Use of Potassium Silicate Amendments in Recirculating Nutrient Solutions to Suppress *Pythium ultimum* on Long English Cucumber

M. CHÉRIF, Graduate Research Assistant, and R. R. BÉLANGER, Assistant Professor, Département de phytologie, Faculté des Sciences de l'Agriculture et de l'Alimentation, Université Laval, Québec, Canada G1K 7P4

ABSTRACT

Chérif, M., and Bélanger, R. R. 1992. Use of potassium silicate amendments in recirculating nutrient solutions to suppress *Pythium ultimum* on long English cucumber. Plant Dis. 76:1008-1011.

Amendment of a recirculating nutrient solution with potassium silicate was evaluated as a means to control *Pythium ultimum* infections on long English cucumber (*Cucumis sativus*). Supplying the solutions with 100 or 200 ppm of silicate significantly reduced mortality, root decay, and yield losses attributed to infection by *P. ultimum*. Treating inoculated plants with potassium silicate increased root dry weights and number of fruit, especially high-grade fruit. Results were slightly superior to noninoculated controls. The two cultivars tested, Corona and Marillo, responded similarly to the treatments. No significant differences were observed between the 100- and 200-ppm silicate treatments. Results were better when greenhouse conditions favored spread of *P. ultimum*. Silicon alone did not increase cucumber yield, suggesting that it acts as a disease suppression agent rather than as a fertilizer. The phenomena by which silicon confers protection against *P. ultimum* infection and disease development are not fully understood, but our results indicate that mechanisms other than a mechanical barrier to fungal penetration are involved.

Pythium spp. are responsible for crown and root rot and yield reductions of several greenhouse-grown crops (11). The production of long English cucumber (*Cucumis sativus* L.) is particularly hampered by this problem, in which symptoms of the disease can be easily overlooked until the plants suddenly wilt (8). To circumvent this problem, some producers grow cucumbers in hydroponic cultures because this system was reported to be disease-free. However, it was soon found that the severity of infection by *Pythium* was intensified by conditions in the hydroponic cultures that favor spread of the fungus (25). To compound the problem, fungicides are not registered for use in hydroponically grown crops and *Pythium*-resistant cultivars are not commercially available (32).

Stanghellini et al (23) experimented with the control of *Pythium* in recirculating hydroponic systems by irradiating the nutrient solution with ultraviolet light. Although this approach gave good control of the disease, it has not gained wide acceptance commercially, probably because of the high cost of irradiation.

In in vitro experiments with *Pythium* and *Phytophthora* spp., Agral, a nonionic surfactant, was shown to disrupt the integrity of the plasma membrane of fungal structures lacking a cell wall, such as zoospores and vesicles (24). Further work showed that various surfactants could control lettuce big vein disease, seemingly caused by a virus, by killing zoospores of *Olpidium brassicae*, the virus vector (26). However, commercial-scale experiments have yet to validate this control method on greenhouse crops.

An interesting approach to disease control that has gained attention is the amendment of nutrient solutions with silicate. Several workers reported a reduction in severity of powdery mildew on cucumber and other crops with this practice (1,17). Although silicon (Si) is not considered an essential nutrient for cucumber (29,30), other workers reported significant yield increases of greenhouse-grown cucumber following soluble Si amendment (1,19). The effect of Si on root diseases has never been studied extensively, but the possibility exists that it may affect the development of *Pythium* infection and result in an increase in the productivity of the plants.

Considering the current problems with *Pythium* diseases in hydroponic cultures and considering the few options offered to producers to overcome these problems, we examined the potential of potassium silicate for the control of Pythium root rot of cucumbers grown in hydroponic solutions. A preliminary report has been presented (5).

Paper No. CRH-39, from the Centre de recherche en horticulture.

Address correspondence to second author.

Accepted for publication 4 May 1992.

MATERIALS AND METHODS

Plant material. Seeds of cucumber cvs. Corona and Marillo were sown in LC-1 Horticubes and fertilized daily with a nutrient solution of N-P-K (7-11-27) for 2–3 wk under greenhouse conditions. Plants were then transferred to gullies in which the nutrient solution coming from 500-L tanks was in constant circulation. The trial design comprised eight storage tanks, each feeding two randomly selected gullies. All gullies were completely isolated from each other. Six plants spaced at 0.75-m intervals were placed in each gully, for a total of 96 plants per experiment. A guard row was placed at each extremity of the experimental design. Plants were grown in a base nutrient solution containing, in parts per million, 219 N, 308 K, 39 P, 146 Ca, 50 Mg, 4 Fe, 1 Mn, 0.4 Zn, 0.14 Cu, 0.3 Bo, and 0.055 Mo. The nutrient solutions were prepared with tap water (<10 ppm of Si), and final pH was adjusted to 5.8 with nitric acid. The electrical conductivity ranged from 1.8 to 2.2 mS/cm, depending on the Si concentration. Each tank originally contained 300 L of nutrient solution; the solution was replaced every 3–4 wk. The temperature of the nutrient solution, monitored daily throughout the experiment, ranged between 17 and 22 C. Air temperature was maintained between 18 and 22 C at night and between 23 and 28 C during the day. The ventilation system was activated when the air temperature in the greenhouse reached 28 C.

