Series	
Gold	Goldsmith ⁴
Pink	Goldsmith
Plum	Goldsmith
Short Stuff Series	
Coral	Goldsmith
Gold	Goldsmith
Scarlet	Goldsmith
Small World Series	
Cherry	Vaughans ⁵
Pink	Vaughan's

¹ Ball Seed Co., West Chicago, Illinois.² Park Seed Co., Greenwood, South Carolina.³ Ernst Benary, Hann, Germany.⁴ Goldsmith Seeds, Inc., Gilroy, California.⁵ Vaughan's Seed Co., Downers Grove, Illinois.

experiment. Once in the field, plants were fertilized one time with approximately 13 ml ammonium nitrate (34N–0P–0K) (Cloud #9 Enterprises, Mooresburg, Tenn.) which was watered in with hand-administered overhead irrigation to prevent volatilization and allowed to grow with only the supplemental irrigation treatments as dictated by the experimental design.

Experimental Design

The experimental design for this study was a split plot randomized complete block with three irrigation methods as treatments. There were four replications within each treatment. A replication consisted of 12 plants of the same cultivar. Plants were divided into two height categories: tall cutflower types (70 cm or taller), and short-medium height types (under 70 cm) (Table 2). This was done to eliminate skewed data due to a short cultivar being “shaded” by an adjacent tall cultivar. The three irrigation treatments were: (1) overhead sprinkler, administered as needed; (2) sub-irrigation, administered as needed; and (3) control, sub-irrigation, administered only to prevent plant mortality.

The experimental field plots consisted of three adjacent beds measuring 16.8 meters x 10.7 meters at the University of Tennessee Knoxville Experiment Station. These beds contained fertile, well-drained soil of Cumberland silty clay loam (USDA, 1955), mulched with shredded hardwood bark. Each treatment plot was divided into quadrants for the four repetitions.

Table 2. Height categorization of *Zinnia elegans* cultivars used in irrigation study.

Series Name	Average height (cm)	Height Category
Short Stuff Series	22.9	Short
Dreamland Series	26.7	Short
Peter Pan Series	27.9	Short
Small World Series	40.6	Short
Oklahoma Series	88.9	Tall
Giant Dahlia Bluepoint Series	114.3	Tall

Cultivars were planted on 30.5 cm centers. The six tall cultivars were planted together, with the eleven short cultivars together. A mixed planting of left-over short cultivars was planted in the space which would have been used by an eighteenth cultivar, had there been one. This was done to achieve a uniform density of plants throughout the two short cultivar rows. No data was collected from the mixed planting.

Soil moisture content was measured daily in each treatment plot with a Watermark™ water sensor meter model 30 KTCD-NL (Irrometer Co., Riverside, Calif.). The meter was used to estimate water potential by measuring electrical resistance caused by soil moisture in eight Watermark™ sensors (model 200) placed within each treatment plot. Sensors were set 17.8 cm deep in order to measure soil moisture over a 10-15 cm range. Sensors were evenly spaced throughout each treatment plot.

When a mean soil moisture reading of 30 KPa (moderately dry) was recorded in either the overhead treatment plot or the sub-irrigation treatment plot, irrigation was administered to that plot. Irrigation was administered to the control plot via sub-irrigation drip tube when mean soil moisture reading of 90 KPa (extremely dry) was achieved or when plants began to show signs of wilting. Additional readings were taken hourly after irrigation was turned on. Irrigation was discontinued when a mean reading of 0-10 KPa (wet) was achieved in each treatment plot.

Treatments

Overhead Irrigation. The overhead irrigation treatment plot was located downwind of prevailing winds in the area to minimize spray drift into adjacent treatment plots. Two Weather-Tec 3/4-inch part-circle impact sprayers, model 15-30 (Weather-Tec Ag Products, Fresno, Calif.) were used to administer overhead irrigation. One sprinkler was placed in the NE corner of the treatment plot and the other was placed in the SW corner of the plot. This arrangement afforded the best overall coverage with the least amount of spray drift into adjacent treatment plots. Both sprinklers were coupled to a single water source. This resulted in even water pressure being applied to both sprinklers for even coverage.

Sub-Irrigation and Control Treatments. The sub-irrigation treatment plot and the control plot were both irrigated by identical irrigation systems; the only difference in these treatments was the frequency with which water was administered. Each planting row contained two plastic pressure-regulating sub-irrigation drip tubes (Agricultural Products, Inc., Haines City, Fla.) allowing each treatment plot to have twelve sub-irrigation tubes. Tubes were spaced 30.5 cm apart, and equidistant (15.3 cm) from the plants. Emitters (Netafim, Fresno, Calif.) were spaced at 30.5 cm intervals, making them on center with the plants. The sub-irrigation tubes were connected to a central water line at one end of the treatment plot. Gate valves were used to administer water to the treatment plots.

Data Collected

After being planted in the experimental plots, plants were evaluated at weekly intervals for 12 weeks for incidence and severity of disease as each of these factors pertained to *Alternaria* blight, powdery mildew and bacterial leaf and flower spot. The following disease severity scale was used for each disease:

- 0.0 = no disease apparent
- 1.0 = $\leq$ 2% affected by disease
- 2.0 = $\leq$ 10% affected by disease
- 3.0 = $\leq$ 25% affected by disease
- 4.0 = $\leq$ 50% affected by disease
- 5.0 = $>$ 50% affected by disease
- 6.0 = plant dead (killed by disease).

Disease data were analyzed using mixed model analysis of variance (SAS Inst., Cary, N.C.). The model tested the factorial effects of cultivars and treatments and had repeated measures over weeks. The statistical mean for the disease severity rating scale for each cultivar was used to determine its susceptibility to each of the three disease pathogens. Cultivars having a disease severity rating ≤ 2.0 ($\leq 10\%$ of plant foliage showing signs and/or symptoms of disease) were judged acceptable in a landscape situation. Those cultivars having a disease severity rating > 2.0 were judged unacceptable in a landscape situation.

RESULTS

Alternaria Blight

For Alternaria blight incidence and severity, statistical analysis showed that the six series and the seventeen cultivars they encompassed could be divided into two response groups to irrigation treatment over the course of the experiment (Appendices A through D). These two response groups were labeled Group A and Group B.

Incidence. Response Group A contained three series (Giant Dahlia Bluepoint, Oklahoma and Small World) which showed similar responses to the three treatments over time (Appendix A). While virtually all of the plants in the study were eventually infected with Alternaria blight, the disease typically spread more slowly in the Response Group A series over the course of the experiment. These cultivars showed lower disease incidence at week 3 (15–50% average range). Incidence increased sharply at week 4, but then the pathogen spread slowly until all plants were infected. These series typically showed Alternaria blight incidence of 100% around week 11. The Response Group B series (Dreamland, Peter Pan and Short Stuff) generally showed higher incidence of Alternaria blight early in the experiment (50–70% average range), and the disease spread rapidly, typically infecting 100% of the plants in these series around week 7–8 (Appendix B). For all series there was little difference in incidence among treatments, but where differences did occur, plants subjected to overhead irrigation showed a higher incidence of Alternaria blight than did plants subjected to drip irrigation or the control for the same time period.

Severity. Severity of Alternaria blight showed a similar set of responses, with the same series falling into Response Group A (Giant Dahlia Bluepoint, Oklahoma and Small World) and Response Group B (Dreamland, Peter Pan and Short Stuff). Response Group A series (Appendix C) generally maintained disease severity ratings ≤ 2.0 and were therefore rated acceptable in the landscape for a longer period of time (typically 6–8 weeks) than Response Group B series (Appendix D) when evaluated for susceptibility to Alternaria blight. In general, cultivars within these series demonstrated disease severity increasing slowly over time. Plants in Response Group A were typically not killed by

Alternaria blight, but showed disease severity ratings around 4.0–5.0 by the end of the experiment.

Response Group B contained three series which showed similar responses to treatments over the course of the experiment. Cultivars in these series generally reached a disease severity rating >2.0 more quickly than Response Group A (5–7 weeks) and once they had reached this level, disease severity increased sharply. Nearly all plants in this category were killed by disease (probably a combination of *Alternaria* blight and bacterial leaf and flower spot) before the end of the experiment. In general, for both response groups, there were few differences in how cultivars in these series responded to the three treatments, but where differences did occur, plants subjected to overhead irrigation were more severely affected than those subjected to drip irrigation or the control for the same evaluation date.

Bacterial Leaf and Flower Spot

For bacterial leaf and flower spot incidence and severity, statistical analysis showed that the six series and the seventeen cultivars they encompassed could be divided into two response groups to irrigation treatment over the course of the experiment (Appendices E through H). These two response groups were labeled Group A and Group B. All cultivars within all series were severely affected with bacterial leaf and flower spot early in the study. Virtually all cultivars had merited disease severity ratings ≥ 2.0 by week 5, making them unacceptable for landscape use beyond this date.

Incidence. Response Group A contained three series (Giant Dahlia Bluepoint, Oklahoma and Small World) which showed similar responses to the three treatments over time (Appendix E). Virtually all of the plants in the study were infected with bacterial leaf and flower spot by week 7. Series in Response Group A showed higher disease incidence (80–100% average range) early in the experiment than did those in Response Group B (Appendix F). Response Group B series (Dreamland, Peter Pan and Short Stuff) generally showed lower incidence of bacterial leaf and flower spot (60–90% average range) early in the experiment. For all series there was little difference in incidence among treatments, but where differences did occur, plants subjected to overhead irrigation

showed a higher incidence of bacterial leaf and flower spot than did plants subjected to drip irrigation or the control.

Severity. Severity of bacterial leaf and flower spot showed a similar set of responses, with the same series falling into Response Group A (Giant Dahlia Bluepoint, Oklahoma and Small World) and Response Group B (Dreamland, Peter Pan and Short Stuff). Response Group A contained three series which showed similar responses to the three treatments over time (Appendix G). In general, cultivars within these series showed a gradual increase in disease severity over time. Plants in this category were typically not killed by bacterial leaf and flower spot, but showed disease severity ratings around 3.5–5.0 by the end of the experiment.

Response Group B contained three series which showed similar responses to treatments over the course of the experiment (Appendix H). Typically, disease severity increased rapidly among series in this group. Nearly all plants in this category were killed by disease (probably a combination of *Alternaria* blight and bacterial leaf and flower spot) before the end of the experiment. In general, for both response groups, there were few differences in how cultivars in these series responded to treatment, but where differences occurred, plants subjected to overhead irrigation were more severely affected than those subjected to drip irrigation or the control at the same evaluation dates.

Powdery Mildew

For powdery mildew incidence and severity, statistical analysis showed that the six series and the seventeen cultivars they encompassed could be divided into two response groups to irrigation treatment over the course of the experiment (Appendices I through L). These two response groups were labeled Group A and Group B.

Incidence. While virtually all of the surviving plants in the study were eventually infected with powdery mildew, Response Group A series (Giant Dahlia Bluepoint, Oklahoma and Small World) generally showed signs of disease earlier in the study (week 10–11), but the pathogen spread more slowly until weeks 12–14, when incidence increased sharply (Appendix I). The disease spread more quickly in Response Group B (Dreamland, Peter Pan and Short Stuff). These series typically showed powdery mildew

incidence of 100% at the same time that the disease was first observed (Appendix J). In general, for both response groups, the pathogen spread more quickly in plants which were subjected to drip irrigation than it did in plants subjected to overhead irrigation or the control for all series for the same evaluation dates.

Severity. Severity of powdery mildew showed a similar set of responses, with the same series falling into Response Group A (Giant Dahlia Bluepoint, Oklahoma and Small World) and Response Group B (Dreamland, Peter Pan and Short Stuff). Response Group A contained three series which responded similarly to the three treatments over time (Appendix K). In general, cultivars in these series began to show signs of disease earlier in the study (week 10–11) than did those series in Response Group B (Appendix L). Response Group A series maintained disease severity ratings ≤ 2.0 and were therefore rated acceptable in the landscape for two to three weeks after signs of the disease first appeared. By weeks 13–14 disease severity increased sharply. Plants in this response group were typically not killed by powdery mildew, but showed disease severity ratings around 2.5–4.0 by the end of the experiment.

Response Group B contained three series which showed similar responses to treatments over the course of the experiment. Nearly all plants in this group were killed by *Alternaria* blight and/or bacterial leaf and flower spot before signs of powdery mildew were observed. The few surviving plants in these series were infected with powdery mildew later in the experiment (week 12–14) than those in Response Group A. In these series, plants in both response groups which were subjected to drip irrigation were generally more severely affected than those subjected to overhead irrigation or the control.

DISCUSSION

While analysis of variance showed significant differences regarding severity of all three diseases among treatments over the course of the study, most plants were so severely affected by one or more pathogens early in the experiment that irrigation method had no effect on suppressing or enhancing disease. Simply stated, no cultivar was acceptable in a landscape situation by week 6, regardless of irrigation method. It is,

however, interesting to note that for *Alternaria* blight and bacterial leaf and flower spot, where differences in response to treatment can be seen, overhead irrigation consistently showed greater disease severity than drip irrigation or the control. Conversely, where differences in response to treatment can be seen for powdery mildew severity, drip irrigation showed greater disease severity than overhead irrigation or the control. This is because germination of powdery mildew conidia is inhibited by the presence of free water, such as would be present under overhead irrigation (Spencer, 1978).

Development of *Alternaria* blight, on the other hand, is favored under conditions of wet foliage (Franklin and Goodwin, 1981). It has also been shown that a direct correlation exists between length of time foliage remains wet and severity of bacterial leaf and flower spot (Jones, 1977). Therefore, there is reason to suspect that irrigation method may play a role in determining which disease(s) may be a problem in the landscape.

For all three pathogens, two identical response groups were found. Response Group A was consistently made up of the same three series: Giant Dahlia Bluepoint, Oklahoma and Small World. These series, while ultimately as likely to be infected with the three pathogens, were seldom killed by them. Response Group B was consistently composed of Dreamland, Peter Pan and Short Stuff series. These series were usually killed by the pathogens before the end of the study. Additional research is suggested to determine if a genetic link between the series in the two response groups exists which could be developed in additional resistance research.

All three pathogens are known to be seed-borne (Neergaard, 1979; Andersen, 1971; Strider, 1973), but it is impossible to determine the source of the initial inoculants in this study. The spring of 1997 saw abnormally high rainfall, and primary inoculum may have been present in the soil before the experimental crop was planted. Once the crop was in place, plants were quickly attacked by the pathogens. It is safe to postulate that once a pathogen had infected one (or a few) individual host(s), it multiplied rapidly due to environmental conditions conducive to its development, spreading quickly throughout the experimental crop.

Plants grown from "clean" seed are not immune to infection from nearby plants which are infected with a pathogen when environmental conditions favor disease. Monoculture situations, such as that encountered in this study, provide ideal conditions for pathogens to spread because of the close proximity of one host plant to another. Had the crop been divided into several separate, smaller lots or alternated with blocks of non-host plants, rather than clustered together, disease problems may have been limited to isolated plots, rather than widespread throughout the entire crop. It is suggested that further research be conducted in this area. Contractors and gardeners who continue to use zinnia in the landscape should consider scattering small groups of zinnia, rather than using the plant in large, closely-planted plots.

While all cultivars proved to be susceptible to all three pathogens, it is important to note that the summer of 1997 manifested atypically high disease pressures. Maximum daily relative humidity readings $\geq 95\%$ were recorded for 56 of the 98 days of the study. Heavy dews, which allow all three pathogens to flourish, are likely to have occurred on those dates. There were a greater than normal number of days with significant rainfall ($\geq .254$ cm) for the months of August and September, providing more opportunities for pathogens to spread by splashing rain (Figure 1).

Despite rainfall amounts which were lower than normal for much of the study period (Figure 2), irrigation treatments were administered relatively few times. This was because soil water sensors indicated that soil moisture rarely dropped into the "dry" range (≤ 30 KPa). Investigation revealed that when the experiment field was first developed several years ago, it was used for turfgrass experiments and a large amount of sawdust had been added in order to retain soil moisture. Had the experiment been conducted in a plot with normal moisture retention qualities, more irrigation treatments would have been administered, and differences in disease incidence and/or severity may have been more pronounced among the different treatments.

Daily high temperatures for most of the study fell into the optimum range for development of bacterial leaf and flower spot (Jones, 1977) (Figure 3). Additionally, daily low temperatures were below normal for weeks 10–13, falling into the optimal temperature

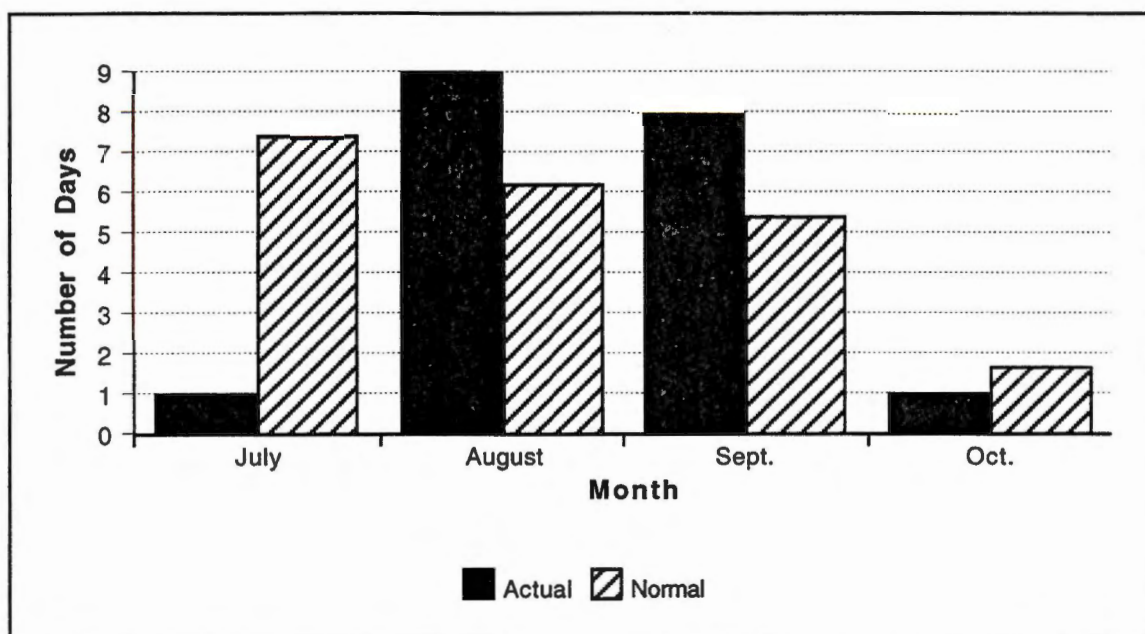


Figure 1. Total number of days with significant rainfall ($\geq .254$ cm) over the period of irrigation study. Actual number of days is calculated from measurements taken in the field. Normal number of days were provided by University of Tennessee Department of Plant and Soil Sciences. Normal number of splash days for month of October is estimated based upon portion of the month encompassed in study and assumed normal distribution of splash days.

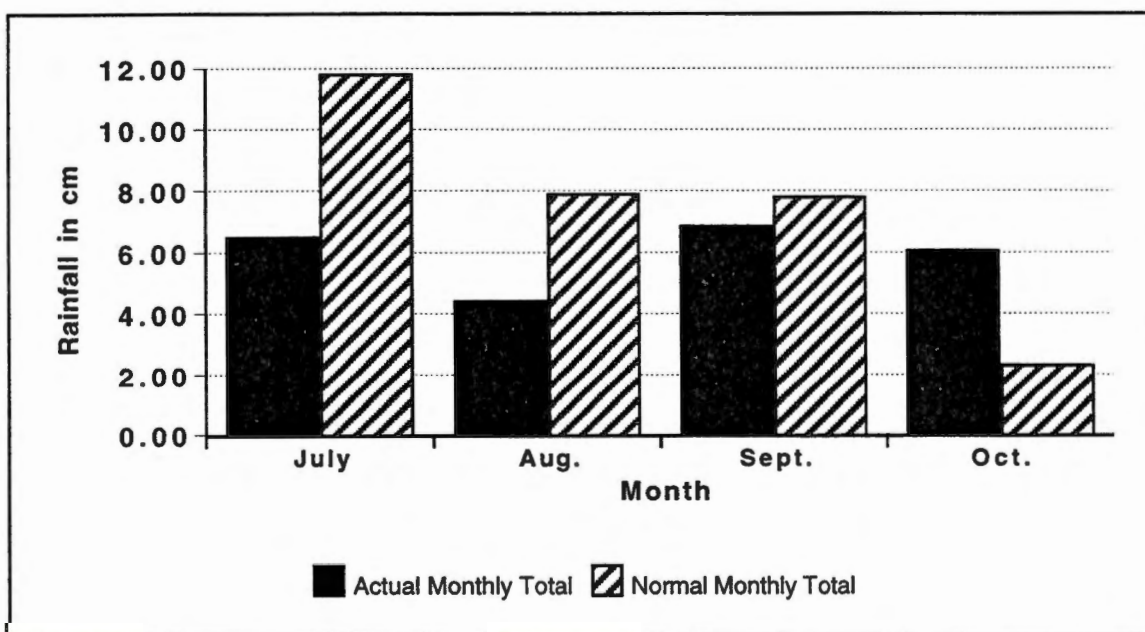


Figure 2. Actual monthly rainfall totals versus normal monthly rainfall totals over the period of irrigation study. Actual totals were measured in the field. Normal totals were provided by University of Tennessee Department of Plant and Soil Sciences. Normal rainfall amounts for month of October is estimated based upon portion of the month encompassed in study and assumed normal distribution of rainfall amounts.

