Comparison of Plastic Mulch and Nitrogen Form on the Incidence of Verticillium Wilt of Eggplant

Wade H. Elmer, Associate Plant Pathologist, The Connecticut Agricultural Experiment Station, P. O. Box 1106, New Haven 06504

ABSTRACT

Elmer, W. H. 2000. Comparison of plastic mulch and nitrogen form on the incidence of Verticillium wilt of eggplant. Plant Dis. 84:1231-1234.

Eggplants (cv. Midnite) were grown during 1996 to 1998 in soils naturally infested with *Verticillium dahliae*. Experimental plots were either mulched with black plastic or grown on bare ground and fertilized with either $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ at 224 kg of N per hectare each season. Compared to bare ground, mulch resulted in a 42 and 68% increase in 1996 and 1997, respectively. Compared to $\text{Ca}(\text{NO}_3)_2$, $(\text{NH}_4)_2\text{SO}_4$ fertilization increased yield by 22 and 18% in 1996 and 1997, respectively. In both years, there were no significant interactions between the mulch and fertilizer treatments on yield or on integrated estimates of the plant canopy growth curve or disease severity. However, the treatment effects were additive. When compared to bare ground, mulching increased the plant canopy 3 weeks after planting and reduced the percentage of symptomatic foliage 8 weeks after planting. Compared to $\text{Ca}(\text{NO}_3)_2$, fertilization with $(\text{NH}_4)_2\text{SO}_4$ increased the plant canopy after 6 weeks, but did not affect the percentage of symptomatic foliage. Mulching or $(\text{NH}_4)_2\text{SO}_4$ fertilization increased the number of flowers compared to no mulching or $\text{Ca}(\text{NO}_3)_2$ fertilization, respectively. The rate of nitrogen fertilizer at planting or as a side-dress application did not affect growth or disease, but plants treated with $(\text{NH}_4)_2\text{SO}_4$ were larger and had less symptoms than $\text{Ca}(\text{NO}_3)_2$ -treated plants. The use of black plastic mulch with $(\text{NH}_4)_2\text{SO}_4$ fertilization complements one another and may reduce damage from Verticillium wilt on eggplant.

Additional keywords: mineral nutrition, soilborne pathogens, *Solanum melongena*

Verticillium wilt, caused by *Verticillium dahliae* Kleb., can be a major constraint on eggplant (*Solanum melongena* L.) production in the northeastern United States. Symptoms include wilt, chlorosis, defoliation, smaller leaves, and a reduction in plant size (11). There are no highly resistant cultivars (10). Fumigation and crop rotation provide partial disease suppression, but they are not always desirable or practical.

Two management strategies that increase eggplant yield in the presence of Verticillium wilt are mulching with black plastic and fertilizing with $(\text{NH}_4)_2\text{SO}_4$ as opposed to $\text{Ca}(\text{NO}_3)_2$ (6,7,23). These practices have never been evaluated together for their combined effects on reducing damage from Verticillium wilt. Combining $\text{NH}_4\text{-N}$ fertilization with other cultural practices, such as rotation crops or biocontrol agents, resulted in more suppression of root diseases on wheat and strawberry than when these practices were used individually (9,18). The current objectives were to

determine if combining black plastic mulch with $(\text{NH}_4)_2\text{SO}_4$ was superior to combinations of mulch with $\text{Ca}(\text{NO}_3)_2$ or to $(\text{NH}_4)_2\text{SO}_4$ alone in its ability to reduce damage from Verticillium wilt on eggplants, and to determine the effect of different rates of $\text{Ca}(\text{NO}_3)_2$ or $(\text{NH}_4)_2\text{SO}_4$ on reductions in disease damage.

MATERIALS AND METHODS

Production of plants. Eggplant seeds of cv. Midnite (Peto Seed Co., Oxnard, CA), a high-yielding cultivar that is susceptible to *V. dahliae* (10), were sown into 7.5-by-7.5-cm cells (1 seedling/cell) containing potting mix (Promix BX, Premier Brand, New Rochelle, NY). Seeds were sown in mid- to late March, transplanted to 1-liter plastic pots for 6 to 7 weeks in the greenhouse (25°C day and 20°C night), and transplanted into the field on 7 June 1996, 24 June 1997, and 23 June 1998. Plants were fertilized twice with Hoagland's nutrient solution (17) prior to field planting.