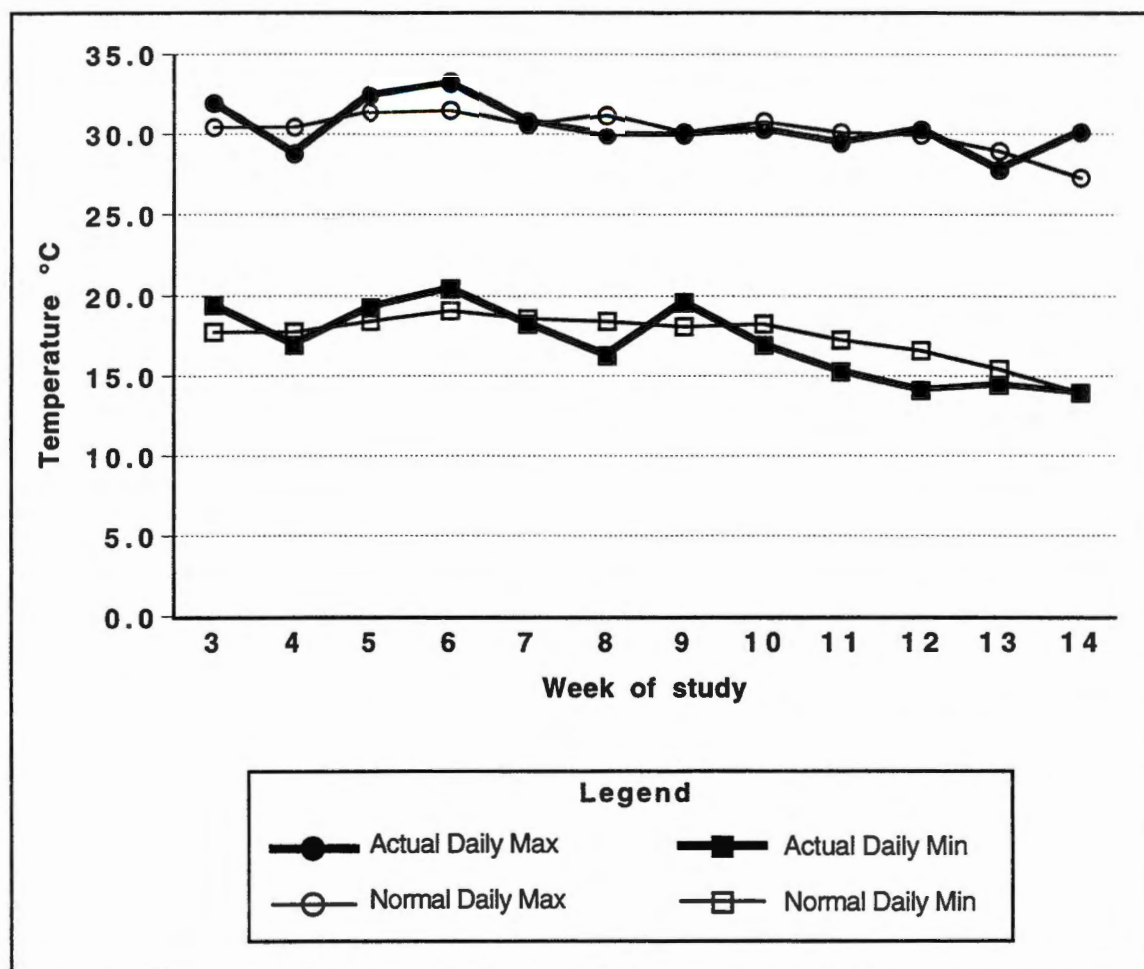


Figure 3. Actual daily minimum and maximum temperatures versus normal daily minimum and maximum temperatures over period of irrigation study. Information provided by University of Tennessee Department of Plant and Soil Sciences.

range for powdery mildew development (Powell and Lindquist, 1992). It is during week 10 that powdery mildew first becomes apparent on surviving plants in the study.

The time period included in this experiment may have played a role in the incidence and severity of disease encountered in this study. While a normal bedding plant crop would be planted during the first two weeks of May, the plants in this study were not planted until the first week of July, by which time daily high temperatures were high enough to cause significant metabolic stress to the young plants, possibly resulting in higher incidence and severity of disease than might have occurred had the crop been firmly established by this date.

The method in which the seeds were sown may have also played a role in the spread of disease for this experiment. Personal experience among some researchers has shown that direct seeding of zinnia seeds into cell-pack inserts, rather than first sowing them in germination row flats, results in lower incidence of some fungal diseases (M. Albrecht, University of Tennessee Department of Ornamental Horticulture and Landscape Design, Knoxville, Tenn., *personal communication*). Additional research into disease incidence in direct-sown versus transplanted zinnia seedlings is suggested.

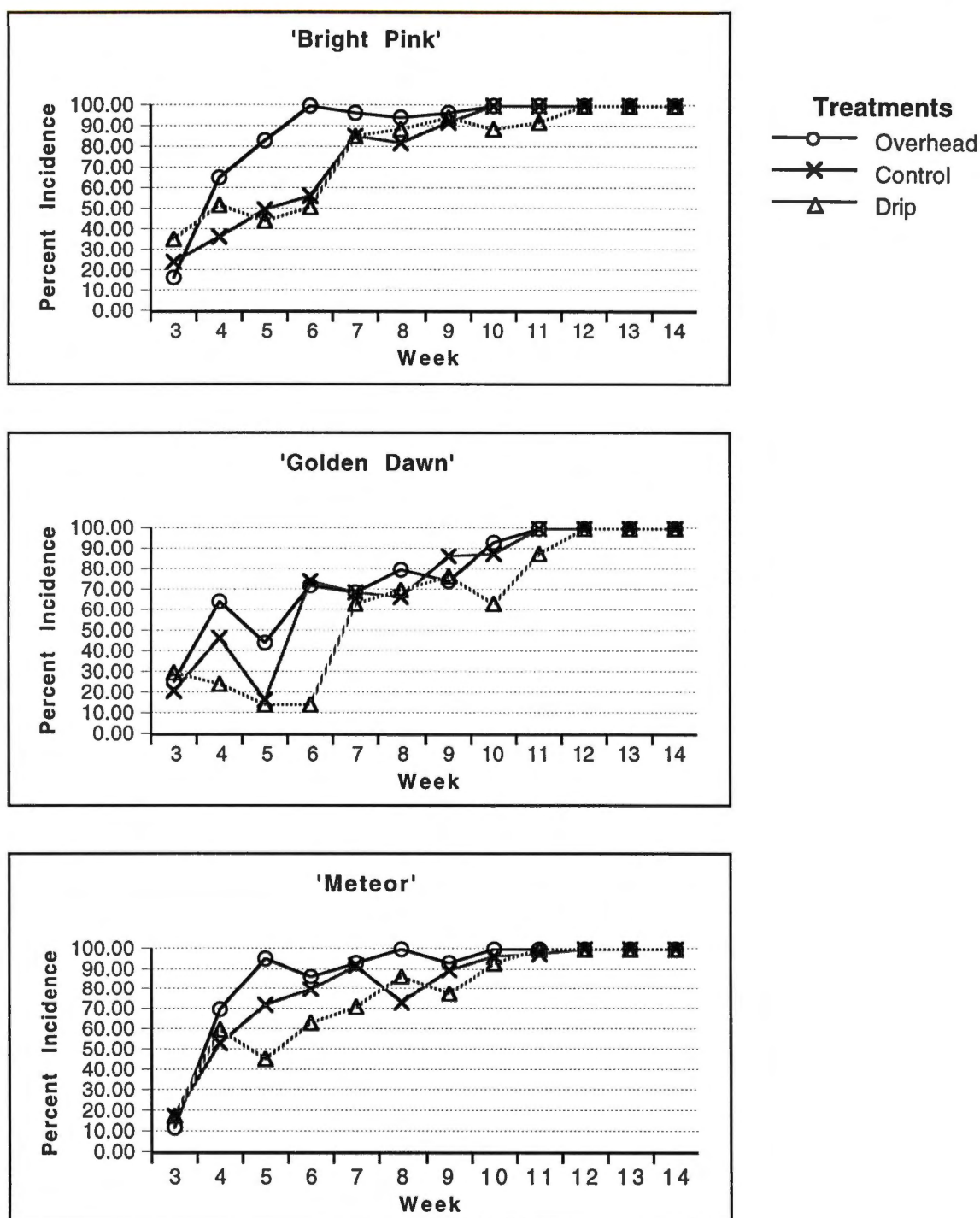
Because many growers and homeowners alike rely on several seed sources, it is impossible to guarantee that any cultivar is safe from contamination by other infected plants. It is therefore recommended that seed producers work to develop pathogen-free seed strains.

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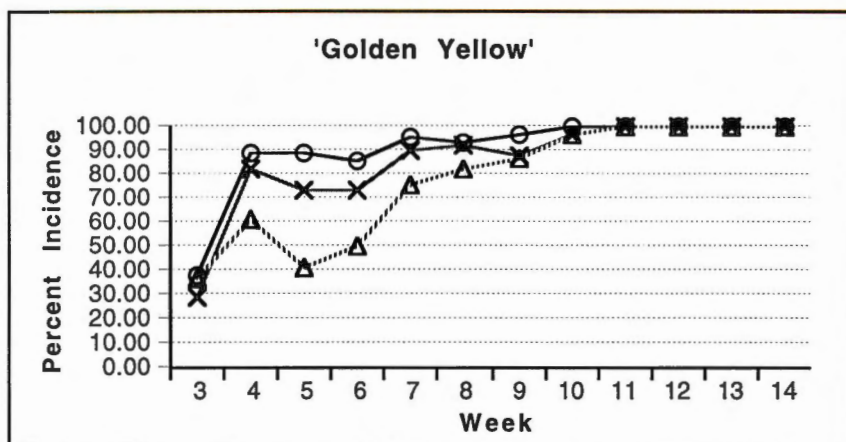
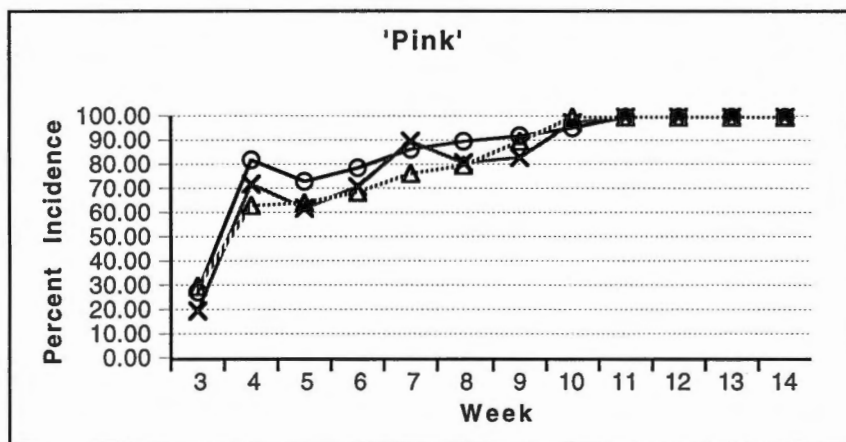
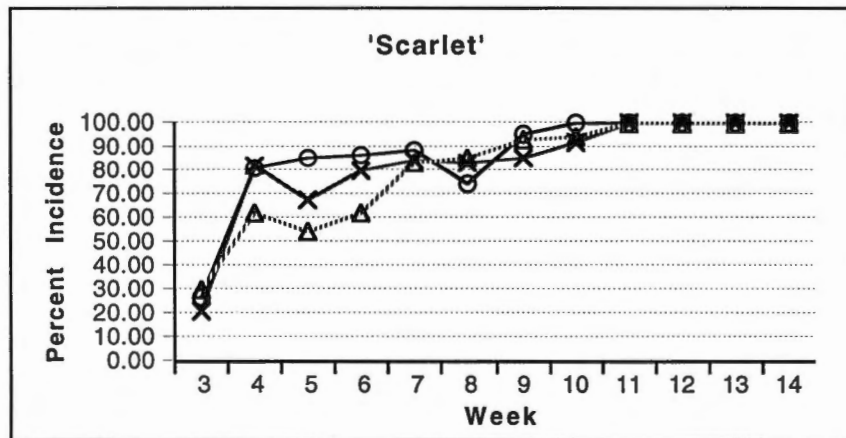
APPENDICES

GIANT DAHLIA BLUEPOINT SERIES ALTERNARIA BLIGHT INCIDENCE



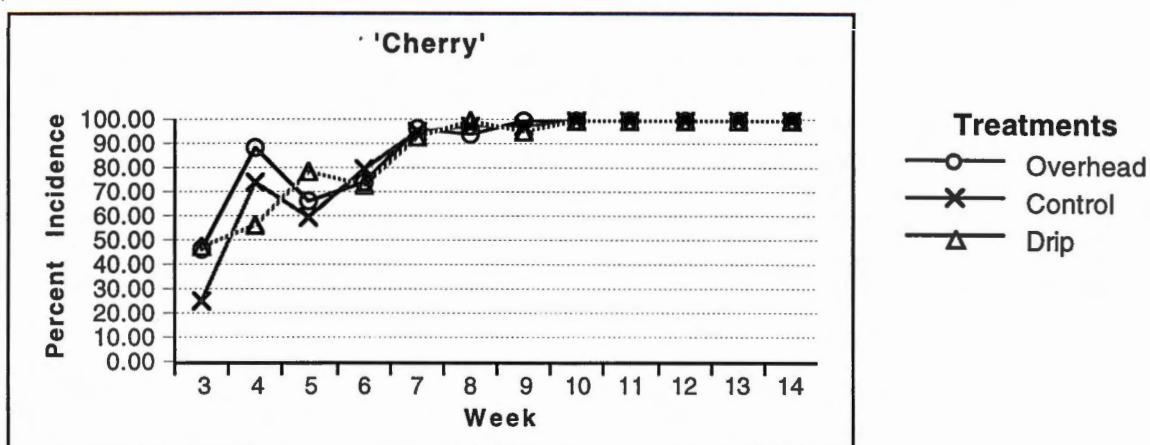
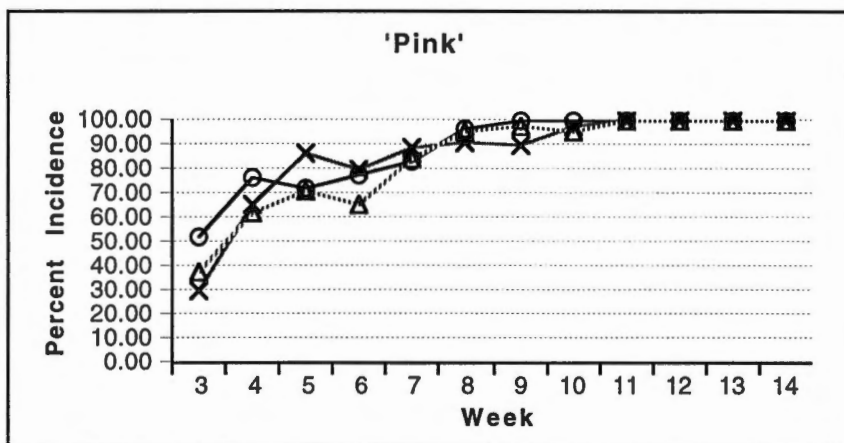
Appendix A. The effect of irrigation treatment on Alternaria blight incidence for response group A.
LSD = 13.16. $P \leq 0.05$.

OKLAHOMA SERIES ALTERNARIA BLIGHT INCIDENCE



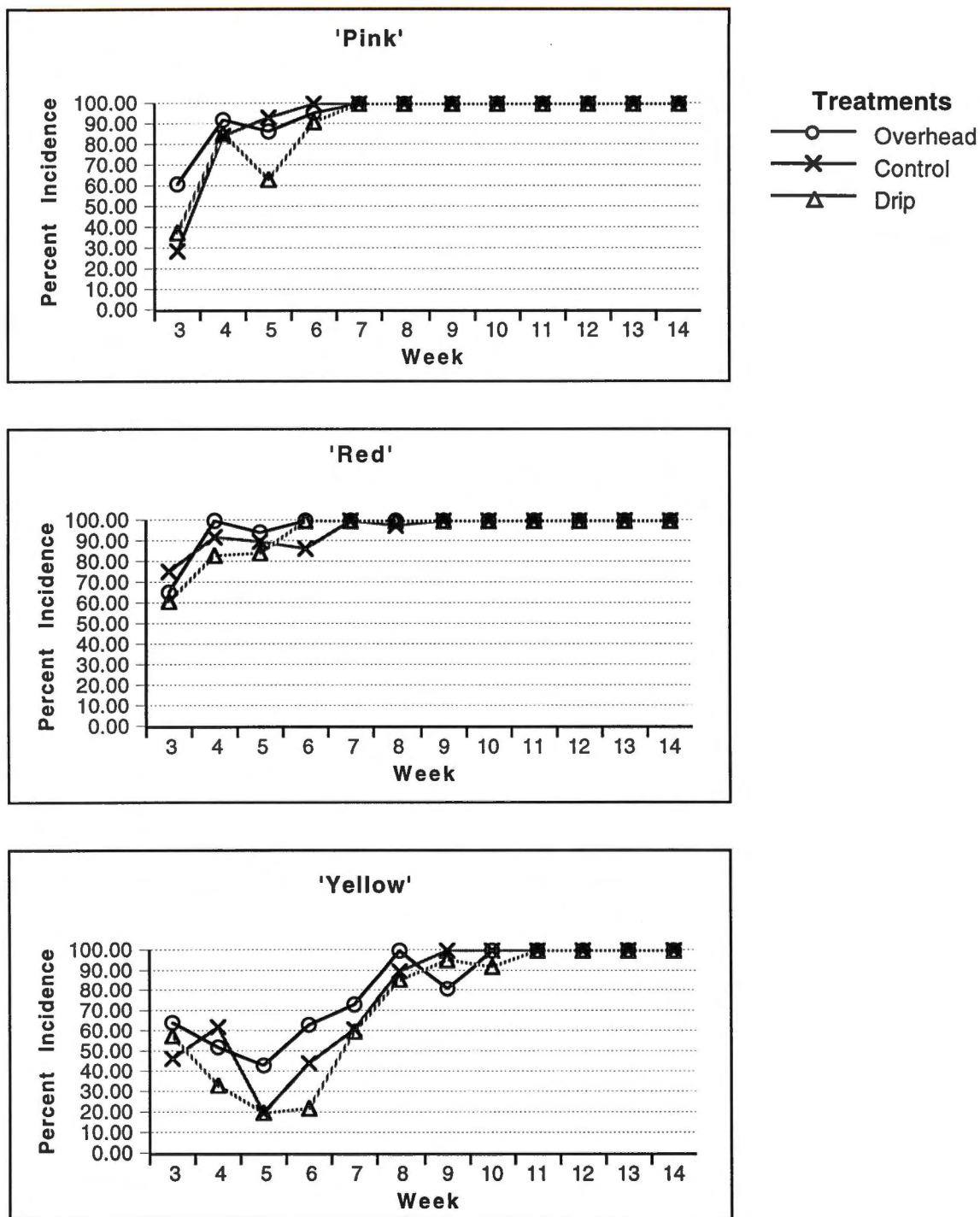
Appendix A. The effect of irrigation treatment on Alternaria blight incidence for response group A, continued. LSD = 13.16. $P \leq 0.05$.

SMALL WORLD SERIES ALTERNARIA BLIGHT INCIDENCE



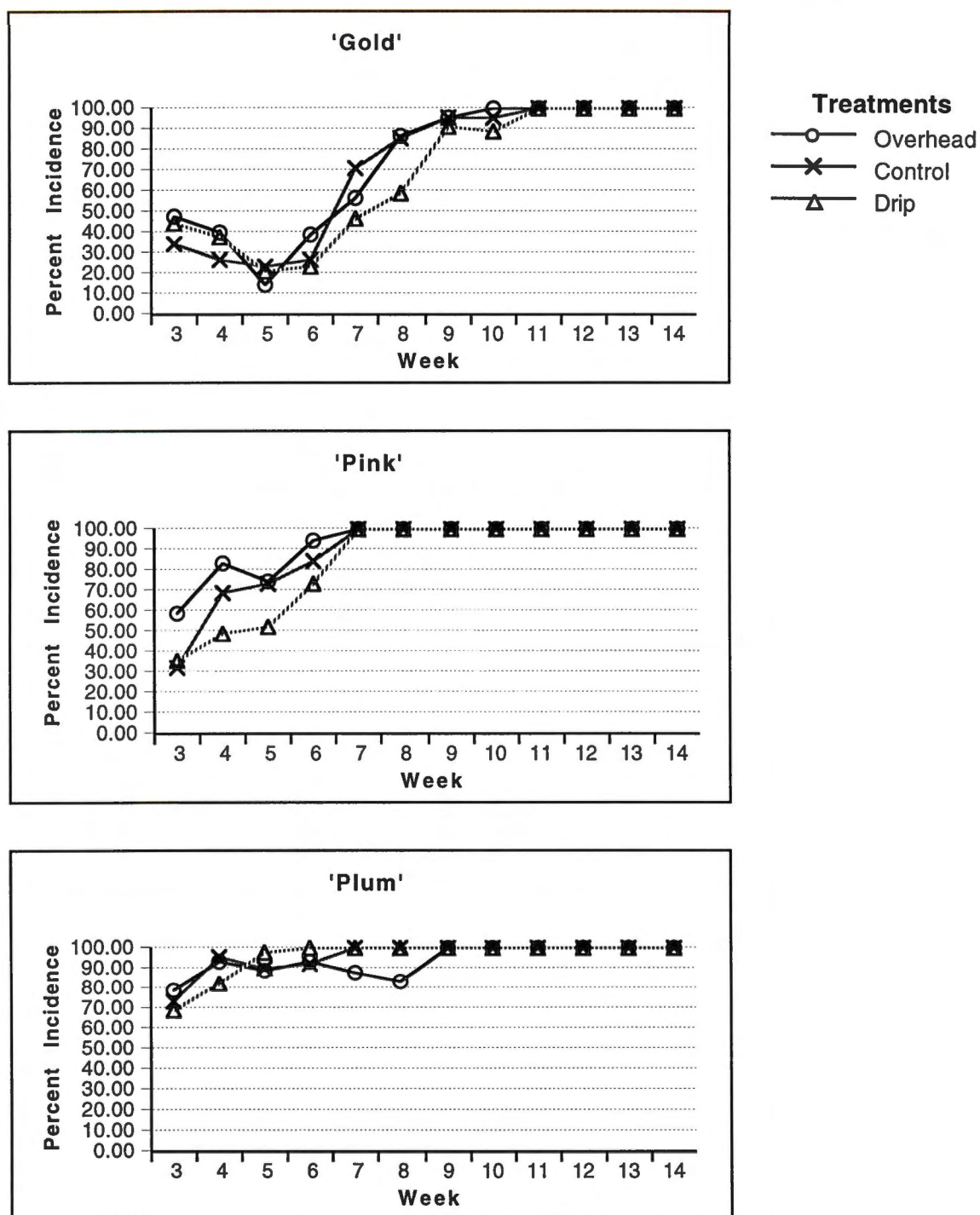
Appendix A. The effect of irrigation treatment on Alternaria blight incidence for response group A, continued. LSD = 13.16. $P \leq 0.05$.