Plot establishment. The field experiments were conducted at the Lockwood Farm in Hamden, CT. The soil was a Cheshire fine sandy loam (57% sand, 33% silt, and 10% clay) with pH 5.9. Soil fertility was determined at the time of planting by subsampling a composite sample of 10 soil cores (15 cm in depth). Soil fertility each year did not vary greatly and averaged 25.0 µg of $\text{NO}_3\text{-N/g}$, 12.0 µg of $\text{NH}_4\text{-$

N/g , 70.0 µg of $\text{PO}_3\text{-P/g}$, 160 µg of K/g , 1,500 µg of Ca/g , and 152 µg of Mg/g , as determined according to the procedures of Lunt et al. (21). Plots received P and K at 56 kg/ha and CaSO_4 at 22 kg/ha to provide adequate supply of P, K, Ca, and S.

In 1996, plots were established in a field that had been cropped to eggplants the previous year. Verticillium wilt incidence had been nearly 100%. In 1997, the same field was used again, but the plots were placed in an area of the field that was left fallow in 1996. In 1998, the plots were put in the same part of the field used in 1996 which was left fallow in 1997. In 1996 and 1997, one-half of the plots were arbitrarily assigned to be mulched with 4-ml black plastic. Intensive measurements were to be taken over the season in each year; therefore, plots consisted of only two transplants spaced 1.2 m apart in rows 1.8 m apart. Plants were fertilized with $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ at the rate of 112 kg of N per hectare at planting and side dressed on 14 July 1996 and 23 July 1997 at the same rate for a total rate of 224 kg of N per hectare. Fertilizers were soil incorporated at planting, but broadcasted around the plant during the side-dress applications. Thus, four treatments (2 N-form $\times$ 2 mulch treatments, 10 replicate plots per treatment) were established in a randomized blocked design (5 replicate plots per block).

In 1998, two experiments were established in adjacent areas in the field. All plots were mulched with 4-ml black plastic. In the first experiment, the nitrogen fertilizers differed in application rate at planting. Four treatments were applied at planting: $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ applied at 56 or 112 kg N/ha. There were no side-dress applications. Treatments in the second experiment in 1998 differed by the amount of fertilizer side dressed. At planting, all plants received either with $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ at 112 kg of N per hectare and were then side dressed with $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$, respectively, at 0, 56, or 112 kg of N per hectare on 23 July. Each experiment in 1998 was designed as a randomized block experiment with five replicate plots per treatment (two plants per plot).

Weeds were removed from bare ground treatments by hand and insects were controlled with applications of Provado (Bayer Chemical Corp., Kansas City, MO). Irrigation was provided when needed to insure at

Corresponding author: W. H. Elmer
E-mail: Wade.Elmer@po.state.ct.us

Accepted for publication 8 August 2000.

least 2.5 cm of rainfall per week. After each season, plastic was removed and fields were plowed and seeded with winter rye.

Plant growth and disease measurements. Beginning 1 week after planting, every plant canopy was measured. Eggplant canopies are elliptical in shape; therefore, the area of this shape (A , dm^2) was estimated from directly overhead using a meter rule. The length (L , dm) and width (W , dm) of the canopy of each plant was used to calculate A using the formula $A = (L \times W)/4 \times \pi$. The percentage of sunlight passing through the canopy (S , %) was also visually estimated from overhead. The canopy size (CS , dm^2) was then calculated in the equation $CS = A \times [1 - (S/100)]$. When symptoms first appeared on leaves, pieces of wilting petioles were surface disinfested in 0.053% sodium hypochlorite for 1 min, rinsed, and placed onto ethanol-water agar supplemented with streptomycin sulfate (ESA medium) at 250 mg/liter (24). The disease severity (DS , %) was visually assessed each time plants were measured by determining the percentage of the plant foliage exhibiting symptoms of chlorosis and wilt. Measurements were made weekly from 1 to 4 weeks after planting and then at least biweekly until 13 weeks after planting (final harvest). The area under the plant canopy growth curve (CGC , dm^2days) or DS curve ($AUDPC$, days) were each integrated over the season using the equation $\Sigma(CGC_i + CGC_{i+1})/2 \times (t_{i+1} - t_i)$ where CGC_1 (or DS_1) is the canopy size or disease severity at that time. The number of flowers and set fruits were also counted until 7 weeks after planting, when heavy fruit set occurred (late July).