DREAMLAND SERIES ALTERNARIA BLIGHT INCIDENCE



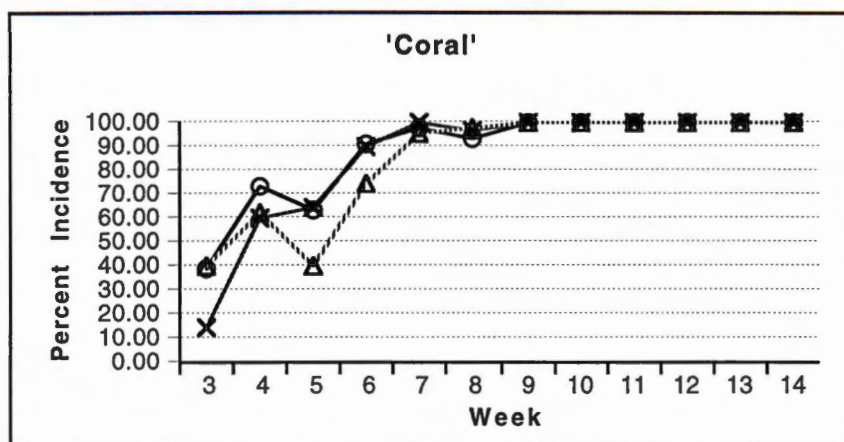
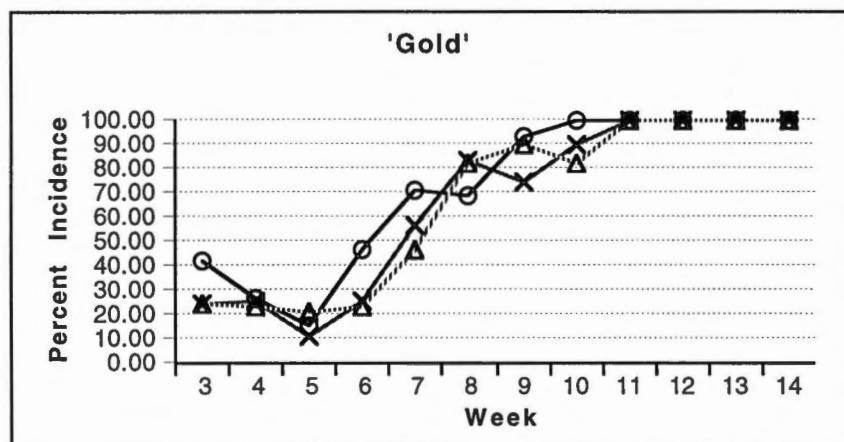
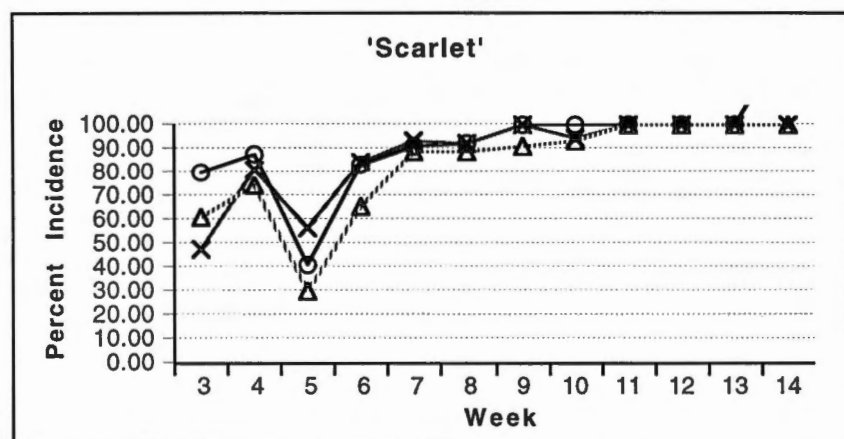
Appendix B. The effect of irrigation treatment on Alternaria blight incidence for response group B.
LSD = 13.16. $P \leq 0.05$.

PETER PAN SERIES ALTERNARIA BLIGHT INCIDENCE



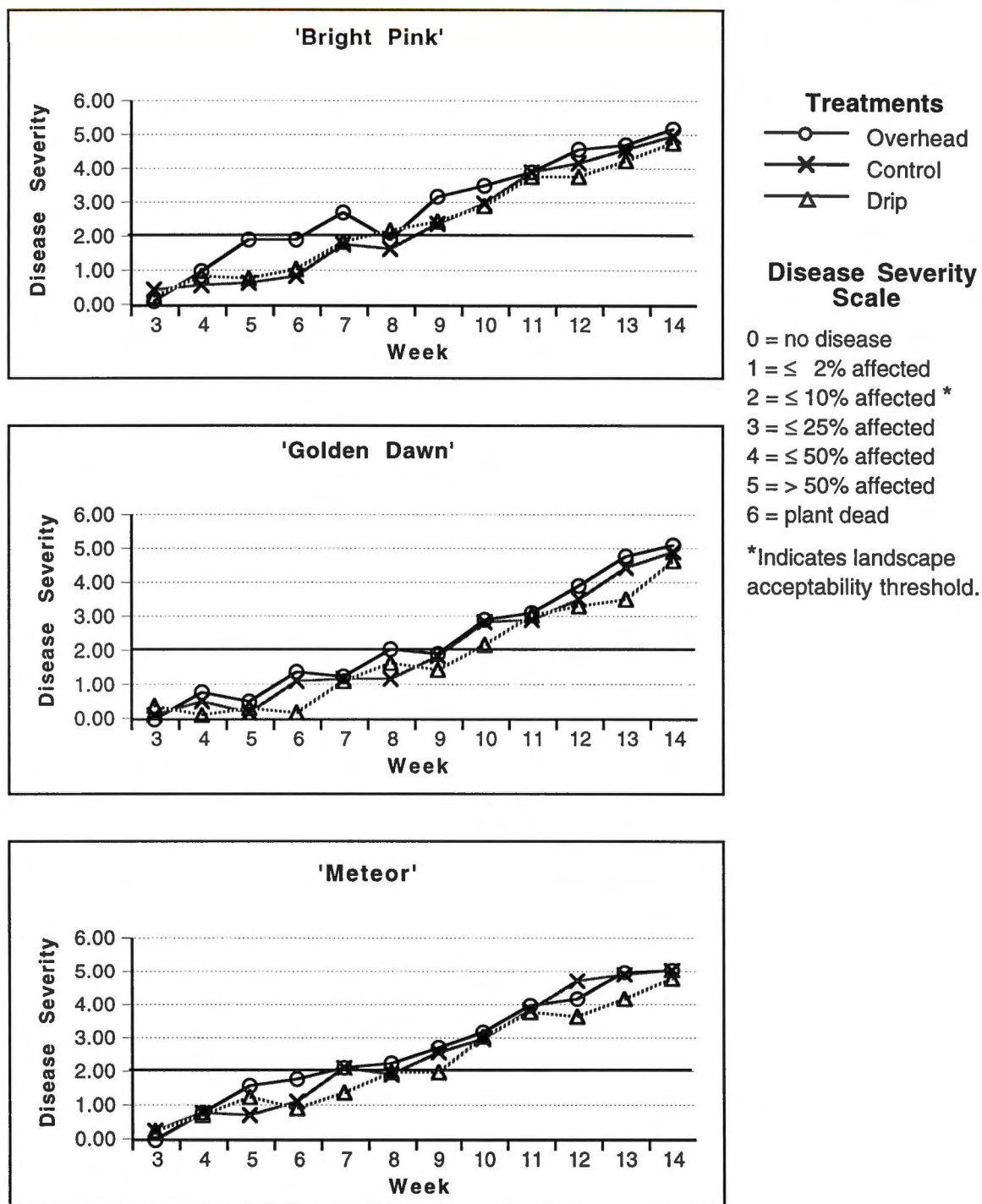
Appendix B. The effect of irrigation treatment on Alternaria blight incidence for response group B, continued. LSD = 13.16. $P \leq 0.05$.

SHORT STUFF SERIES ALTERNARIA BLIGHT INCIDENCE



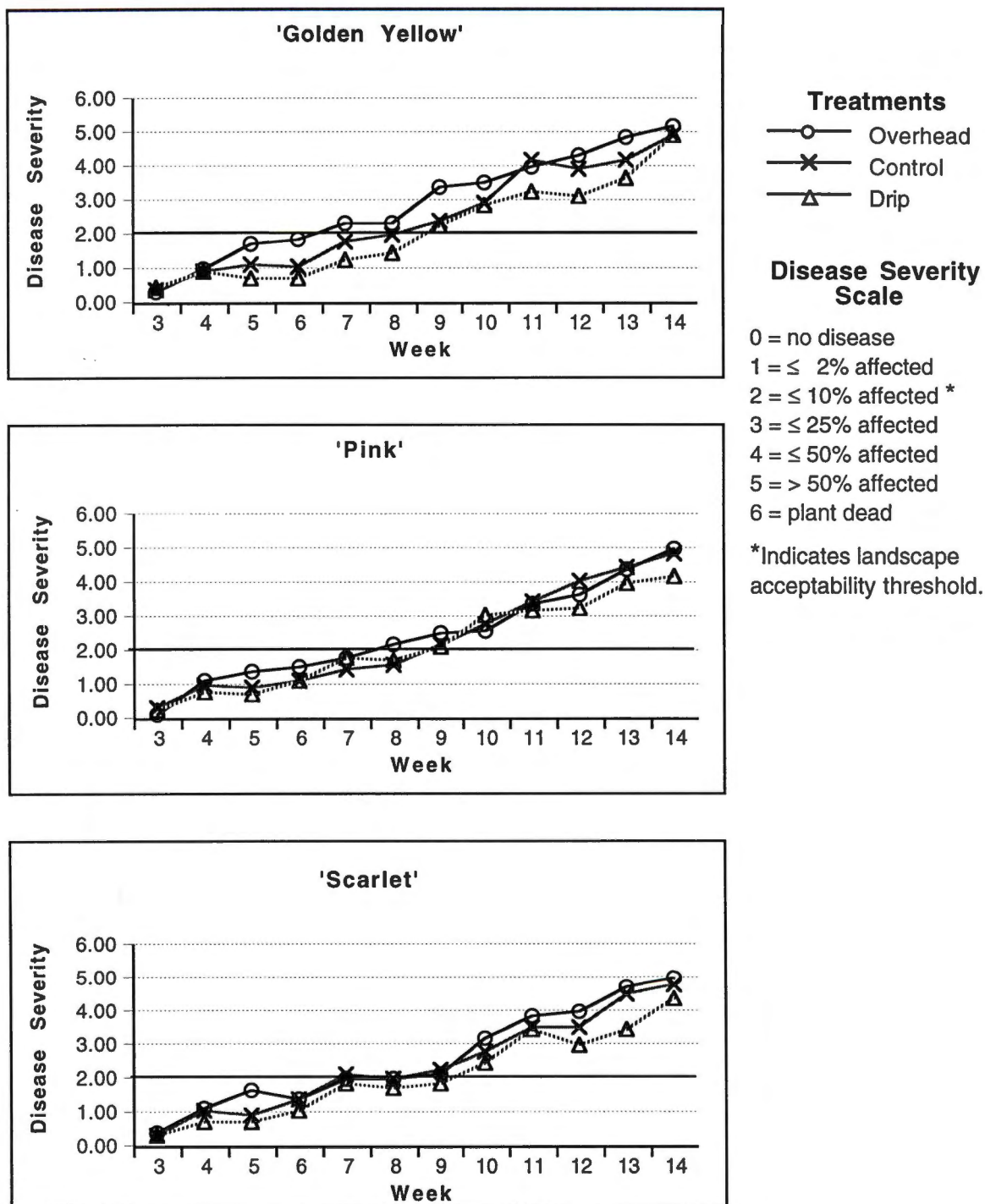
Appendix B. The effect of irrigation treatment on Alternaria blight incidence for response group B, continued. LSD = 13.16. $P \leq 0.05$.

GIANT DAHLIA BLUEPOINT SERIES ALTERNARIA BLIGHT SEVERITY



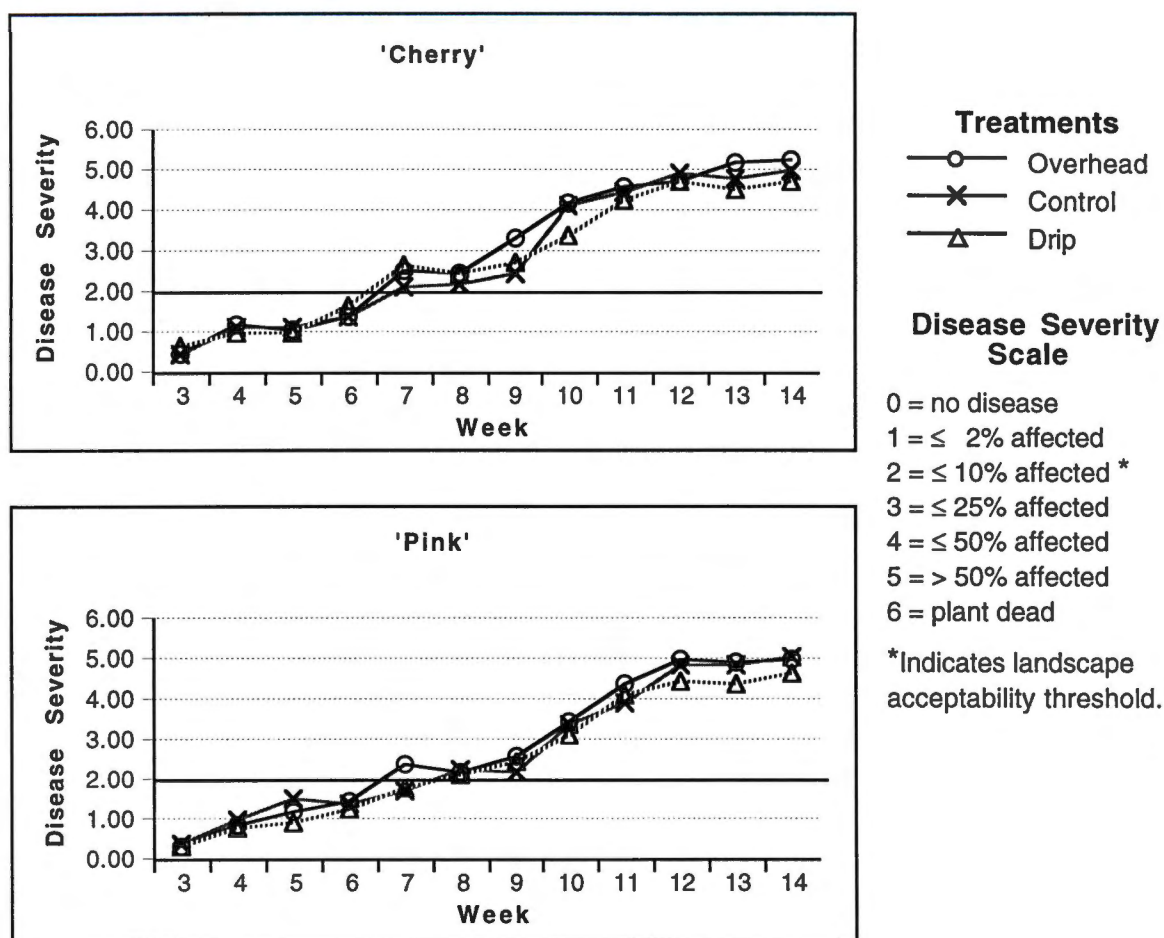
Appendix C. The effect of irrigation treatment on Alternaria blight severity for response group A.
LSD = 0.50. $P \leq 0.05$.

OKLAHOMA SERIES ALTERNARIA BLIGHT SEVERITY



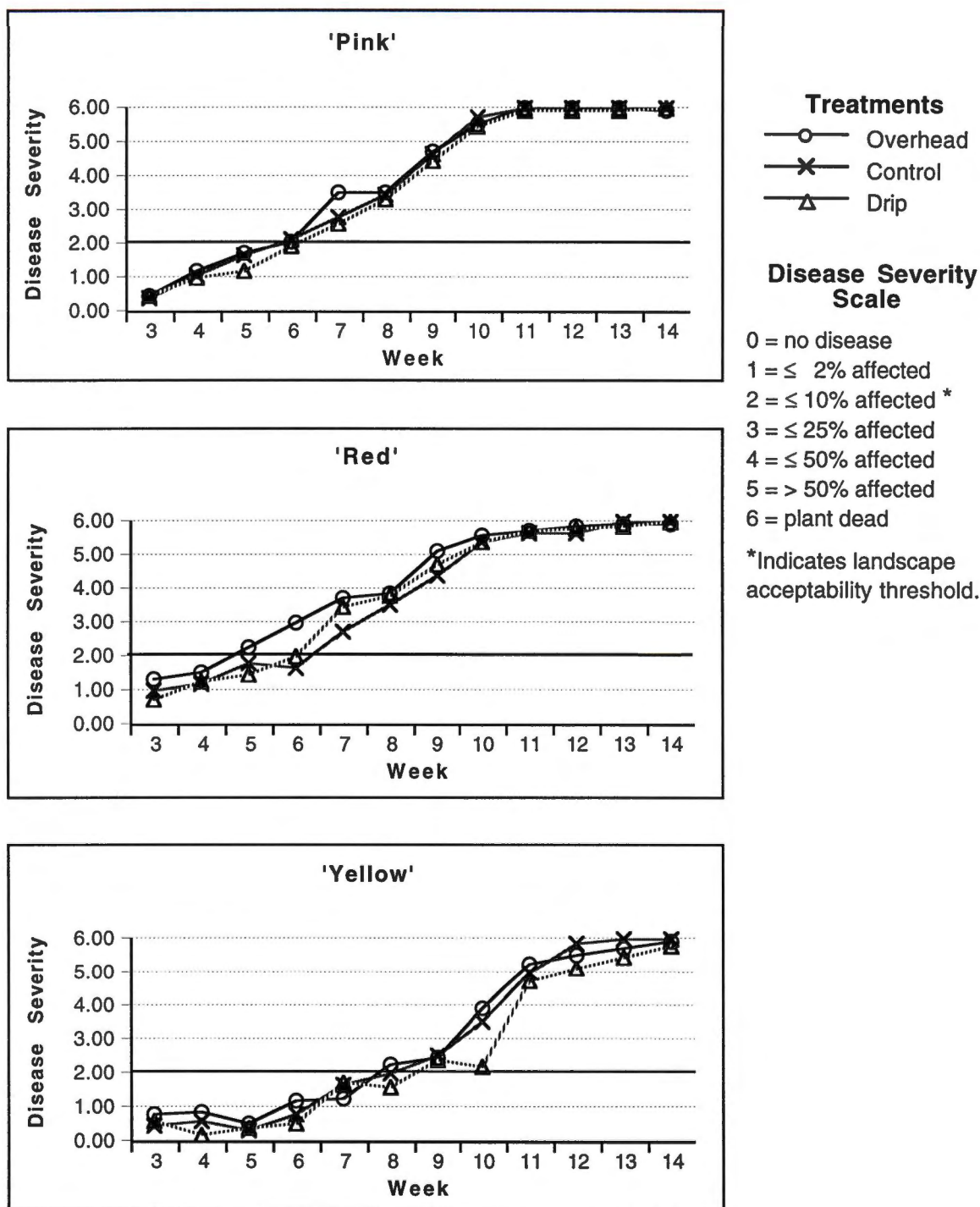
Appendix C. The effect of irrigation treatment on Alternaria blight severity for response group A, continued. LSD = 0.50. $P \leq 0.05$.