Marketable fruit were counted and weighed every 4 to 5 days from late July through mid-September. At the final harvest, all remaining fruit were removed and weighed.

Elemental analyses. One fully expanded nonsymptomatic leaf was removed from each plant on 20 July 1996, 1 August 1997, and 21 July 1998. Replicate samples within each block were bulked, dried, and ground with a mortar and pestle. Samples

were prepared for analysis of total N using the Nessler reaction. P, K, Ca, Mg, S, Fe, Mn, Cu, and Zn were determined by inductively coupled plasma emission spectroscopy. Dried tissue (0.5 g) was digested in HCl and HNO_3 in a CEM MDS 81D microwave (CEM Co., Matthews, NC), and analyzed on an ARL 3520 ICP-OES spectrophotometer (Fison Instruments, Dearborn, MI). Mineral concentrations were expressed as micromoles per gram of dried leaf tissue.

Statistical procedures. Data were subjected to an analysis of variance and analyzed as a randomized blocked design for two by two factorial study. Pairwise comparisons were made using Tukey's test at $P < 0.05$. Regression analyses were used to analyze the effect of rate nitrogen side-dressing. Analyses were conducted using Systat V.5. (SPSS Science, Chicago, IL).

RESULTS

The first foliar symptoms of *Verticillium* wilt appeared approximately 5 weeks after planting each year, which was always after anthesis. Isolations from the wilted petioles on ESA medium yielded characteristic colonies of *Verticillium* spp. 5 to 7 days later. The colonies were subcultured and microscopically identified as *V. dahliae* based on the presence of microsclerotia.

In 1996 and 1997, there were no interactions between treatments and year; therefore, data from both years were pooled. The severity of the disease in 1997 was less than in 1996 ($P < 0.001$) (Table 1). There were no significant interactions between black plastic mulch and nitrogen fertilizers on the CGC or the $AUDPC$, but there were additive effects. The black plastic mulch treatment increased the values of CGC ($P < 0.001$) and decreased the values of $AUDPC$ ($P < 0.001$) when compared with eggplants grown on bare ground. The values of $AUDPC$ were inversely related to CGC ($r = -0.62$; $P < 0.001$). The treatment effects on flowering were also additive. Differences were greatest 7 weeks after planting (Table 1). Mulched plants had 42% more flowers than plants grown on bare ground ($P =$

0.02). Similarly, fertilization with $(\text{NH}_4)_2\text{SO}_4$ produced 21% more flowers than those treated with $\text{Ca}(\text{NO}_3)_2$ ($P = 0.04$).

Compared to bare ground, the plastic mulch treatment increased the mean plant canopy size 3 weeks after planting in 1996 ($P = 0.01$) (Fig. 1, top). Differences grew larger over time. However, it took 8 weeks for the plastic mulch treatment to show a significant reduction in the percentage of the canopy with symptomatic foliage when compared to bare ground ($P = 0.05$) (Fig. 1, bottom). Thus, the effect of the mulch treatment on the canopy size was observed 5 weeks before it affected the percentage of symptomatic foliage. After 6 weeks, the canopies of plants treated with $(\text{NH}_4)_2\text{SO}_4$ were significantly larger than plants treated with $\text{Ca}(\text{NO}_3)_2$ ($P = 0.05$) (Fig. 2, top). The percentage of symptomatic foliage was not affected by nitrogen fertilizers (Fig. 2, bottom). In 1997, the same pattern developed (*data not shown*). Compared to bare ground, the plastic mulch increased the canopy size after 3 weeks and 5 weeks

Fig. 1. Influence of black plastic mulch on the size of eggplant canopies during 1996 (top) and on the percentage of symptomatic foliage (bottom) of eggplant grown in soil infested with *Verticillium dahliae*. Asterisks represent first date when a significant difference was detected between treatments according to Tukey's test at $P = 0.05$.