SMALL WORLD SERIES ALTERNARIA BLIGHT SEVERITY



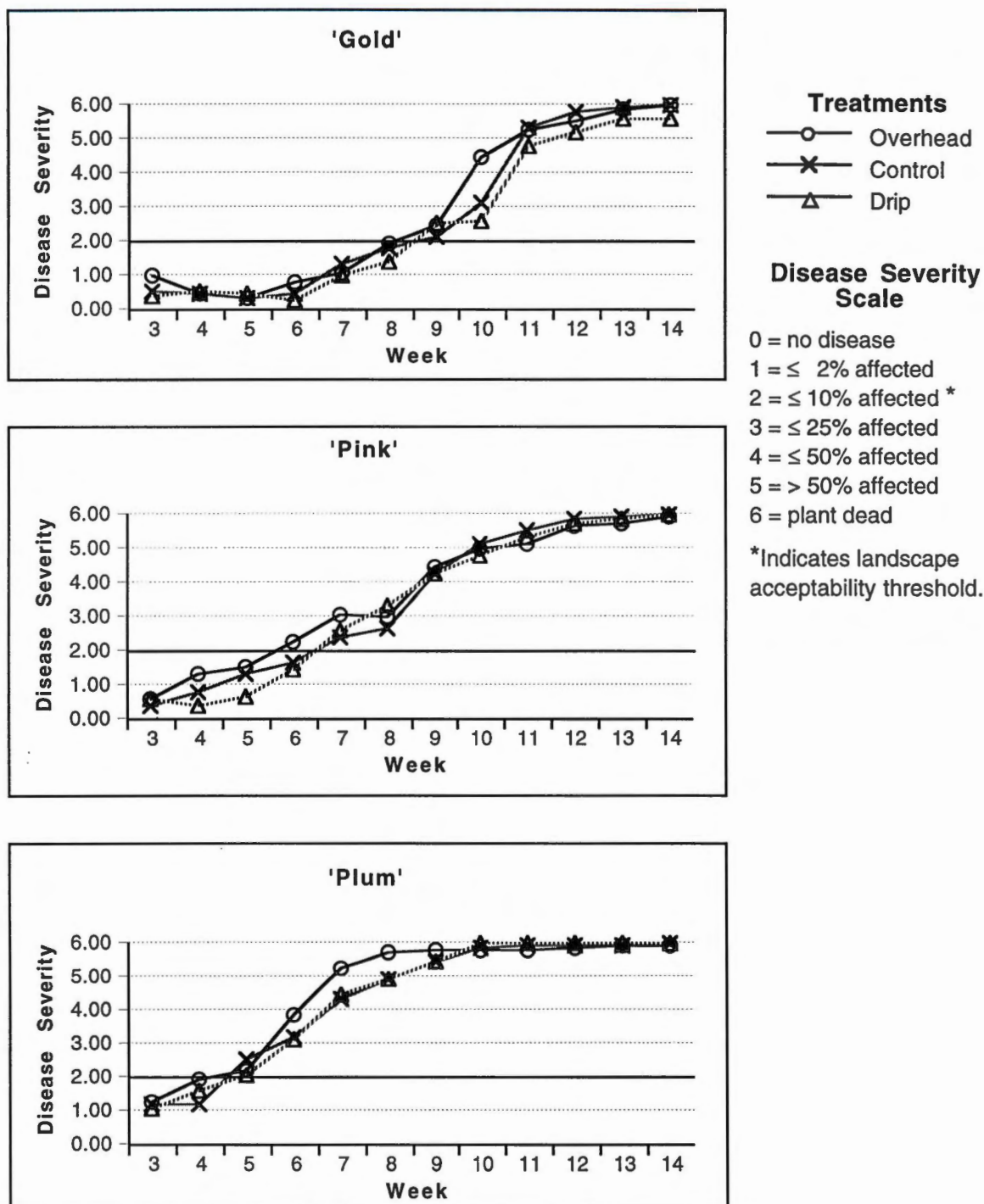
Appendix C. The effect of irrigation treatment on Alternaria blight severity for response group A, continued. LSD = 0.50. $P \leq 0.05$.

DREAMLAND SERIES ALTERNARIA BLIGHT SEVERITY



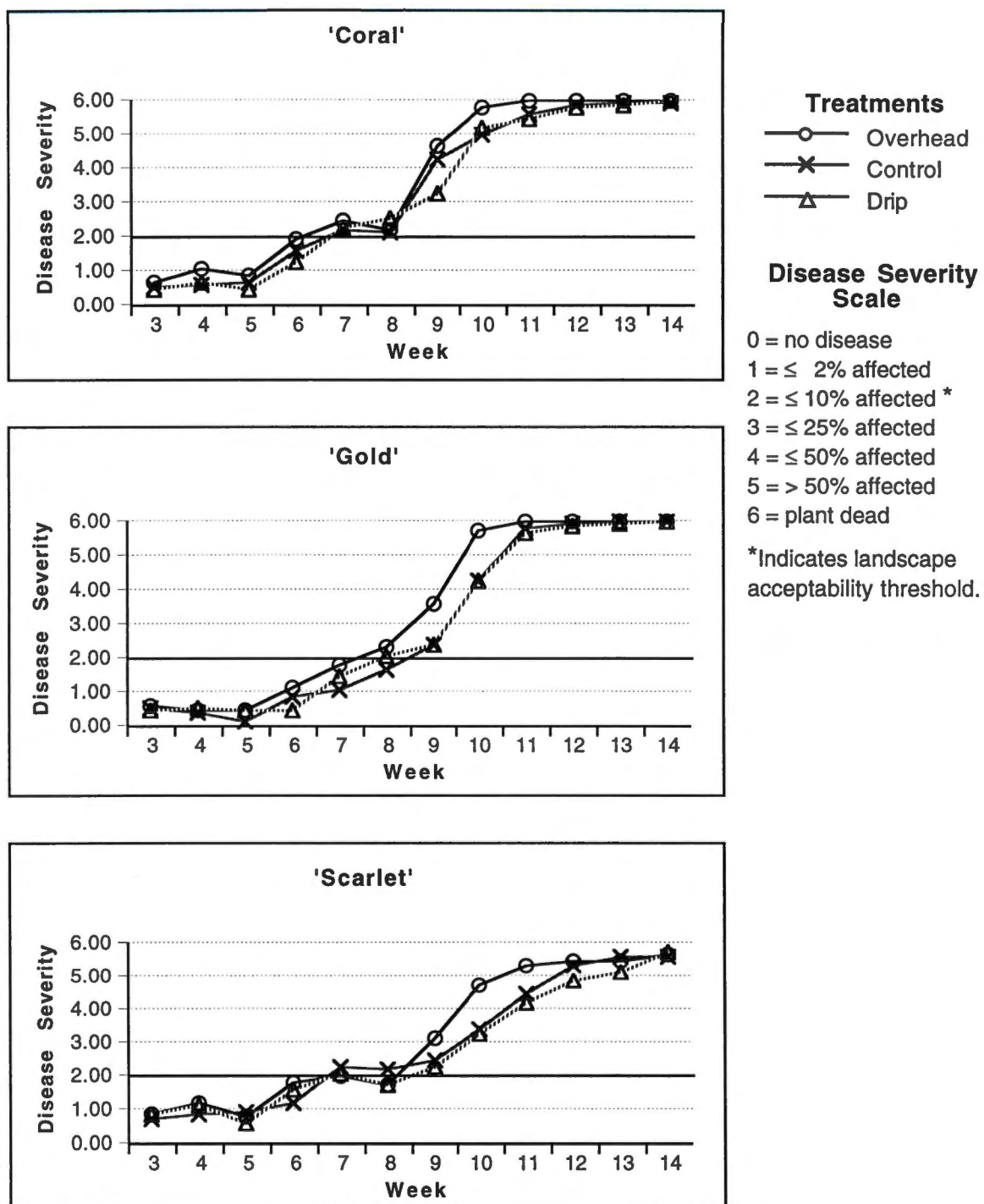
Appendix D. The effect of irrigation treatment on Alternaria blight severity for response group B. LSD = 0.50. $P \leq 0.05$.

PETER PAN SERIES ALTERNARIA BLIGHT SEVERITY



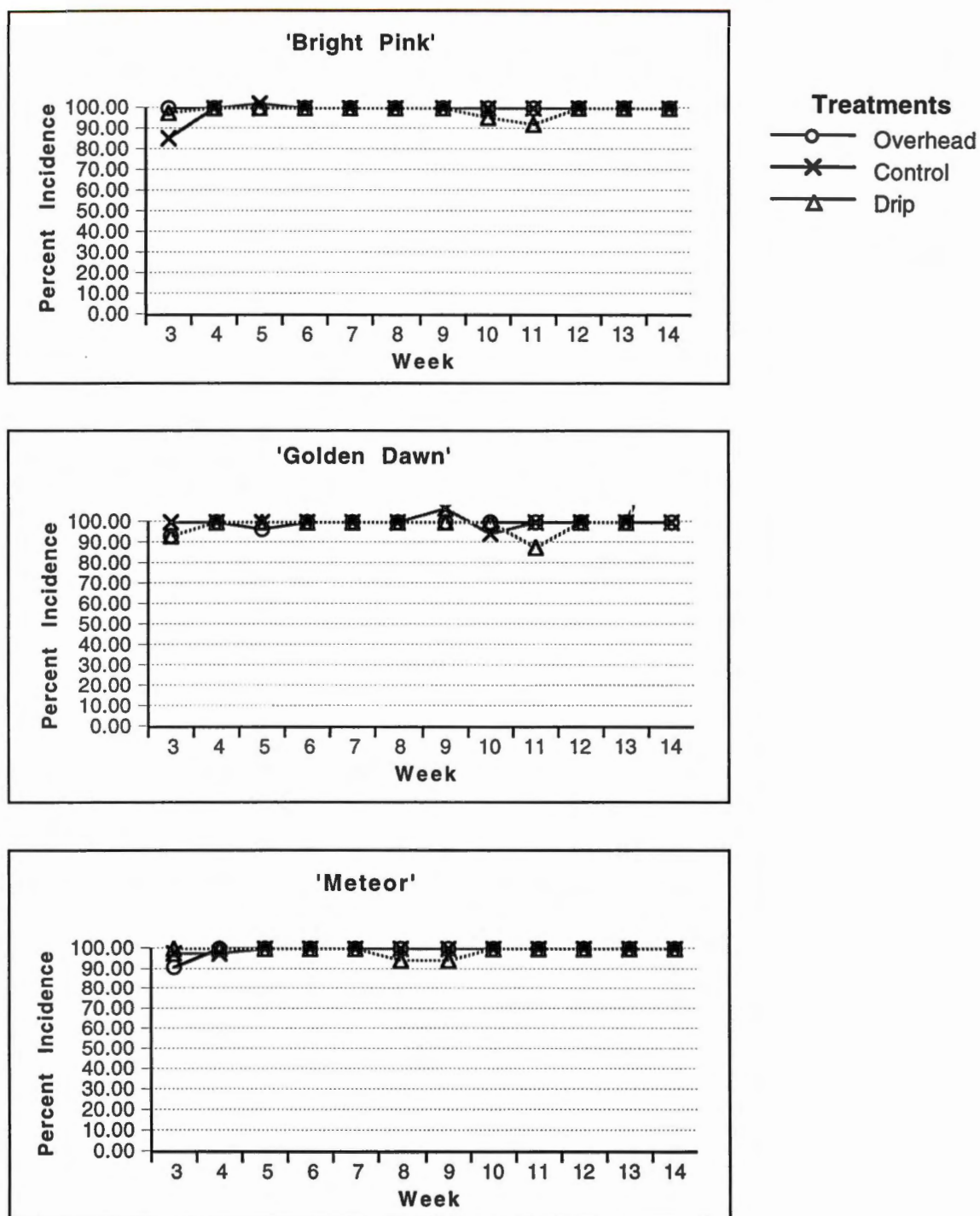
Appendix D. The effect of irrigation treatment on Alternaria blight severity for response group B, continued. LSD = 0.50. $P \leq 0.05$.

SHORT STUFF SERIES ALTERNARIA BLIGHT SEVERITY



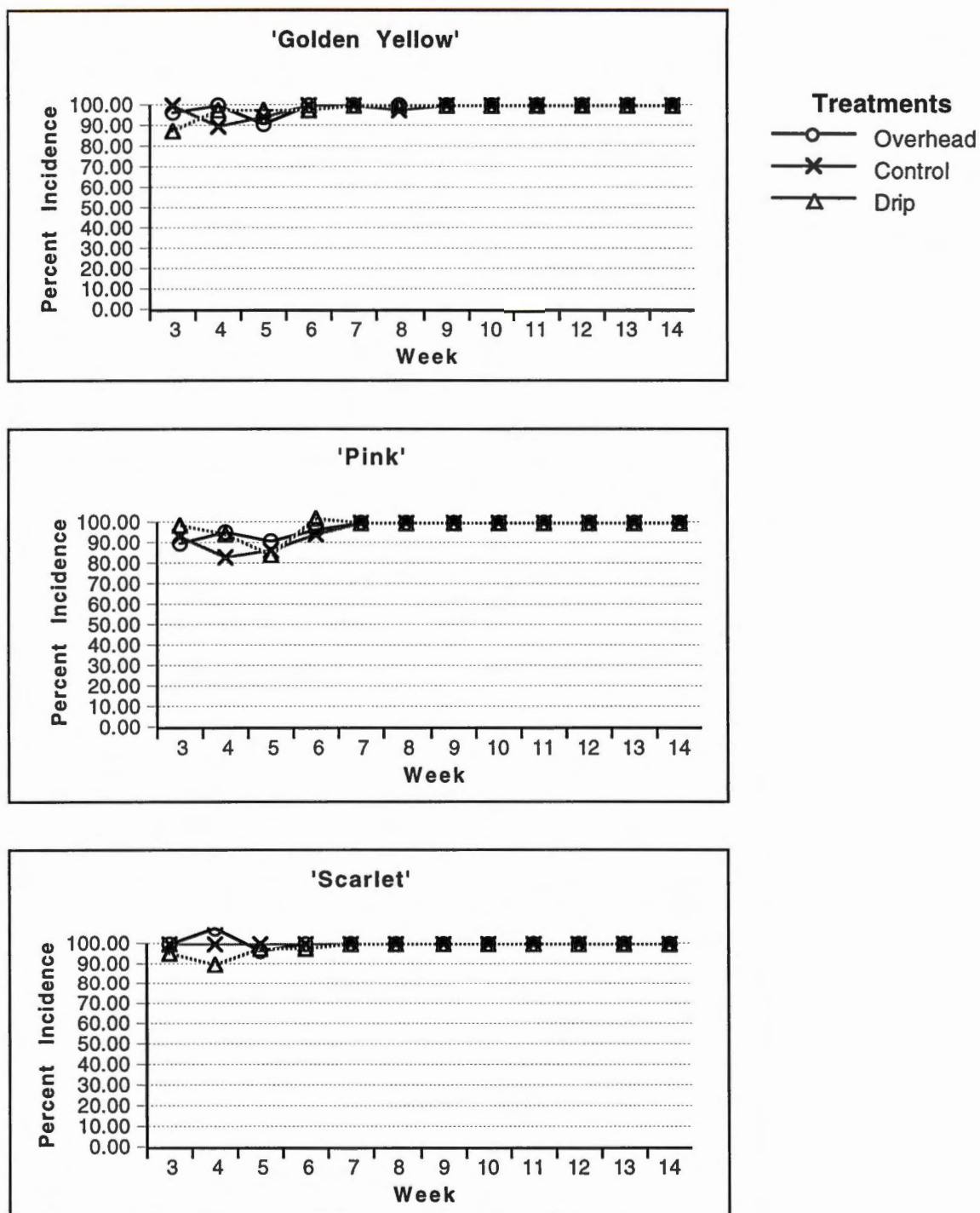
Appendix D. The effect of irrigation treatment on Alternaria blight severity for response group B, continued. LSD = 0.50. $P \leq 0.05$.

GIANT DAHLIA BLUEPOINT SERIES BACTERIAL LEAF & FLOWER SPOT INCIDENCE



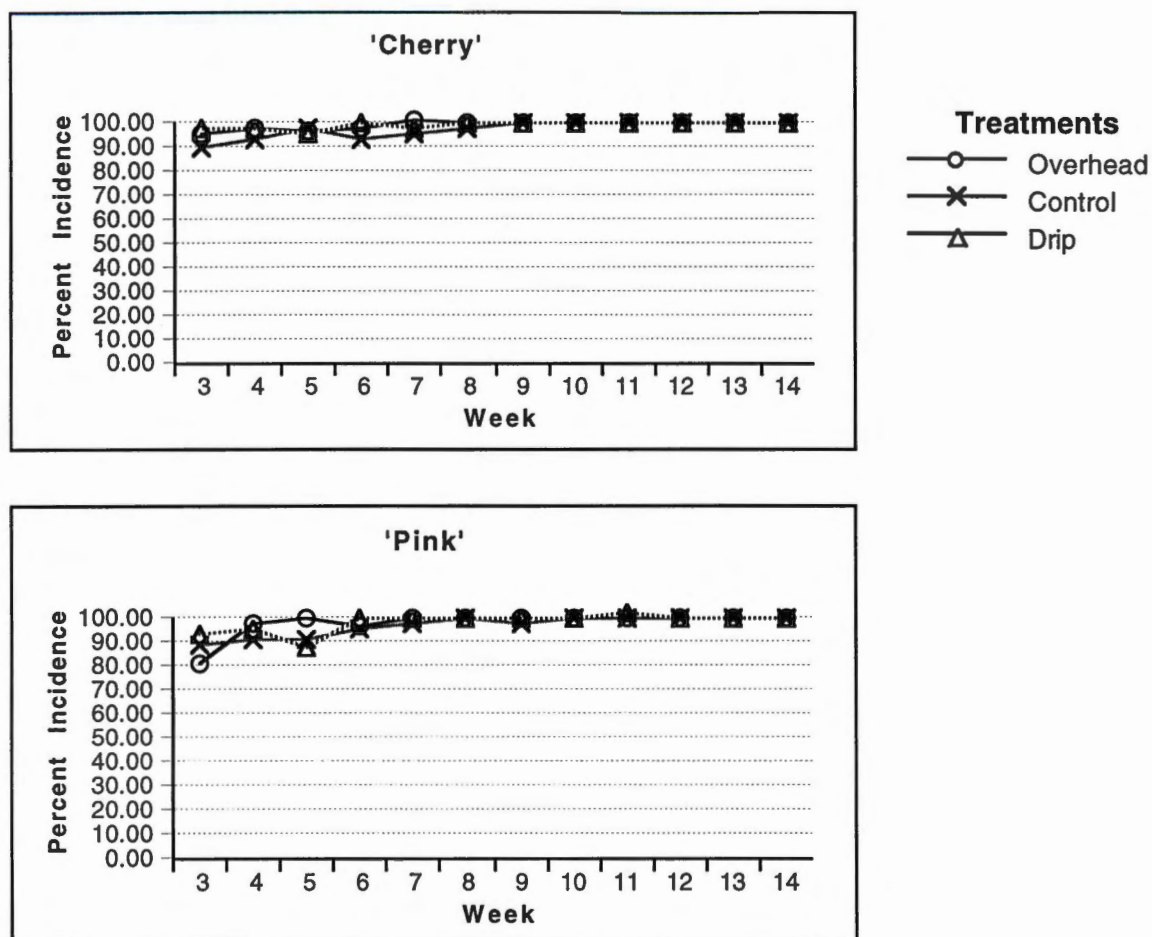
Appendix E. The effect of irrigation treatment on bacterial leaf and flower spot incidence for response group A. LSD = 8.36. $P \leq 0.05$.

OKLAHOMA SERIES BACTERIAL LEAF & FLOWER SPOT INCIDENCE



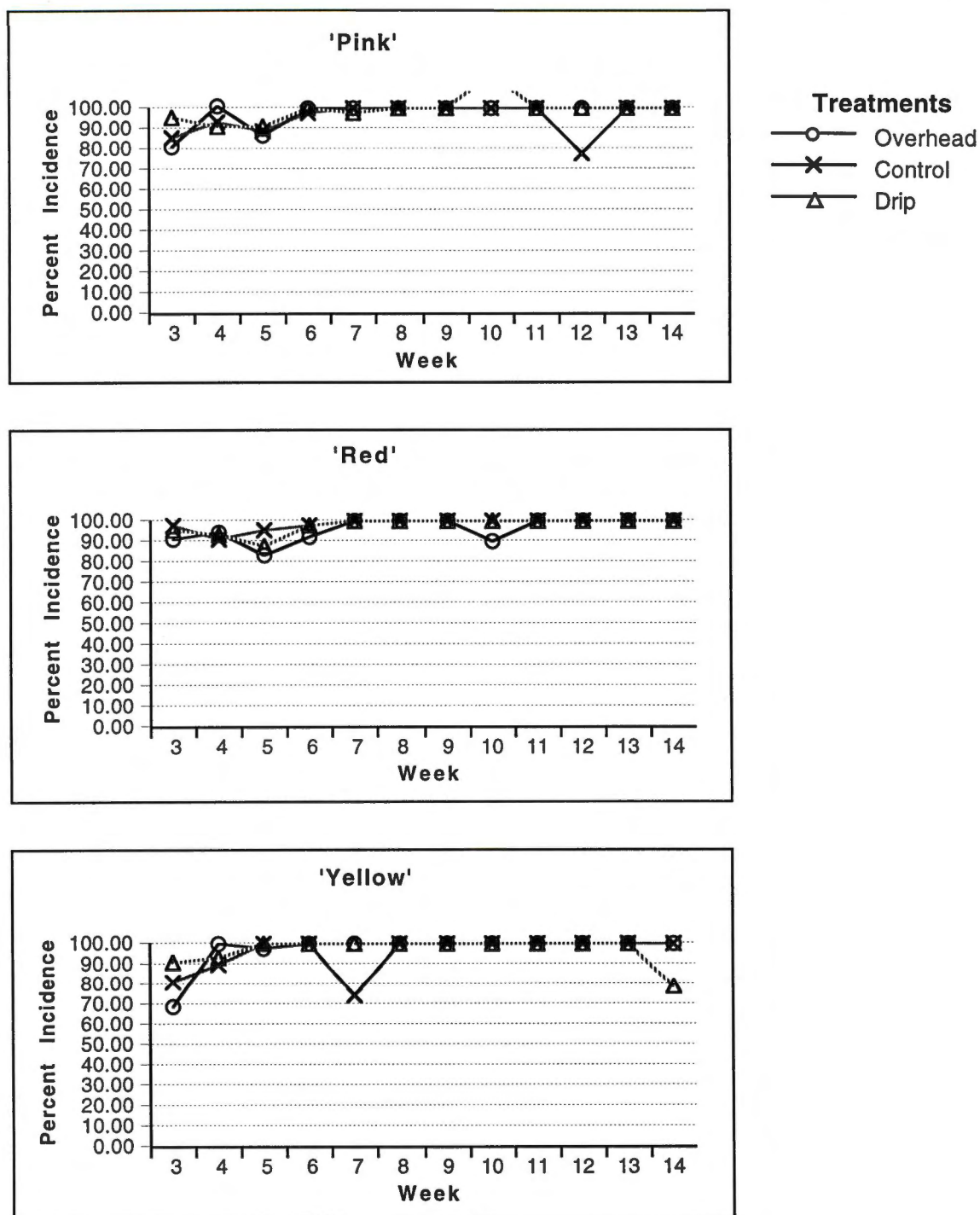
Appendix E. The effect of irrigation treatment on bacterial leaf and flower spot incidence for response group A, continued. LSD = 8.36. $P \leq 0.05$.

SMALL WORLD SERIES BACTERIAL LEAF & FLOWER SPOT INCIDENCE



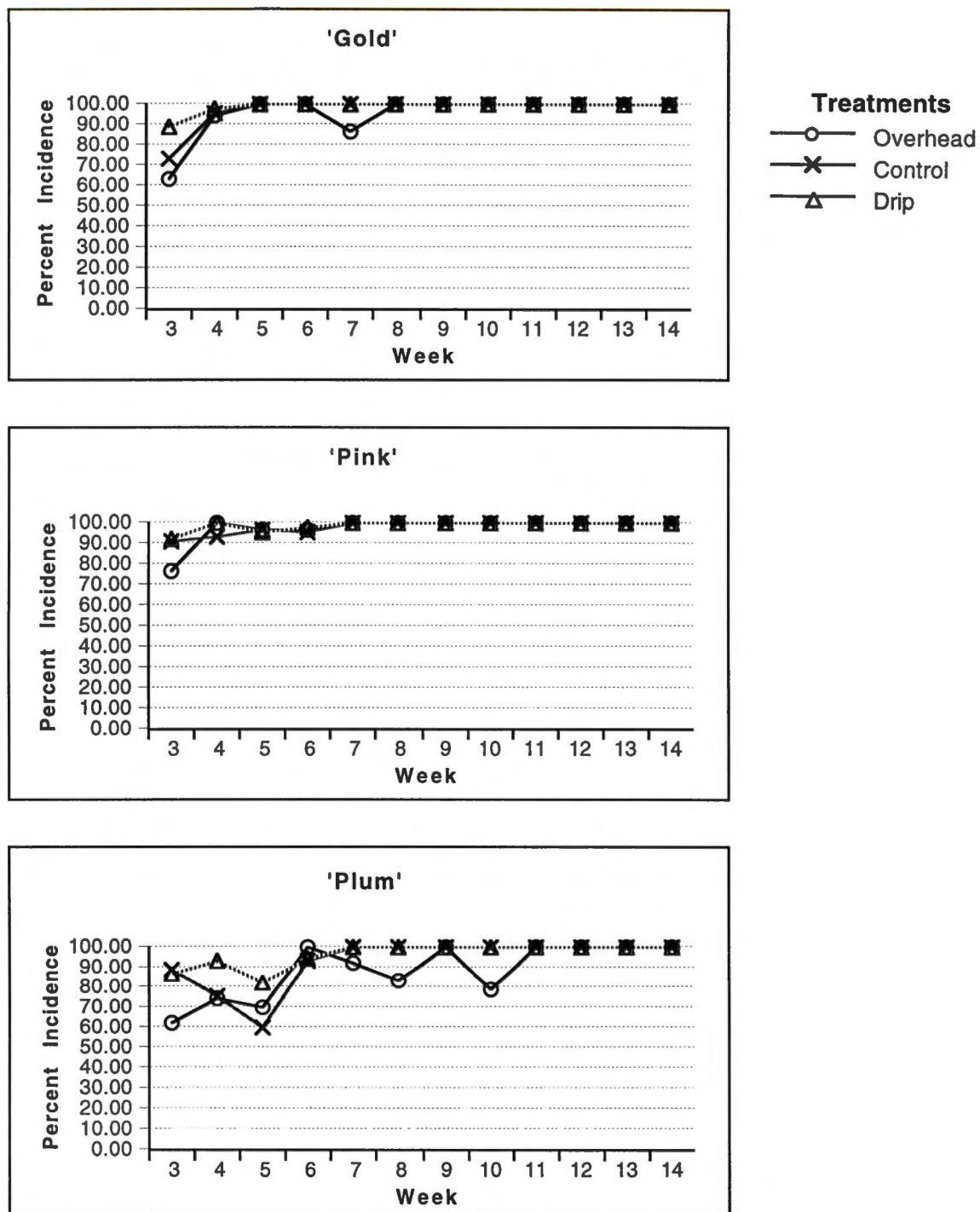
Appendix E. The effect of irrigation treatment on bacterial leaf and flower spot incidence for response group A, continued. LSD = 8.36. $P \leq 0.05$.

DREAMLAND SERIES BACTERIAL LEAF & FLOWER SPOT INCIDENCE



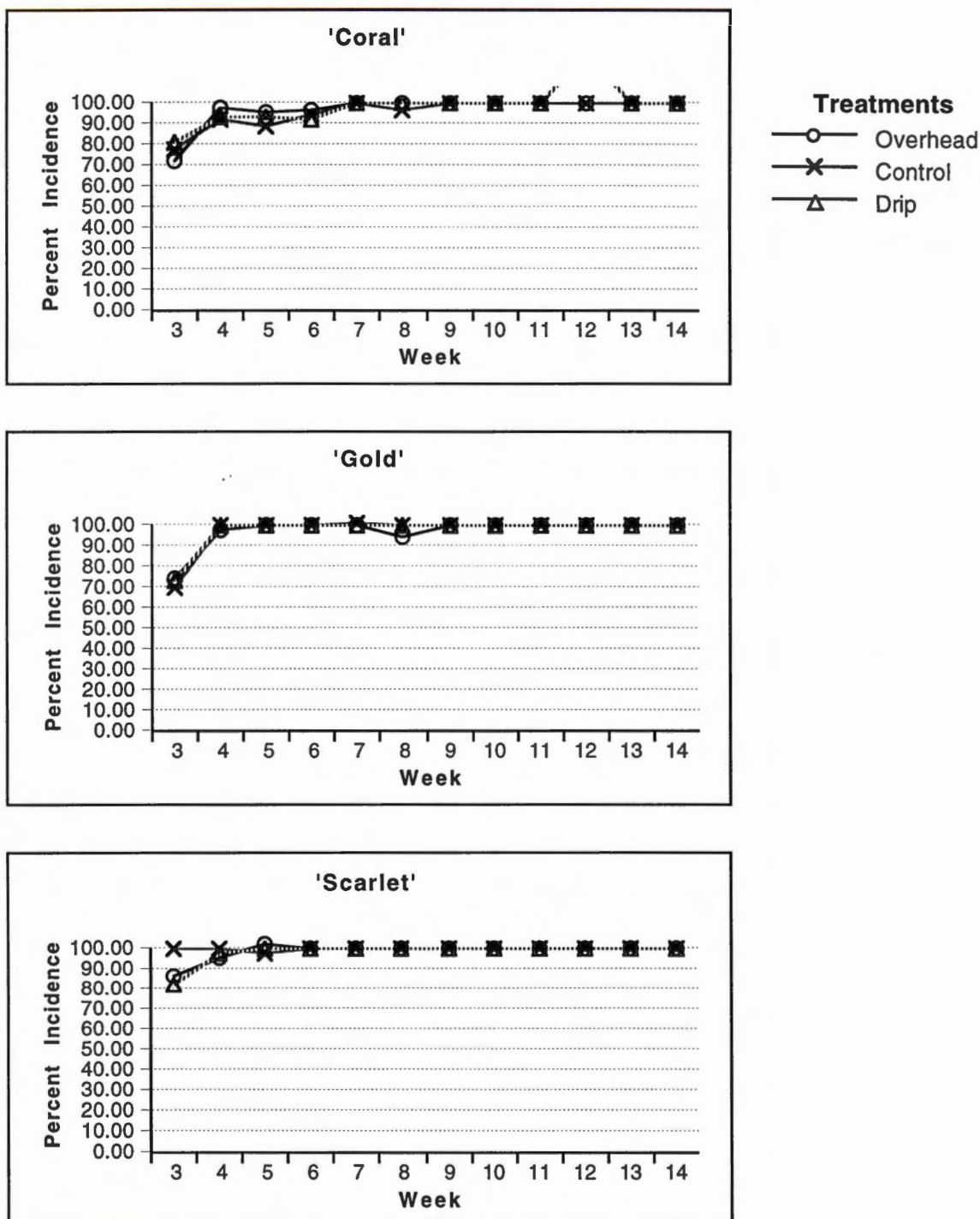
Appendix F. The effect of irrigation treatment on bacterial leaf and flower spot incidence for response group B. LSD = 8.36. $P \leq 0.05$.

PETER PAN SERIES BACTERIAL LEAF & FLOWER SPOT INCIDENCE



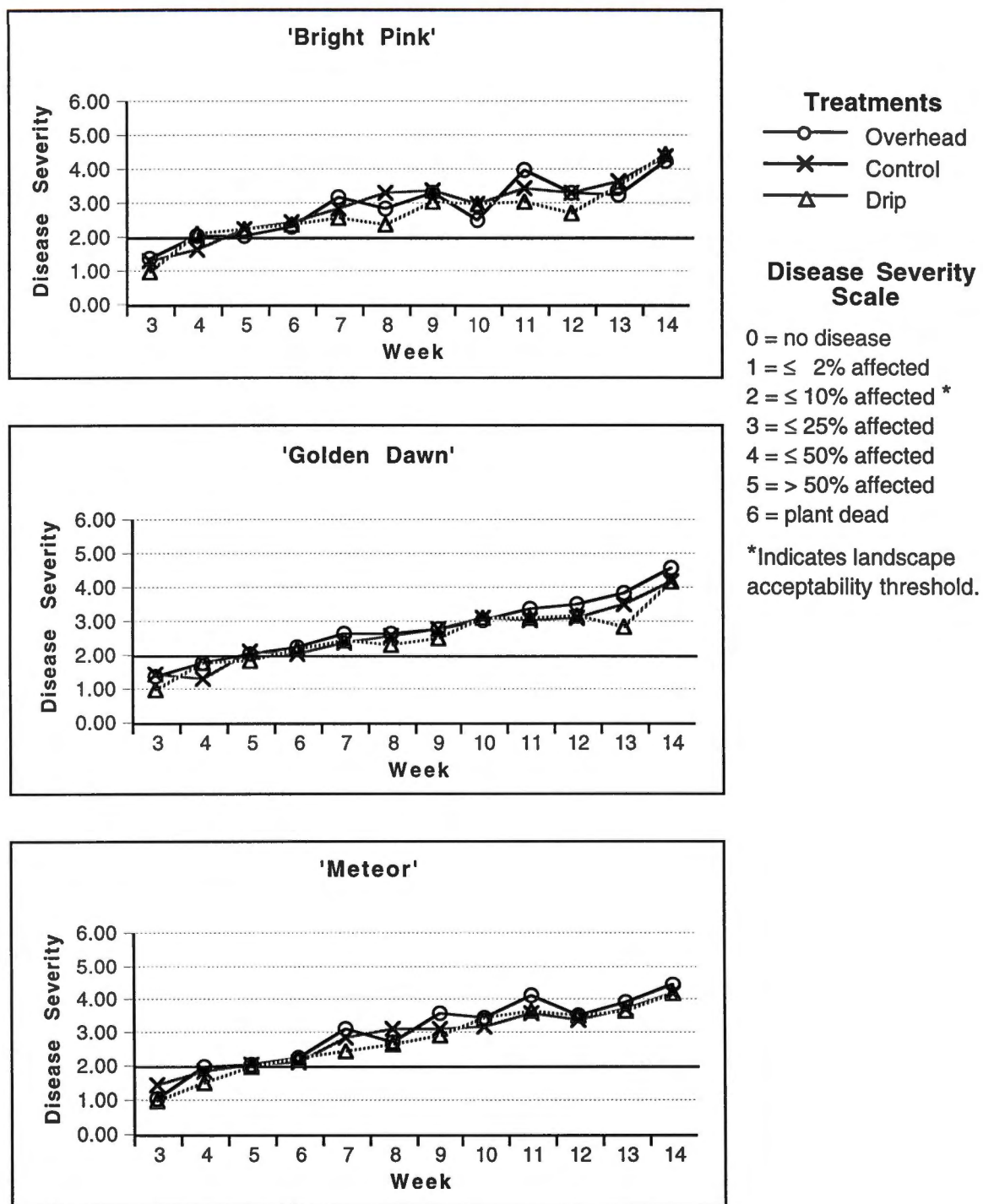
Appendix F. The effect of irrigation treatment on bacterial leaf and flower spot incidence for response group B, continued. LSD = 8.36. $P \leq 0.05$.

SHORT STUFF SERIES BACTERIAL LEAF & FLOWER SPOT INCIDENCE



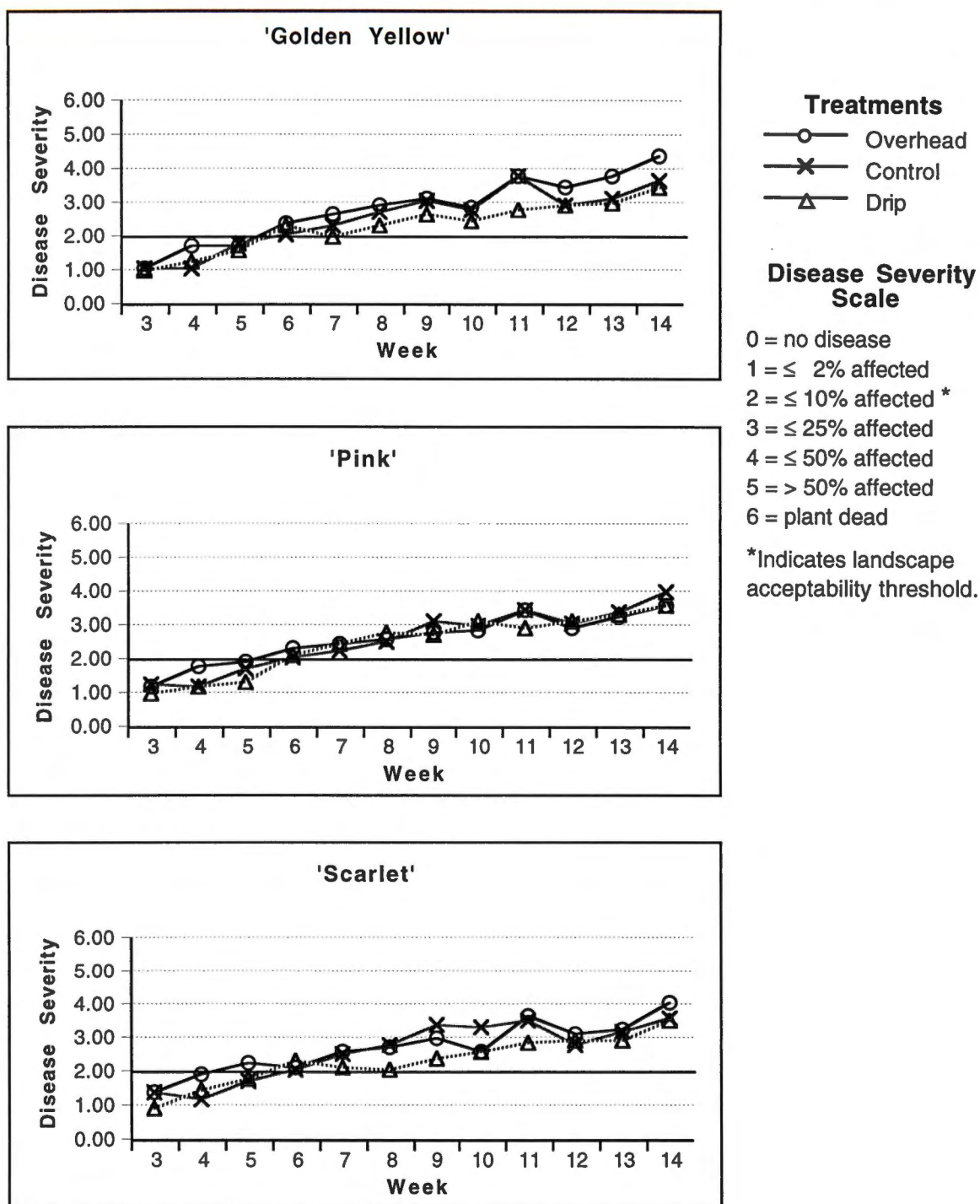
Appendix F. The effect of irrigation treatment on bacterial leaf and flower spot incidence for response group B, continued. LSD = 8.36. $P \leq 0.05$.

GIANT DAHLIA BLUEPOINT SERIES BACTERIAL LEAF & FLOWER SPOT SEVERITY



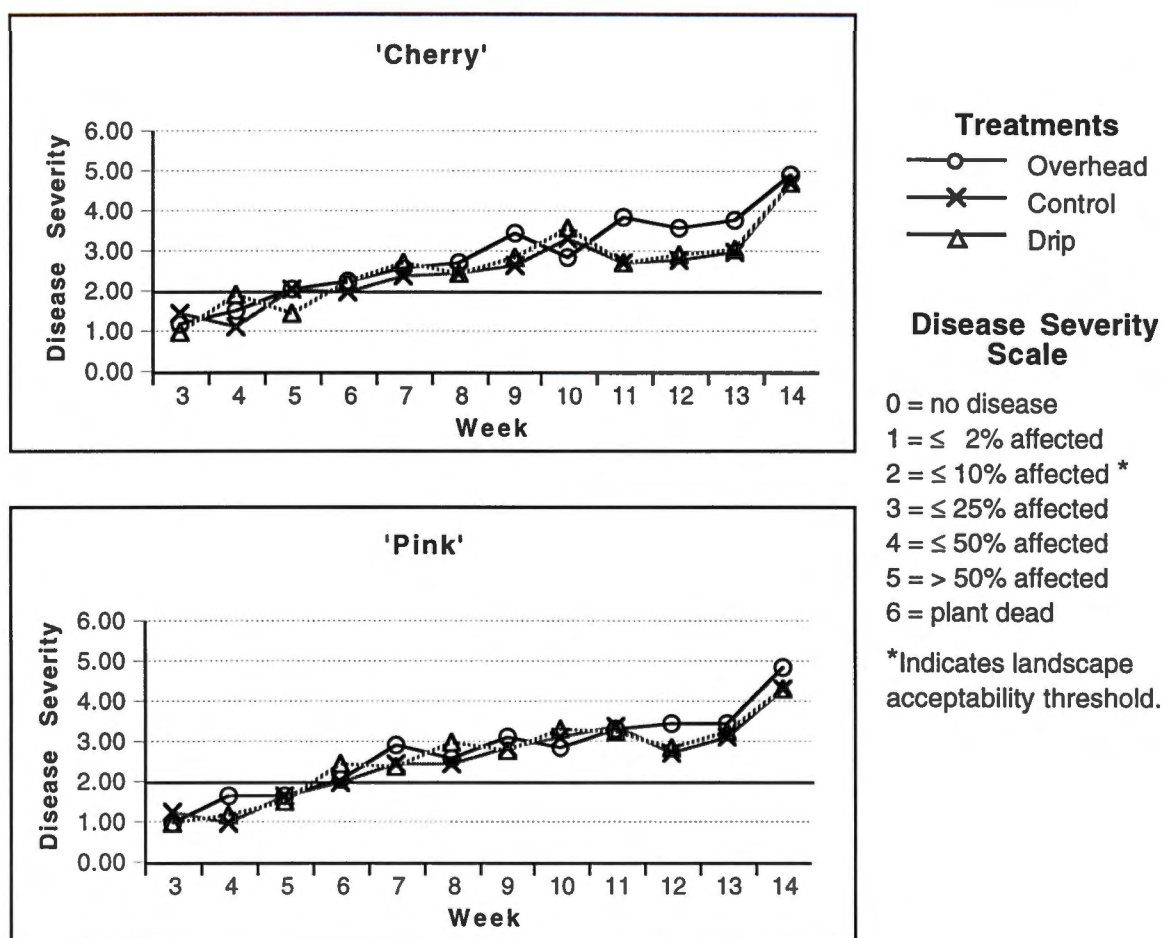
Appendix G. The effect of irrigation treatment on bacterial leaf and flower spot severity for response group A. LSD = 0.44. $P \leq 0.05$.