Table 1. Effect of combining black plastic mulch with $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ on estimates of disease severity curve ($AUDPC$), canopy growth curve (CGC), and flowers per plant of eggplants grown in soil infested with *Verticillium dahliae*

Treatment, year ^a	$AUDPC$ (days) ^w	CGC (dm^2days) ^x	Flowers per plant ^y
Bare ground + $\text{Ca}(\text{NO}_3)_2$	1,453 a ^z	2,257 a	1.8 a
Bare ground + $(\text{NH}_4)_2\text{SO}_4$	1,358 a	2,369 ab	2.5 b
Plastic Mulch + $\text{Ca}(\text{NO}_3)_2$	1,074 b	2,848 bc	2.9 bc
Plastic Mulch + $(\text{NH}_4)_2\text{SO}_4$	979 b	3,051 c	3.2 c
Averaging over treatments			
1996	1,913 a	2,392 a	2.8 a
1997	519 b	2,877 b	1.2 b

^a Mulch was 4-ml black plastic; nitrogen fertilizer was applied at 112 kg of N at plant and side-dressed at midseason.

^w Area under the disease progress curve; an integrated estimate of percentage of days when plants exhibited symptomatic foliage on the plant.

^x Canopy growth curve (days); an integrated estimate of the plant canopy size (dm^2) measured weekly.

^y Mean number of flowers per plant 7 weeks after planting.

^z Values represent 10 replicate plots, two plants per plot; values in columns followed by differing letters are significantly different by Tukey's test ($P = 0.05$).

before it reduced the percentage of symptomatic foliage. However, in this year, the $(\text{NH}_4)_2\text{SO}_4$ treatment increased only the CGC relative to the $\text{Ca}(\text{NO}_3)_2$ treatment ($P = 0.05$). The percentage of symptomatic foliage, again, was not affected by the nitrogen fertilizers.

Fruit yield was greater in 1997 than in 1996 ($P < 0.001$), but there were no interactions between the treatments in either year (Fig. 3). Mulch had the greatest effect on fruit yield ($P < 0.001$) and resulted in 42 and 68% increase in 1996 and 1997, respectively. Compared to $\text{Ca}(\text{NO}_3)_2$, $(\text{NH}_4)_2\text{SO}_4$ fertilization increased yield by 22 and 18% in 1996 and 1997, respectively ($P = 0.012$). Treatment effects on fruit number were similar to those on fruit yield, indicating that fruit size was not affected (*data not shown*). Average fruit size for 1996 and 1997 was 261 and 267 g, respectively.

N and Mn were the only leaf elements affected by the nitrogen fertilizers in both years. Leaf N in plants treated with $(\text{NH}_4)_2\text{SO}_4$ was 11% higher than in plants

treated with $\text{Ca}(\text{NO}_3)_2$ (3.25 versus 2.93 mmol per gram of tissue; respectively, $P < 0.001$). Levels of leaf Mn in plants treated with $(\text{NH}_4)_2\text{SO}_4$ were 65% higher than with $\text{Ca}(\text{NO}_3)_2$ (2.0 versus 1.2 μmol per gram of tissue, respectively; $P < 0.001$). Mulching had no effect on leaf nutrient concentrations. Levels of other elements in the leaf averaged as follows: K = 861, P = 130, Ca = 584, Mg = 274, S = 149, Fe = 2.6, Zn = 0.36, Cu = 0.31, and B = 4.0 μmol per gram of leaf tissue.

The rate of $(\text{NH}_4)_2\text{SO}_4$ applied at planting (56 or 112 kg of N per A) did not affect the canopy size or development of symptoms, but plants treated with the 112 kg of N per A rate of $\text{Ca}(\text{NO}_3)_2$ had lower AUDPC values and more flowers per plant than plants treated with 56 kg of N per A (Table 2). When the rates were averaged and the N-forms compared, plants treated with $(\text{NH}_4)_2\text{SO}_4$ had more yield, larger canopies, and more flowers than plants treated with $\text{Ca}(\text{NO}_3)_2$. Regression analyses revealed that the side-dressed rate had no significant effect on yield, plant canopies, or flowers per plant or percentage of symptomatic foliage (*data not shown*). Averaging over of the sidedress rates, the $(\text{NH}_4)_2\text{SO}_4$ treatment produced more yield than $\text{Ca}(\text{NO}_3)_2$ (8.3 versus 6.9 kg per plant, respectively, $P = 0.05$), larger values of CGC than the $\text{Ca}(\text{NO}_3)_2$ treatment (2,541

days versus 2,152 days, respectively, $P = 0.001$), and greater leaf Mn than the $\text{Ca}(\text{NO}_3)_2$ treatment (1.03 versus 0.88 μmol per gram, respectively, $P = 0.05$).