OKLAHOMA SERIES BACTERIAL LEAF & FLOWER SPOT SEVERITY



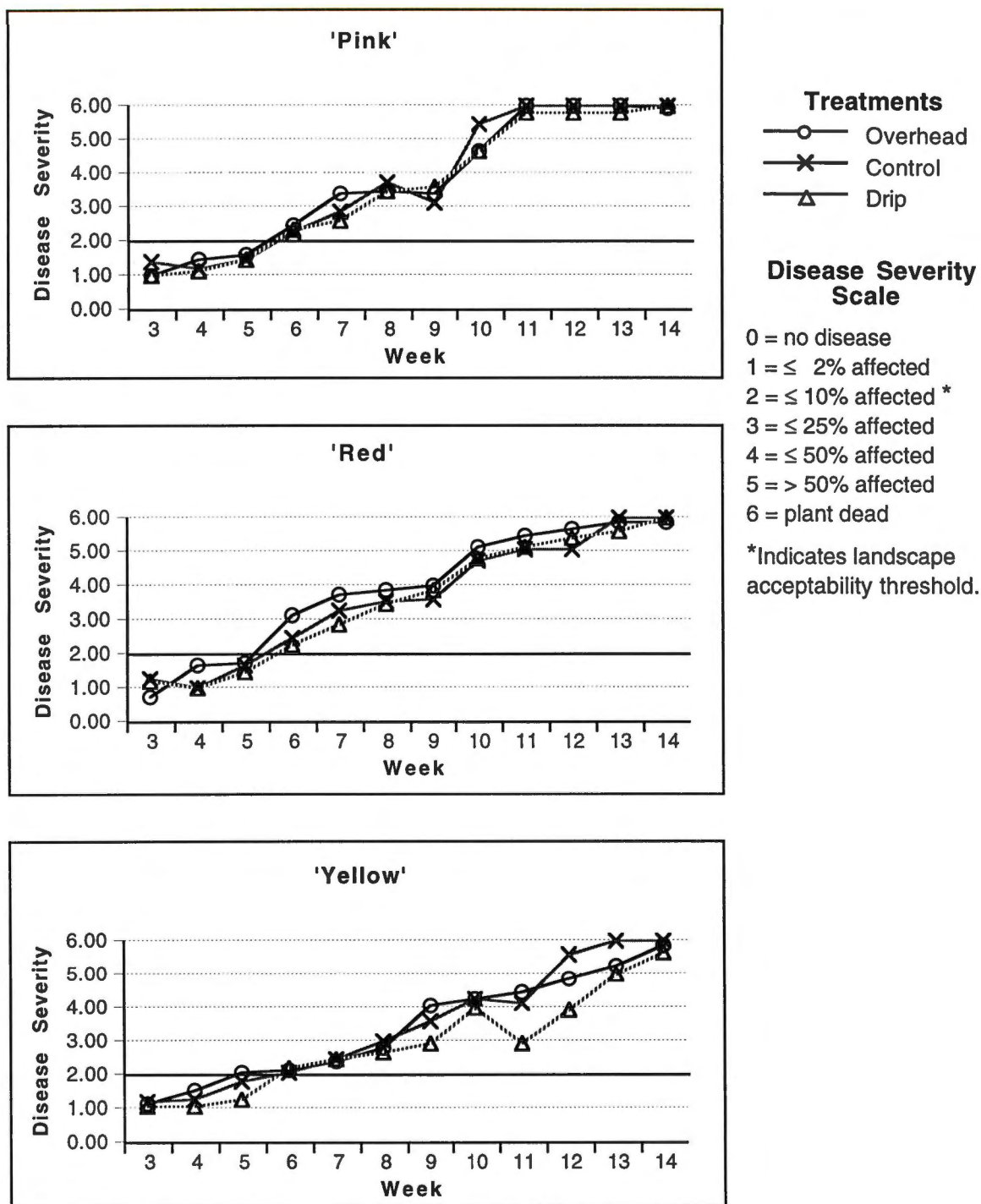
Appendix G. The effect of irrigation treatment on bacterial leaf and flower spot severity for response group A, continued. LSD = 0.44. $P \leq 0.05$.

SMALL WORLD SERIES BACTERIAL LEAF & FLOWER SPOT SEVERITY



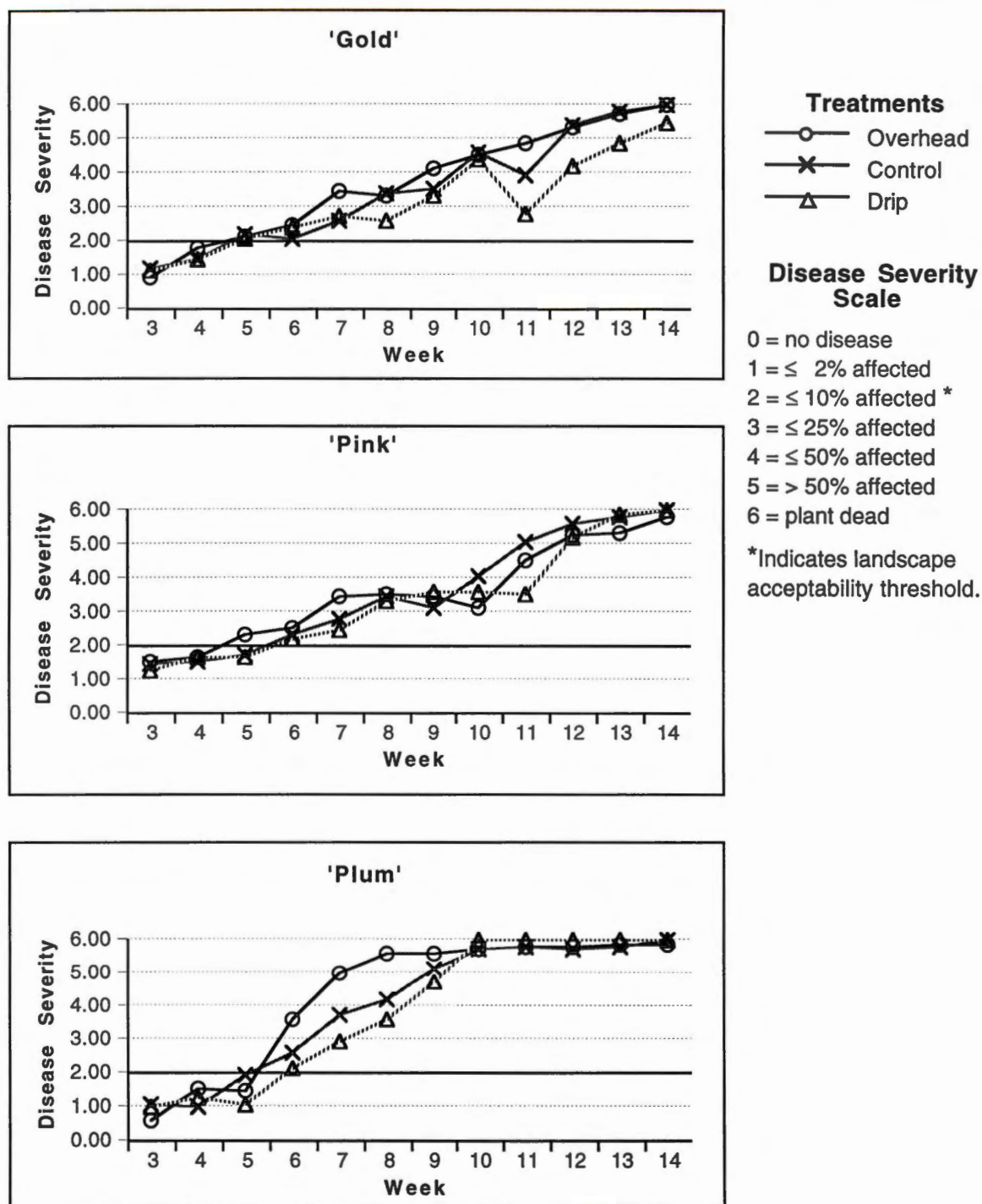
Appendix G. The effect of irrigation treatment on bacterial leaf and flower spot severity for response group A, continued. LSD = 0.44. $P \leq 0.05$.

DREAMLAND SERIES BACTERIAL LEAF & FLOWER SPOT SEVERITY



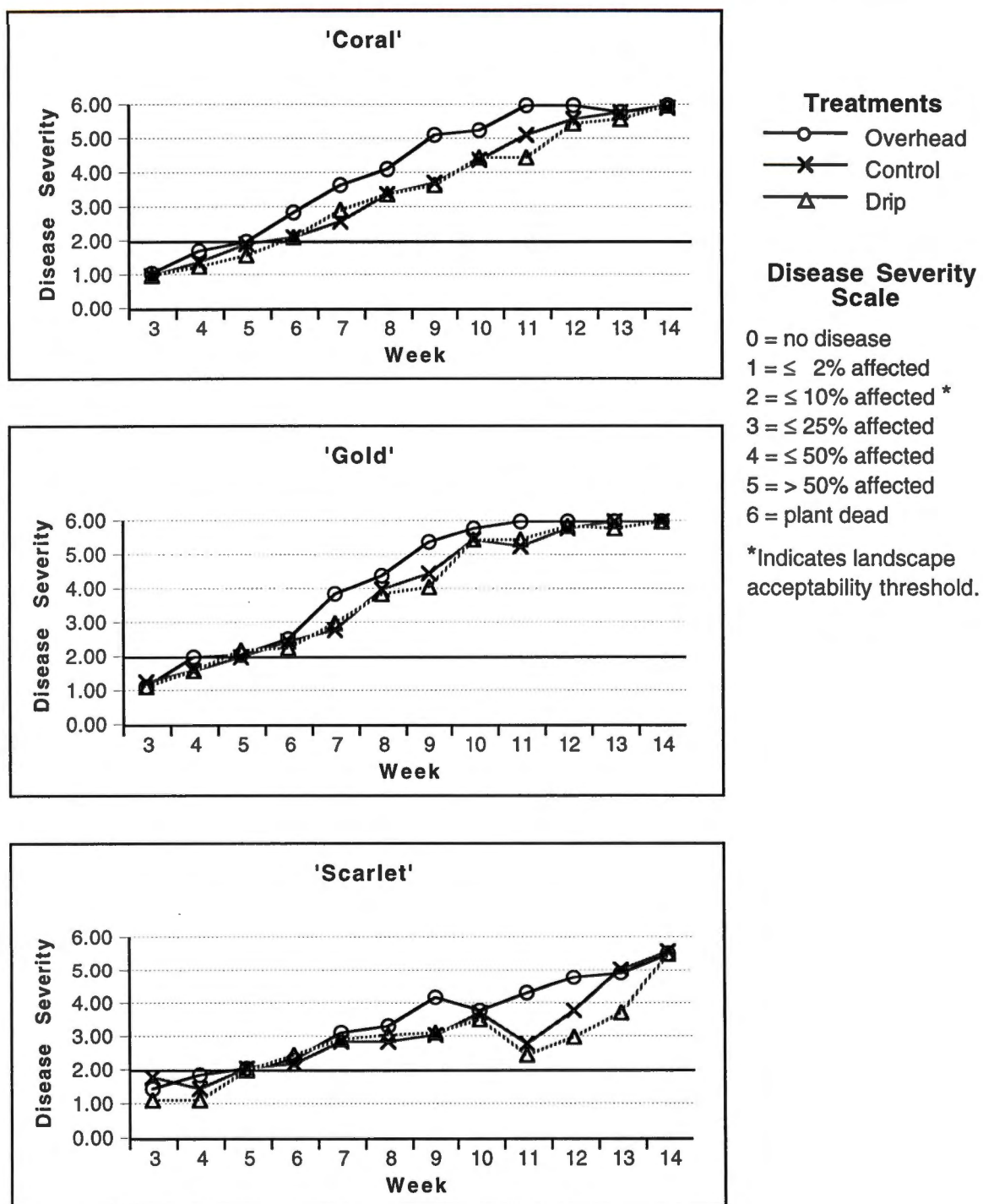
Appendix H. The effect of irrigation treatment on bacterial leaf and flower spot severity for response group B. LSD = 0.44. $P \leq 0.05$.

PETER PAN SERIES BACTERIAL LEAF & FLOWER SPOT SEVERITY



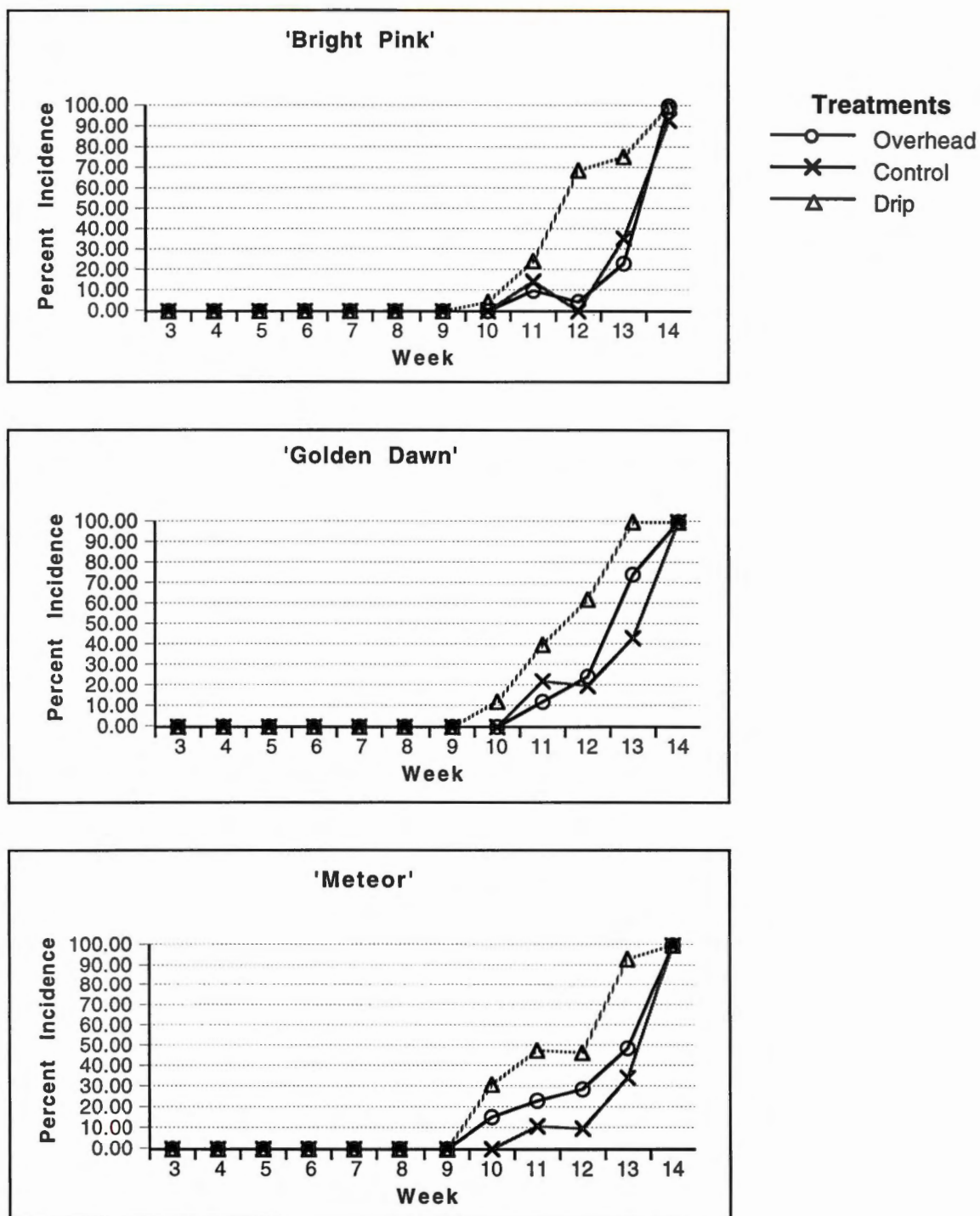
Appendix H. The effect of irrigation treatment on bacterial leaf and flower spot severity for response group B, continued. LSD = 0.44. $P \leq 0.05$.

SHORT STUFF SERIES BACTERIAL LEAF & FLOWER SPOT SEVERITY



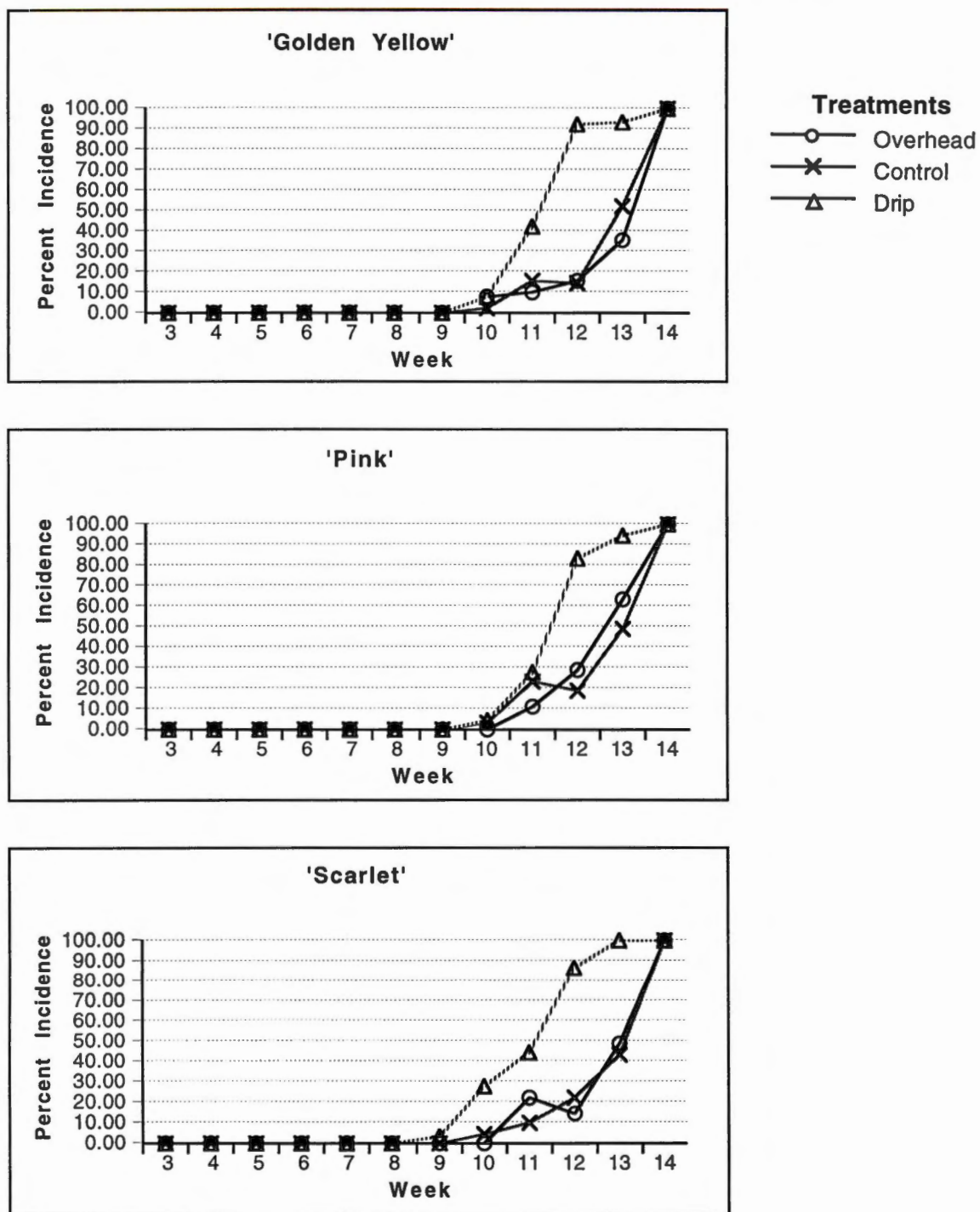
Appendix H. The effect of irrigation treatment on bacterial leaf and flower spot severity for response group B, continued. LSD = 0.44. $P \leq 0.05$.

GIANT DAHLIA BLUEPOINT SERIES POWDERY MILDEW INCIDENCE



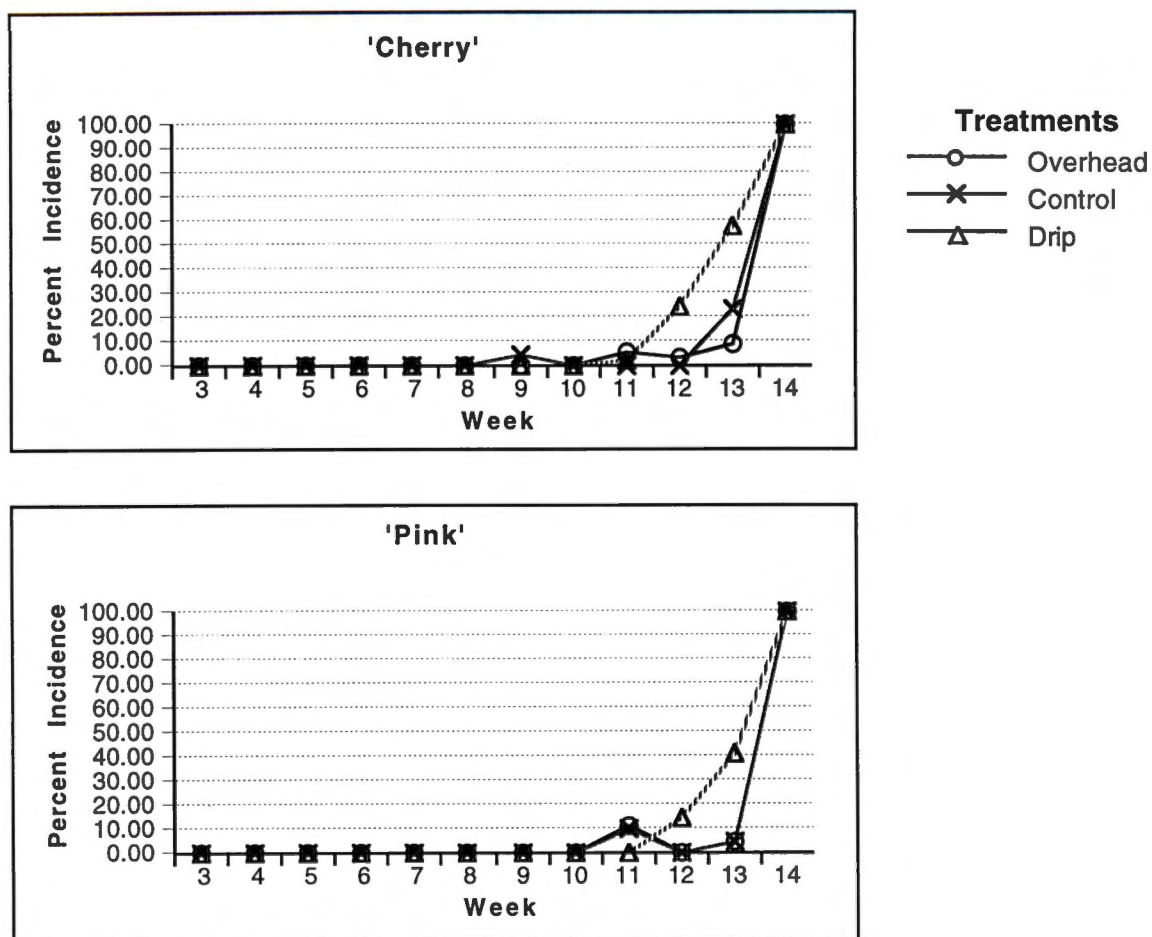
Appendix I. The effect of irrigation treatment on powdery mildew incidence for response group A.
 LSD = 10.68. $P \leq 0.05$.

OKLAHOMA SERIES POWDERY MILDEW INCIDENCE



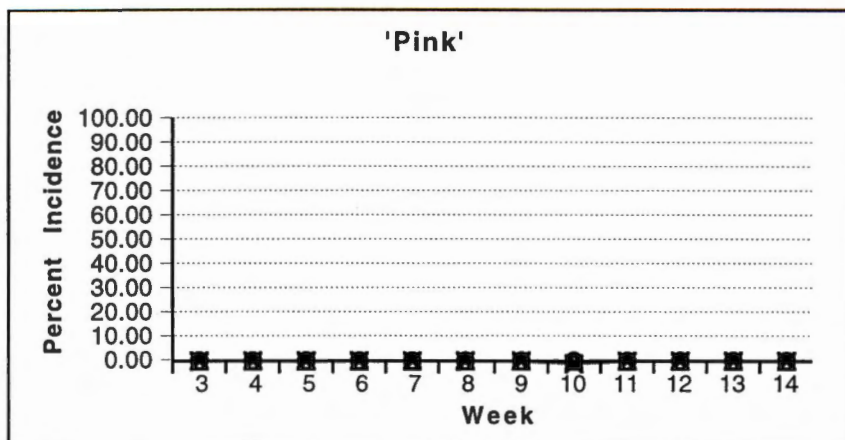
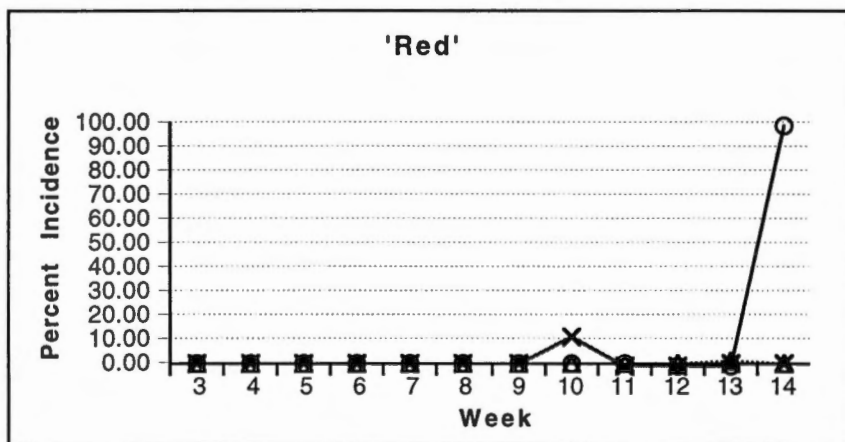
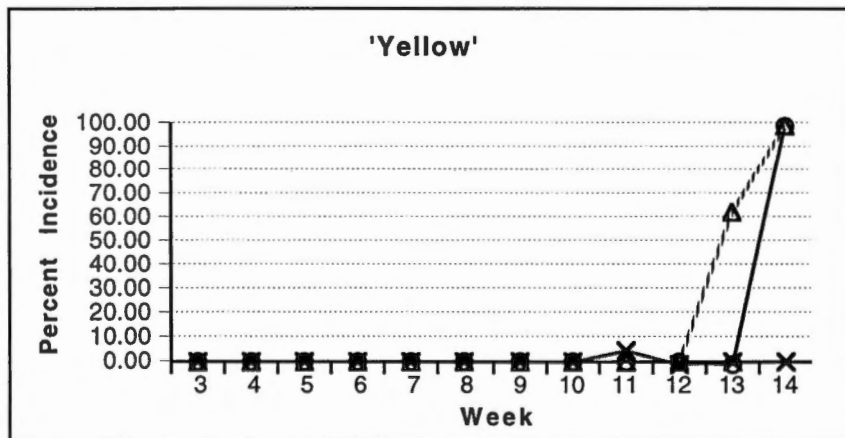
Appendix I. The effect of irrigation treatment on powdery mildew incidence for response group A, continued. LSD = 10.68. $P \leq 0.05$.

SMALL WORLD SERIES POWDERY MILDEW INCIDENCE



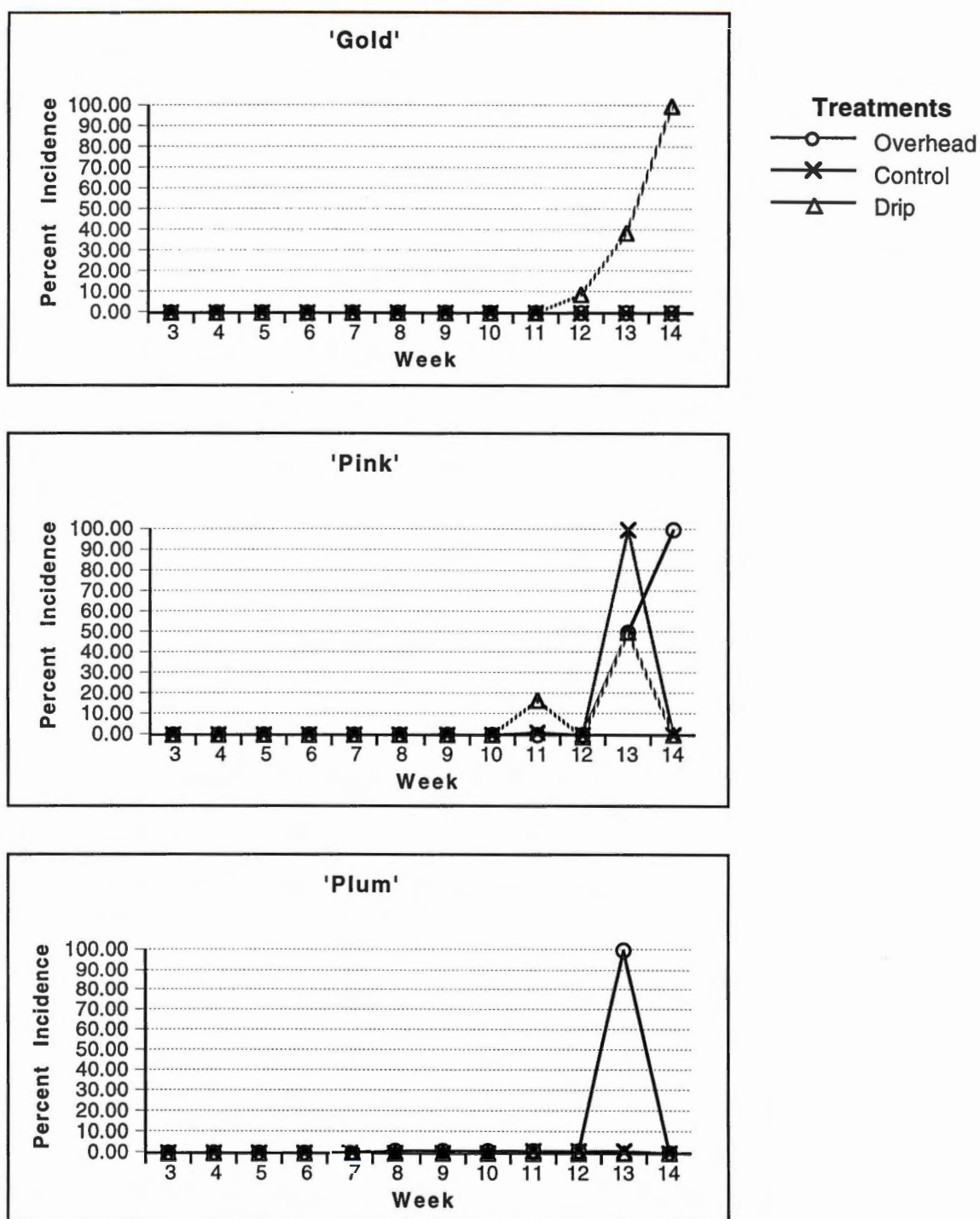
Appendix I. The effect of irrigation treatment on powdery mildew incidence for response group A, continued. LSD = 10.68. $P \leq 0.05$.

DREAMLAND SERIES POWDERY MILDEW INCIDENCE



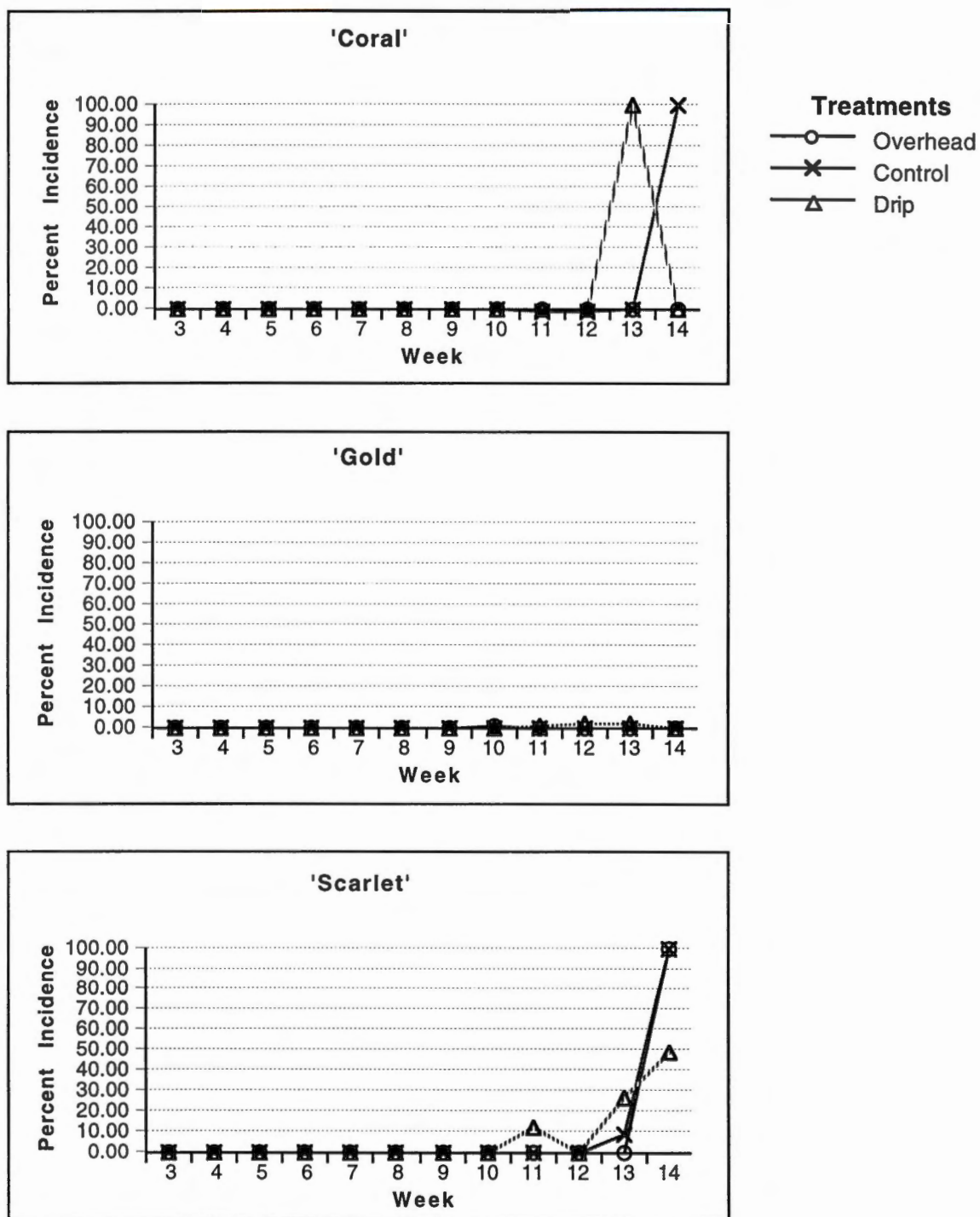
Appendix J. The effect of irrigation treatment on powdery mildew incidence for response group B.
 LSD = 10.68. $P \leq 0.05$.

PETER PAN SERIES POWDERY MILDEW INCIDENCE



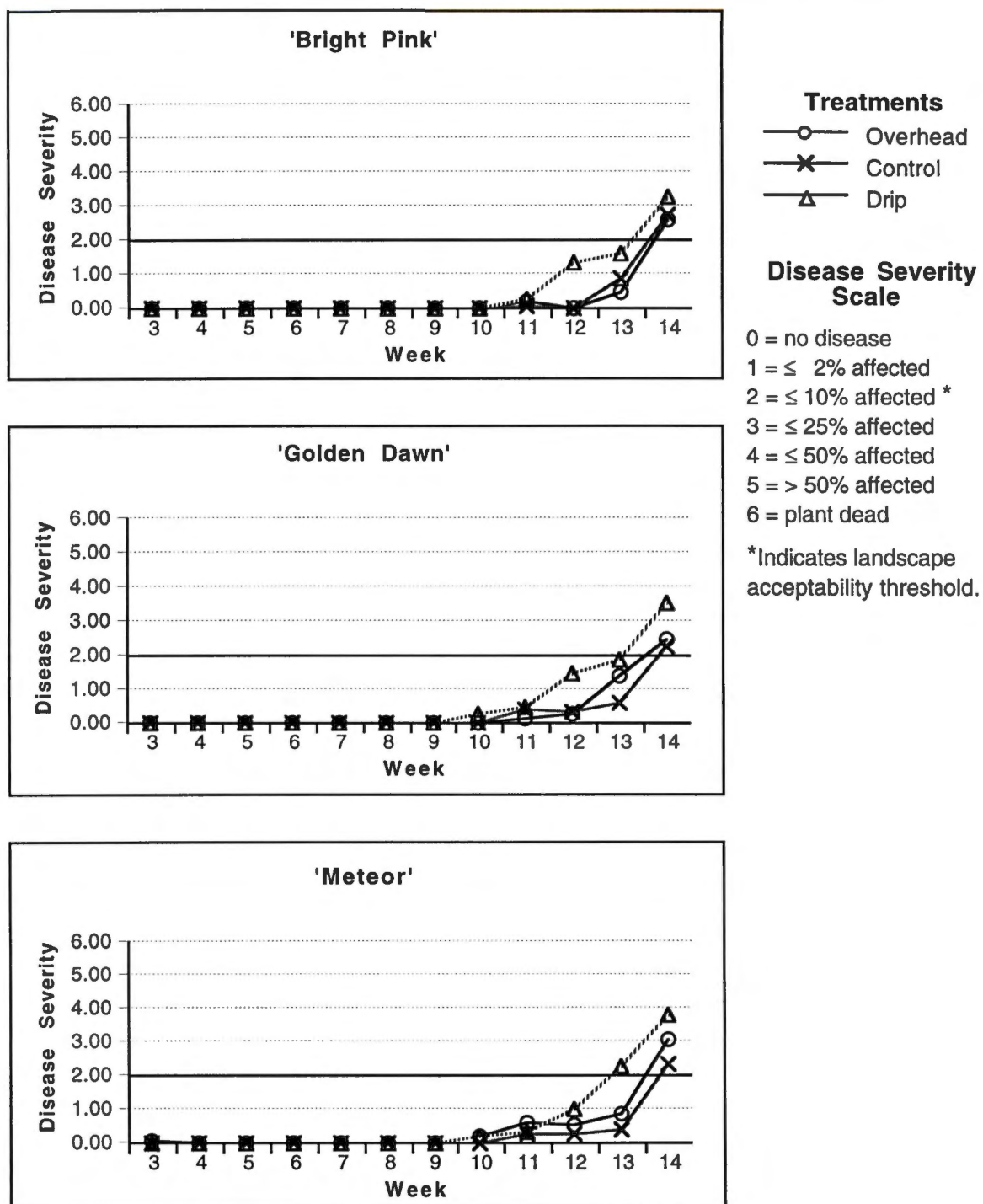
Appendix J. The effect of irrigation treatment on powdery mildew incidence for response group B, continued. LSD = 10.68. $P \leq 0.05$.

SHORT STUFF SERIES POWDERY MILDEW INCIDENCE



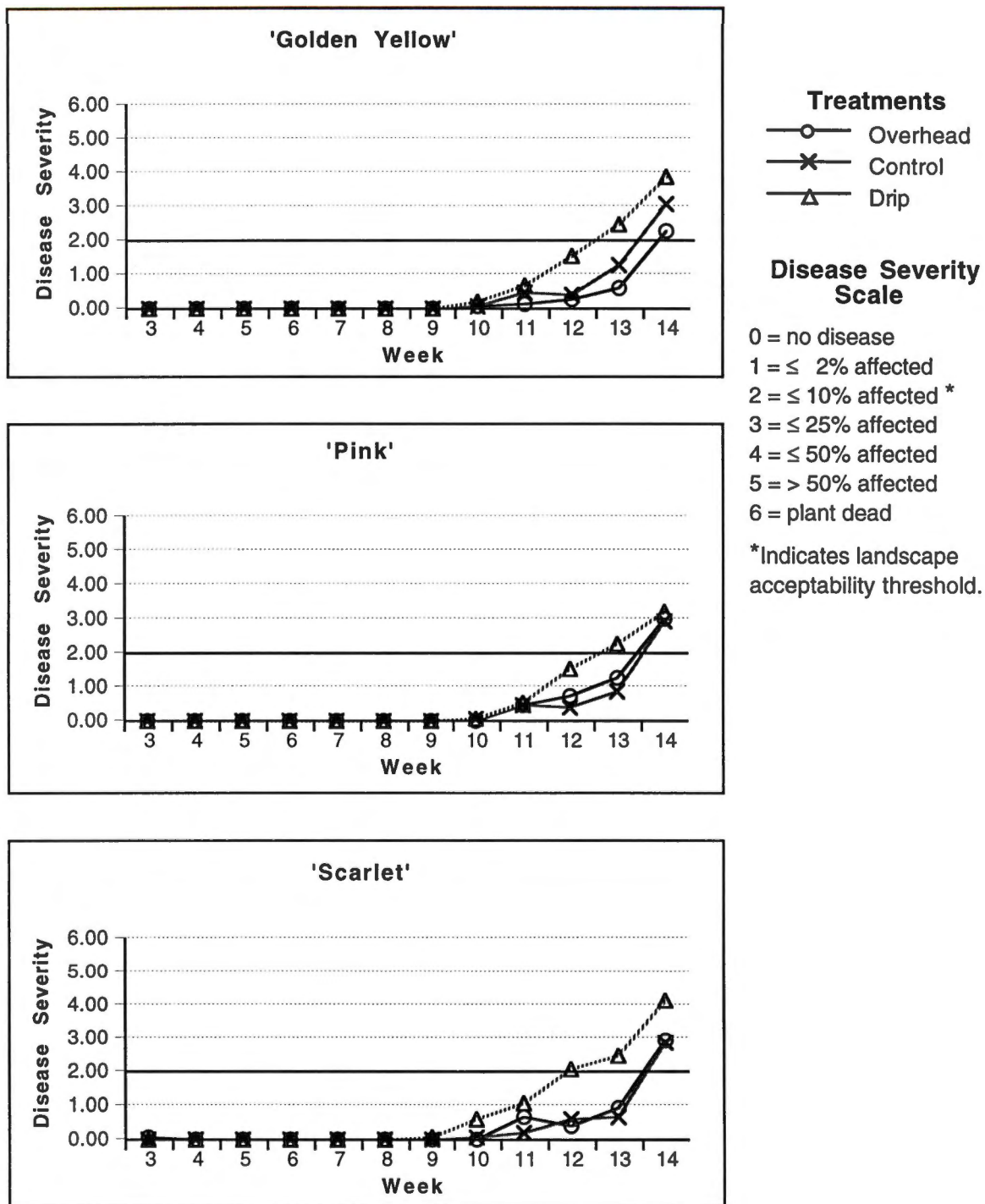
Appendix J. The effect of irrigation treatment on powdery mildew incidence for response group B, continued. LSD = 10.68. $P \leq 0.05$.