DISCUSSION

Combining $(\text{NH}_4)_2\text{SO}_4$ with black plastic mulch enhanced eggplant flowering, canopy size, and yield and reduced the percentage of symptomatic foliage caused by *V. dahliae*, but there was no evidence of an interaction occurring between these treatments. Nevertheless, the treatments complemented one another and provided two strategies for reducing damage from Verticillium wilt on eggplant.

The treatments probably influence separate growth-promoting mechanisms which may directly or indirectly enhance host defense. Aside from the obvious benefit that black plastic mulching has on conserving soil moisture and suppressing weed competition, it may also alter root architect and soil temperatures (1,20) and prevent the leaching of nutrients (1,14). Mulching with black plastic produced plants that had a larger percentage of roots in the top 10 cm of soil than plants on bare ground (20). Black plastic mulch also raised soil temperatures in the top 10 cm of soil a few degrees (1,2). Verticillium wilt is a cool-season disease (26); therefore, an increase in soil temperatures where a large percentage of roots are present may reduce the number of root infections as compared to roots of plants grown on bare ground. This hypothesis needs to be validated.

In the current study, fertilization with $(\text{NH}_4)_2\text{SO}_4$ produced larger plants with more flowers than with $\text{Ca}(\text{NO}_3)_2$, but there was no effect on early flowering. Claussen and Lenz (3) observed that eggplants grown in sand buffered with CaCO_3 and fertilized with $\text{NH}_4\text{-N}$ were larger, flowered earlier, and had more total flowers than those fertilized with $\text{NO}_3\text{-N}$. Flowering in apple (12), aster (15), carnation (13), and chrysanthemum (28) was also enhanced by $\text{NH}_4\text{-N}$ when compared to $\text{NO}_3\text{-N}$. Flowering may affect host defense. Mol (22) and Schnathorst (26) reported that germination and root infection by *V. dahliae* could occur early in the sea-

Fig. 2. Influence of $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ on the size of eggplant canopies during 1996 (top) and on the percentage of symptomatic foliage (bottom) of eggplants grown in soil infested with *Verticillium dahliae*. Asterisks represent first date when a significant difference was detected between treatment according to Tukey's test at $P = 0.05$. Standard error bars for selected means are provided.

Fig. 3. Influence of black plastic mulch and $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ on the yield of eggplant grown in soil infested with *Verticillium dahliae*. Like bars marked with differing letters (a,b,c for 1996 and x,y,z, for 1997) are significantly different according to Tukey's test at $P = 0.05$.

Table 2. Effect of the fertilizer rate at planting of $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ on fruit yield, estimates of disease severity (AUDPC), canopy growth curve (CGC), and flowers/plant of eggplants grown in soil infested with *Verticillium dahliae*

Nitrogen fertilizer	Rate (N in kg/ha)	Fruit yield (kg/plant)	AUDPC (days) ^w	CGC (dm ² days) ^x	Flowers per plant ^y
$(\text{NH}_4)_2\text{SO}_4$	56	9.1 a ^z	503 a	2,491 a	4.6 a
$(\text{NH}_4)_2\text{SO}_4$	112	8.5 a	300 ab	2,684 a	6.1 a
$\text{Ca}(\text{NO}_3)_2$	56	6.5 b	611 a	2,185 b	1.5 b
$\text{Ca}(\text{NO}_3)_2$	112	7.9 ab	286 b	2,453 ab	2.5 b
Averaging over N rate					
$(\text{NH}_4)_2\text{SO}_4$	...	8.8 a	401 a	2,587 a	5.4 a
$\text{Ca}(\text{NO}_3)_2$	...	7.2 b	448 a	2,319 b	2.0 b

^w Area under the disease progress curve; an integrated estimate of days where symptomatic foliage was visible on the plant.

^x Canopy growth curve; an integrated estimate of the plant canopy size (dm²) measured weekly.

^y Mean number of flowers per plant 7 weeks after planting.