GIANT DAHLIA BLUEPOINT SERIES POWDERY MILDEW SEVERITY



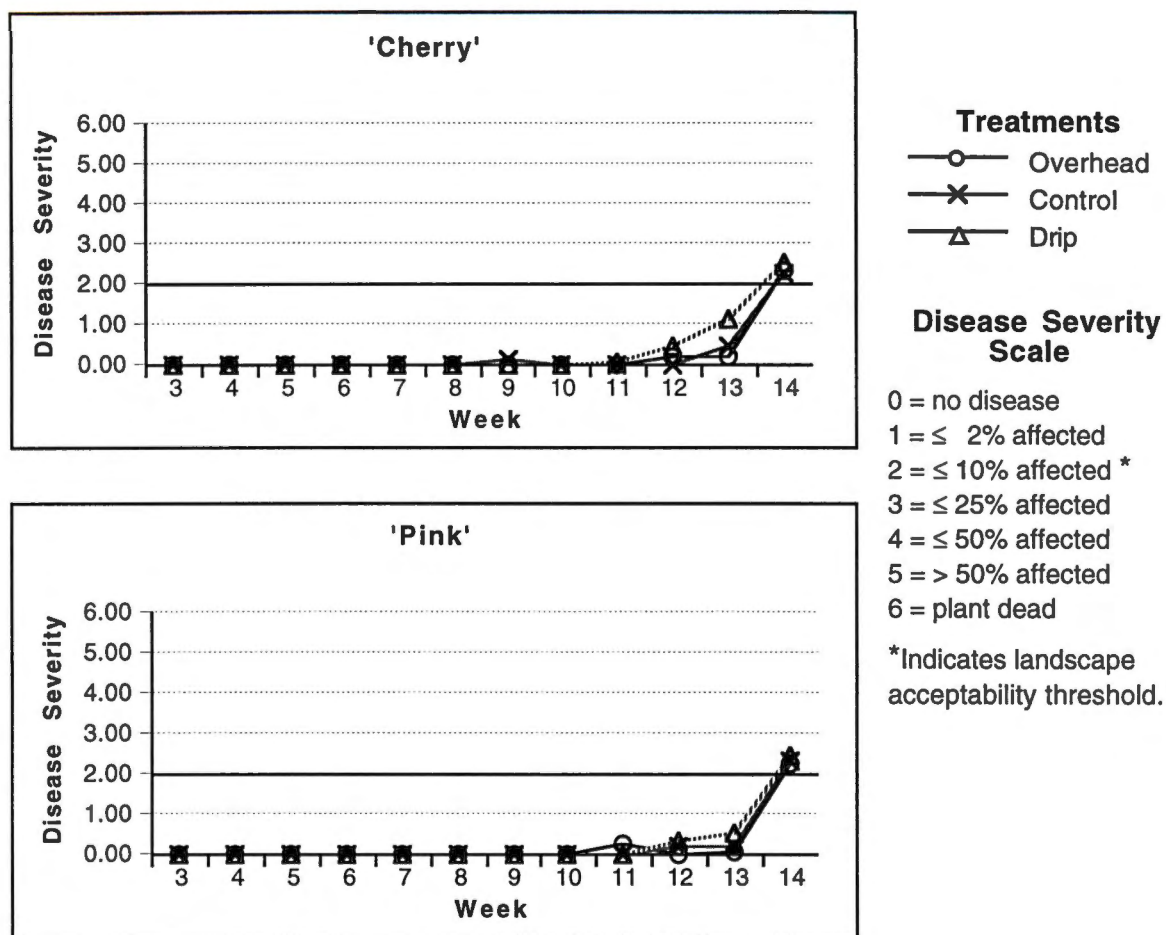
Appendix K. The effect of irrigation treatment on powdery mildew severity for response group A. LSD = 0.22. $P \leq 0.05$.

OKLAHOMA SERIES POWDERY MILDEW SEVERITY



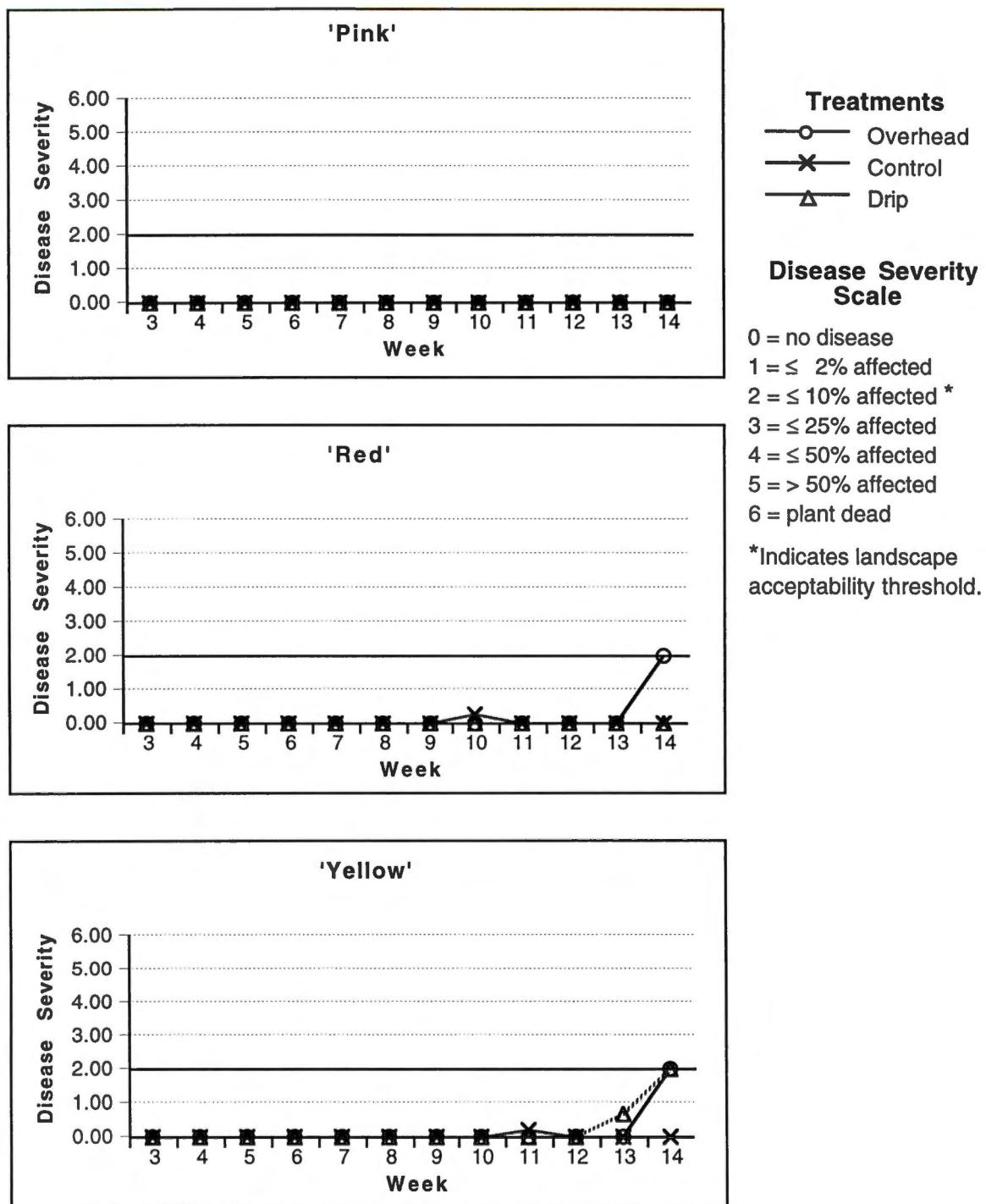
Appendix K. The effect of irrigation treatment on powdery mildew severity for response group A, continued. LSD = 0.22. $P \leq 0.05$.

SMALL WORLD SERIES POWDERY MILDEW SEVERITY



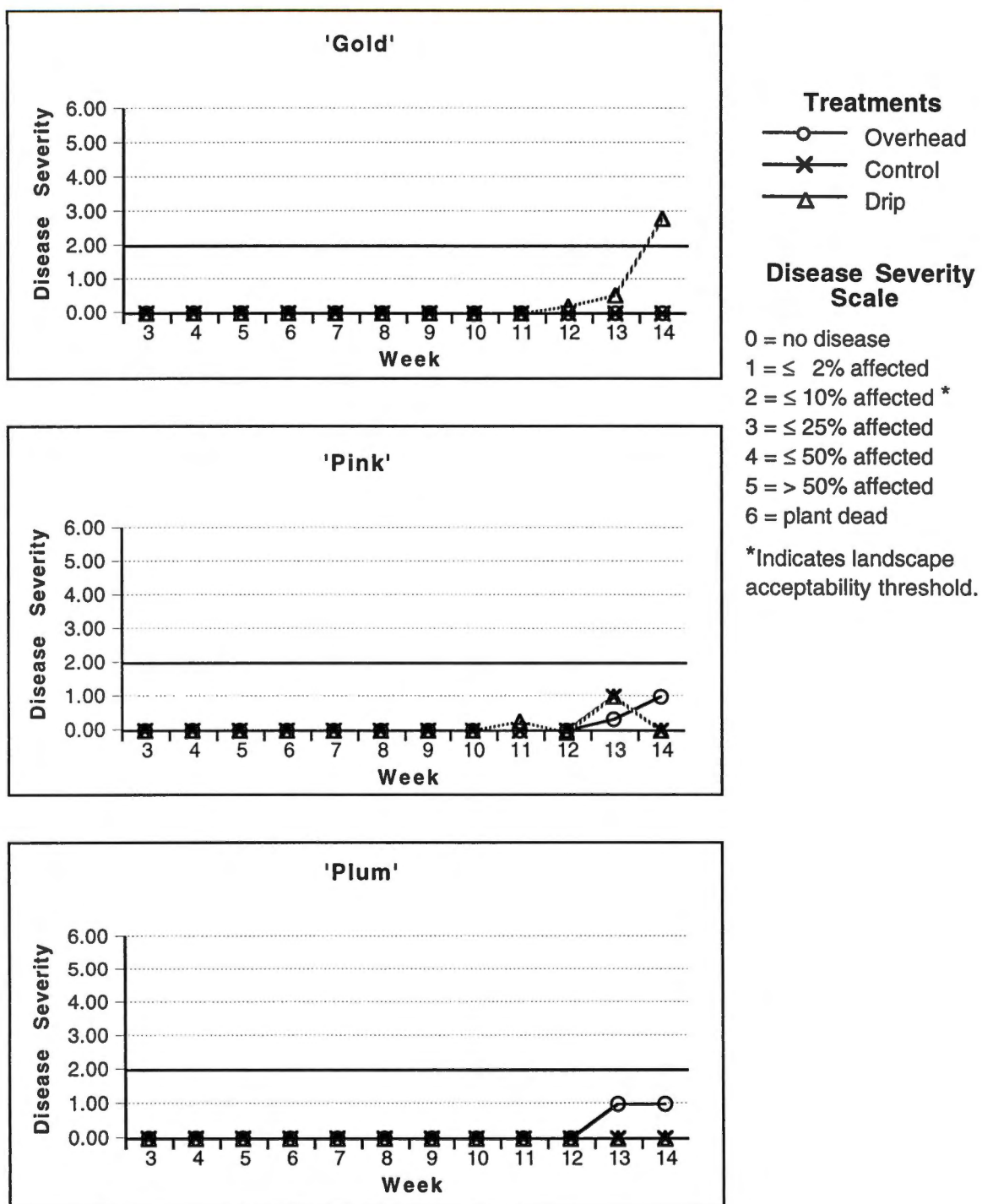
Appendix K. The effect of irrigation treatment on powdery mildew severity for response group A, continued. LSD = 0.22. $P \leq 0.05$.

DREAMLAND SERIES POWDERY MILDEW SEVERITY



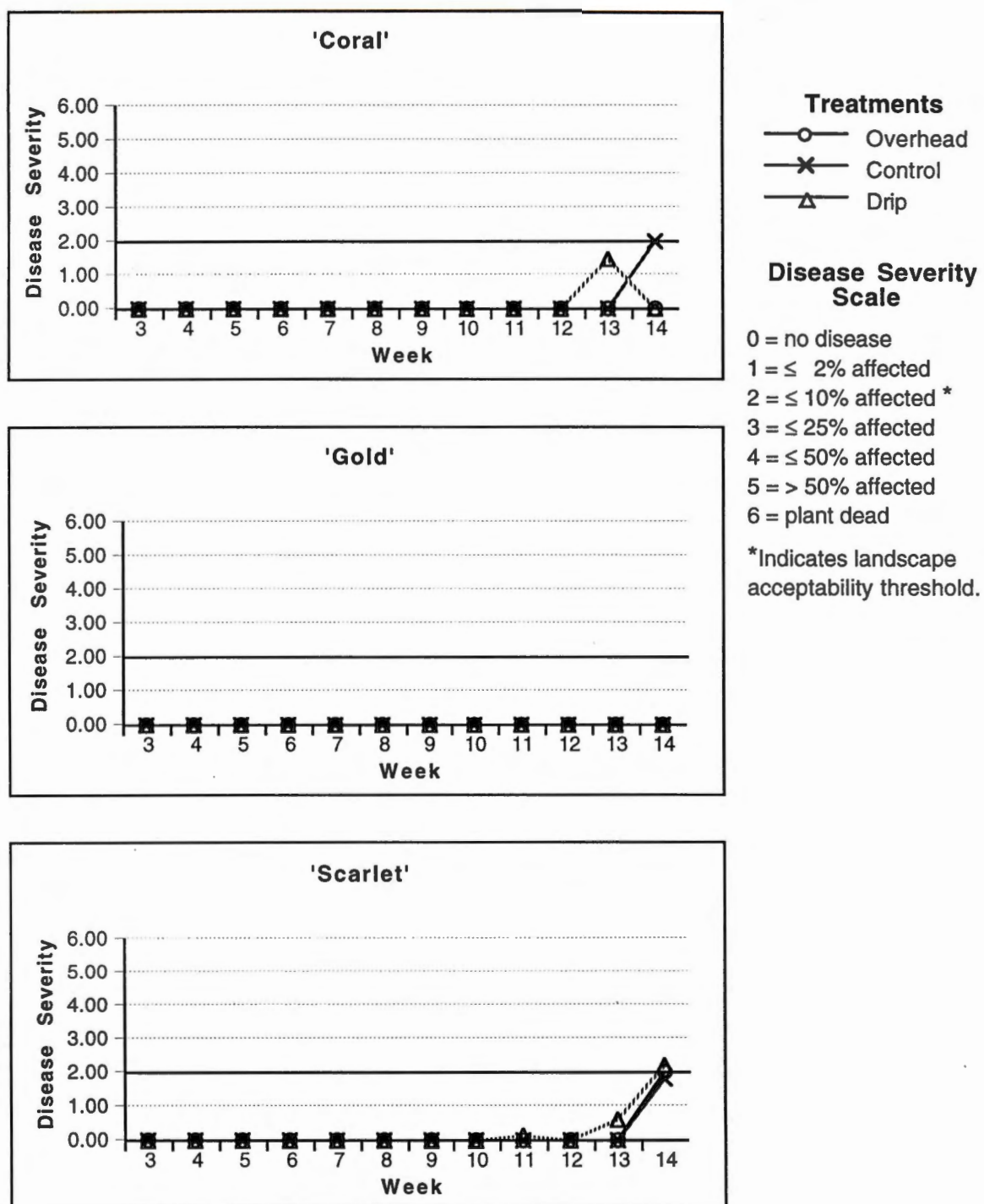
Appendix L. The effect of irrigation treatment on powdery mildew severity for response group B.
LSD = 0.22. $P \leq 0.05$.

PETER PAN SERIES POWDERY MILDEW SEVERITY



Appendix L. The effect of irrigation treatment on powdery mildew severity for response group B, continued. LSD = 0.22. $P \leq 0.05$.

SHORT STUFF SERIES POWDERY MILDEW SEVERITY



Appendix L. The effect of irrigation treatment on powdery mildew severity for response group B, continued. LSD = 0.22. $P \leq 0.05$.

PART 5
CONCLUSIONS AND RECOMMENDATIONS
FOR FURTHER STUDY

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

This research showed that in landscape situations which favor disease development, *Alternaria* blight, powdery mildew and/or bacterial leaf and flower spot may cause severe disease damage to *Zinnia elegans* and that none of the 57 cultivars we evaluated are immune. While it may appear that this research condemns the once-popular bedding plant and cutflower, this is not the case. In the right landscape situation, zinnia can still be a fine garden annual. As a result of this research, the right landscape situation appears to be a home garden where large monoculture plantings, which favor the spread of disease, are not typically used. Therefore, marketing of zinnia should be directed towards home gardeners rather than toward commercial landscape contractors.

Home gardeners should use zinnia in small isolated plantings tucked in among other types of plants in mixed garden settings, so not to provide a large host plant population where pathogens can flourish and spread. When a disease problem is found, treatment may be rendered on a small scale, such as a home garden, far more easily than on a large commercial scale. If chemical treatment is not a practical option, roguing diseased plants is far less painful in the small home garden than in a large commercial landscape. Relatively little time and money are lost, and the effect of the missing plants on the aesthetics of the garden are often not dramatic. Home gardeners often have a higher threshold for disease damage than professional landscapers. A plant with 10% foliage damage may not be viewed as "unacceptable" in the home landscape, while it may well be by a commercial landscaper.

These studies also showed that zinnia is not a suitable plant for season long color display because of its susceptibility to disease. For short-term color (10–12 weeks) zinnia appears to be a good choice. Few plants flower as reliably or as soon after planting as zinnia. These traits also make zinnia to be a good choice for cutflower production. Therefore, marketing zinnia towards cutflower producers is recommended.

In the irrigation study, *Alternaria* blight and bacterial leaf and flower spot were slightly more severe under overhead irrigation, while powdery mildew was slightly more severe with drip irrigation. This could lead one to the erroneous conclusion that drip

irrigation may help suppress *Alternaria* blight and bacterial leaf and flower spot. In the cultivar study, drip irrigation was used on the entire crop, yet severity of these diseases were no less severe in this study than they were in the irrigation study. Powdery mildew did not appear in either study, regardless of irrigation method, until late in the experiment, when night-time temperatures were conducive to its development. By the end of both experiments, powdery mildew infection was severe in all surviving plants, regardless of irrigation method used. Therefore, it appears that irrigation method has little effect on disease severity and there is no need for home gardeners to feel compelled to replace already existing overhead irrigation systems in the hope that disease severity will decrease under drip irrigation.

These studies showed that the environment under which zinnias are grown may determine what disease(s) will affect the plants. Plants grown outdoors in field plots were severely affected by *Alternaria* blight and bacterial leaf and flower spot, while those grown in the greenhouse showed virtually no damage from these diseases. On the other hand, zinnias grown in the greenhouse were affected by powdery mildew, which did not even appear on plants in the field until very late in the season. In this research, plants which were grown in field plots were sown in germination row trays and then transplanted into cell-packs and finally, transplanted into the field. Zinnias grown in the greenhouse were direct-seeded into pots where they remained for the duration of the study. Further research on whether direct-seeding is an effective means of suppressing disease in zinnia is suggested. Greenhouse growers who produce zinnias may want to consider direct-seeding as a possible means of suppressing disease.

These studies also indicated that some pre-germination seed treatments may have an effect on germination rate of zinnia seed. While many treatments used in this study proved to have a detrimental effect on germination rate, one, *Trichoderma harzianum* strain T-22, showed promise as a germination stimulation agent. Enhancing germination rate is of economic importance to growers and further research into the affect of this biological agent on other ornamental seed-grown crops is recommended.

VITA

Linda Luann Gombert was born in Huntsville, Alabama on December 28, 1960. She lived in Huntsville, Alabama; Merritt Island, Florida; and Knoxville, Tennessee during childhood and graduated from Farragut High School in Knoxville in 1978. She made her living by working in the printing industry in Knoxville while attending the University of Tennessee. Later she moved to Wilmington, North Carolina with the intention of returning to college to complete a degree in biology. In January, 1995, she returned to the University of Tennessee, Knoxville and earned the Bachelor of Science degree with a major in Ornamental Horticulture and Landscape Design in December, 1996. In January, 1997, she entered the Master's program in Ornamental Horticulture and Landscape Design at the University of Tennessee. In December, 1998, she was granted the Master of Science degree from The University of Tennessee, Knoxville, with a major in Ornamental Horticulture and Landscape Design. While working toward this degree, she was employed by the University of Tennessee Agricultural Experiment Station as a Graduate Teaching and/or Research Assistant in the Department of Ornamental Horticulture and Landscape Design.

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