^z Values represent five replicate plots, two plant per plot; values in columns followed by differing letters are significantly different by Tukey's test ($P = 0.05$).

son when young roots grow near microsclerotia. However, in past studies, the pathogen has never been isolated from roots or stems in eggplant until after anthesis, when symptoms appear (7,11). It is possible that the fungus resides at low densities in the apoplast until some alteration in the host physiology, such as flowering, triggers it to invade the symplast. At flowering, hormonal levels and source/sink relationships between the leaf and root are altered to accommodate the young fruit (16). If this scenario is accurate in eggplant, $(\text{NH}_4)_2\text{SO}_4$ may function indirectly in this metabolism and suppress the ingress of the fungus into living tissues. Future research should examine if flowering alters host physiology and the onset of pathogenesis.

Measurements of the canopy size were far more sensitive to the effects of mulch and N-form than were the percentages of symptomatic foliage. Symptomatic leaves usually wilt and drop from the plant within a few days; therefore, it may not be surprising that this measurement provides an incomplete estimate of the damage due to disease. Gent et al. (11) found that, although *Verticillium* wilt reduced yield by reducing total gas exchange and photosynthesis, the loss was a function of total leaf area reduction and not due to reduced photosynthetic efficiency. Stunting and production of small leaves is also a symptom of *Verticillium* wilt (7); therefore, estimates of canopy size should be included along with estimates of chlorotic and wilted foliage.

Mulch did not affect nutrient levels in the leaves sampled midseason. Late-season samples of collards grown under black plastic mulch had significantly higher levels of N than plants grown on bare ground (14). It is not known if the time of sampling would have altered the finding in the current study. The increased tissue concentrations of N and Mn in $(\text{NH}_4)_2\text{SO}_4$ -treated plants compared to $\text{Ca}(\text{NO}_3)_2$ -treated plants was previously observed in eggplant and strawberry (7-9). The enhanced N concentrations under NH_4 -N nutrition can be due to the more rapid assimilation of NH_4^+ ions compared to NO_3^- ions (16,25). Of the micronutrients, only Mn levels were higher in $(\text{NH}_4)_2\text{SO}_4$ -treated plants when compared to $\text{Ca}(\text{NO}_3)_2$. Higher levels of Mn are associated with *Verticillium* wilt suppression in cotton

(27), potato, and tomato (4). Manganese may act through a direct role in phenol metabolism (19). Conditions that immobilize Mn and limit uptake, such as NO_3 -N nutrition (19), may compromise plant defenses and lead to greater disease severity. Acidification of the rhizosphere following $(\text{NH}_4)_2\text{SO}_4$ nutrition will increase uptake of Mn and other micronutrients. However, only Mn was increased; therefore, the soil acidification may not completely explain the effect of $(\text{NH}_4)_2\text{SO}_4$ on Mn availability. Microbial transformation of Mn may be another mechanism that increases Mn availability and disease suppression (5).

ACKNOWLEDGMENTS

We thank E. O'Dowd and J. Mae White for technical assistance; and E. Naughton, J. Rich, and M. Amore for help in field preparation.

LITERATURE CITED

- Ashworth, S., and Harrison, H. 1983. Evaluation of mulches for use in the home garden. *HortScience* 18:180-182.
- Carter, J., and Johnson, C. 1988. Influence of different types of mulches on eggplant production. *HortScience* 23:143-145.
- Claussen, W., and Lenz, F. 1995. Effect of ammonium and nitrate on net photosynthesis, flower formation growth and yield of eggplants (*Solanum melongena* L.). *Plant Soil* 171:267-274.
- Dutta, B. K., and Bremner, E. 1981. Trace elements as plant chemo-therapeutants to control *Verticillium albo-atrum*. *Z. Pflanzenkr. Pflanzenschutz* 88:405-412.
- Elmer, W. H. 1995. The association among Mn-reducing bacteria and sodium chloride applications in the suppression of *Fusarium* crown and root rot of asparagus. *Phytopathology* 85:1461-1467.
- Elmer, W. H., and Ferrandino, F. J. 1991. Effect of black plastic mulch and nitrogen side-dressing on *Verticillium* wilt of eggplant. *Plant Dis.* 75:1164-1167.
- Elmer, W. H., and Ferrandino, F. J. 1994. Comparison of ammonium sulfate and calcium nitrate fertilization effects on *Verticillium* wilt of eggplant. *Plant Dis.* 78:811-816.
- Elmer, W. H., and LaMondia, J. A. 1995. Influence of mineral nutrition on strawberry black root rot. *Adv. Strawberry Res.* 14:42-48.
- Elmer, W. H., and LaMondia, J. A. 1999. Suppression of strawberry black root rot with rotation crops and Ammonium sulfate. *Plant Dis.* 83:119-124.
- Ferrandino, F. J., and Elmer, W. H. 1993. Eggplant tolerance to *Verticillium* wilt. *Biol. Cult. Control Tests* 8:21.
- Gent, M. N. P., Ferrandino, F. J., and Elmer, W. H. 1995. The effect of *Verticillium* wilt on gas exchange of entire eggplants. *Can. J. Bot.* 73:557-565.
- Grasmanus, V. O., and Leeper, G. W. 1967. Ammonium nutrition and flowering of apple trees. *Aust. J. Biol. Sci.* 20:761-767.
- Green, J. L., Holley, W. D., and Thaden, B. 1973. Effects of $\text{NH}_4^+:\text{NO}_3^-$ ratio, chloride, N-Serve, and simiazine on carnation flower production and plant growth. *Proc. Fla. Hortic. Soc.* 86:383-388.
- Guertal, E. A., and Edwards, J. H. 1996. Organic mulch and nitrogen affect spring and fall collards yields. *HortScience* 31:823-826.
- Haynes, R. J., and Goh, K. M. 1967. Evaluation of potting media for commercial production of container grown plants. II. Effect of media, fertiliser nitrogen, and nitrification inhibitor on yield and nitrogen uptake of *Calistephus chinensis* (L.) Nees 'Pink Princes'. *N. Z. J. Agric. Res.* 20:371-381.
- Haynes, R. J., and Goh, K. M. 1978. Ammonium and nitrate nutrition of plants. *Biol. Rev.* 53:465-510.
- Hoagland, D. R., and Arnon, D. I. 1938. The water culture method for growing plants without soil. *Calif. Agric. Exp. Stn. Circ.* 347.
- Huber, D. M., and McCay-Buis, T. S. 1993. A multiple component analysis of the take-all disease of cereal. *Plant Dis.* 77:437-447.
- Huber, D. M., and Wilhelm, N. S. 1988. The role of manganese in resistance to plant disease. Pages 155-173 in: *Manganese in Soils and Plants*, R. D. Graham, R. J. Hannam, and N. C. Uren. eds. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Knave, D. E., and Mohr, H. C. 1967. Distribution of roots of four different vegetables under paper and polyethylene mulches. *J. Am. Hortic. Sci.* 91:589-597.
- Lunt, H. A., Swanson, C. L., and Jacobson, H. G. M. 1950. The Morgan soil testing system. *Conn. Agric. Exp. Stn. Bull.* No. 541.
- Mol, L. 1995. Effect of plant roots on the germination of microsclerotia of *Verticillium dahliae*. *Eur. J. Plant Pathol.* 101:673-678.
- Moorman, G. W. 1982. Effect of black plastic mulching on infection rates of *Verticillium* wilt and yield of eggplant. *Phytopathology* 72:1412-1414.
- Nadakavukaren, M. J., and Horner, C. E. 1959. An alcohol agar medium selective for determining *Verticillium* microsclerotia in soil. *Phytopathology* 49:527-528.
- Pate, J. S. 1973. Uptake, assimilation and transport of nitrogen compounds by plants. *Soil Biol. Biochem.* 5:109-119.
- Schnathorst, W. C. 1981. Life Cycle and Epidemiology of *Verticillium*. Pages 81-111 in: *Fungal Wilt Diseases of Plant*, M. E. Mace, A. A. Bell, and C. H. Beckman, eds. Academic Press, New York.
- Shao, F. M., and Foy, C. D. 1982. Interaction of soil manganese and reaction of cotton to *Verticillium* wilt and *Rhizoctonia* root rot. *Commun. Soil Sci. Plant Anal.* 13:21-38.
- Tsujita, M. J., Kiplinger, D. C., and Tayama, H. K. 1974. The effects of nitrogen nutrition, temperature, and light intensity on the growth, flowering quality, and chemical composition of 'Indianapolis yellow' chrysanthemum. *HortScience* 9:294.