Effect of potassium silicate. *Experiment 1.* Nutrient solutions were supplemented with either 1.7 mM (100 ppm = Si+) or 3.4 mM (200 ppm = Si++) silicate in the form of potassium silicate (Kasil No. 6, 23.6% SiO_2), which was fed to the plants for the duration of the experiment. Proper adjustments were made to the nutrient solutions to compensate for the additional input of K. This experiment comprised four treatments: 1) no Si amendment and no inoculation with *Pythium* (Si−P−), 2) no Si amendment and inoculation with *Pythium* (Si−P+), 3) Si+P+, and 4) Si++P+. Each treatment was replicated twice. Seeds of cvs. Marillo and Corona were sown on 28 May 1990. Seedlings were transferred to the hydroponic system on 6 June 1990 and, when applicable, inoculated with *P. ultimum* Trow on 9 July 1990. This experiment was maintained for 12 wk after the seedlings were transferred to the gullies. Throughout the experiment, fruit were harvested and graded according to the standard system applied in Canada (4). Root and aerial dry weights were measured after 12 wk.

Experiment 2. Only seeds of cv. Corona were used. Nutrient solutions were amended with 1.7 mM (100 ppm) silicate. The four treatments were silicate amendment with (Si+P+) or without (Si+P−) *P. ultimum* inoculations and no silicate amendment with (Si−P+) or without (Si−P−) *P. ultimum* inoculations. Each treatment comprised two replicates. Seeds were sown on 31 January 1991. Seedlings were transferred to the hydroponic system on 20 February 1991 and, when applicable, inoculated with *P. ultimum* on 13 March 1991. This experiment was maintained for 12 wk after the seedlings were transferred to the gullies. The same variables as in experiment 1 were measured.

Inoculations. Inoculum was prepared from one strain of *P. ultimum* (Barr 447; Biosystematics Research Institute, Ottawa, Ont.) previously reported to be virulent on cucumber (7). The strain was grown on potato-dextrose agar (PDA) on 9-cm petri dishes for 5 days. For each tank to be inoculated, three petri dish cultures were mixed with 300 ml of distilled water and blended for 1 min; sterile agar was used for the controls. The fungal broth was added directly to the nutrient solution of the tanks. The presence of *P. ultimum* was monitored by taking root and nutrient solution samples every week after the date of inoculation. Root samples were dissected from two or three plants selected at random from both replicates in each treatment, washed thoroughly in distilled water, surface-disinfested in 3% aqueous sodium hypochlorite for 5 min, rinsed for a few minutes in distilled water, blotted dry, then plated onto a selective medium (10) and incubated at 21 C. Presence of *P. ultimum* was determined after 7 days of incubation. Identification was based on morphological features (27).

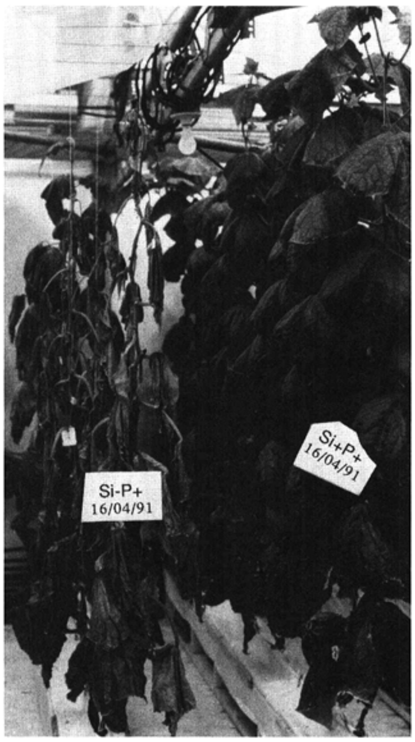

Fig. 1. Effect of potassium silicate on control of *Pythium ultimum* infections on long English cucumber plants grown in a recirculating nutrient solution system. Plants on the left (Si−P+) were grown in a basic nutrient solution inoculated with *P. ultimum*; plants on the right (Si+P+) were grown in a nutrient solution inoculated with *P. ultimum* and amended with 100 ppm of silicon.

Data analysis. The effects of the treatments were analyzed by ANOVA and means were separated by Duncan's multiple range test ($P \leq 0.05$). The software SuperANOVA (Abacus Concepts, Berkeley, CA) was used for the statistical analysis.

RESULTS

In both experiments, all inoculated control plants started showing symptoms of wilting within 2 wk after inoculation. The experiments were terminated 9 wk after inoculation because most of the inoculated controls either were dead or had reached an advanced stage of wilting, root decay, and senescence and had stopped producing fruit. In the other treatments, all plants went through the production period without obvious problems with disease. Their root systems were well developed and did not show symptoms of decay. A visual comparison between inoculated plants grown with (Si+P+) and those grown without (Si−P+) potassium silicate showed that the benefits of using potassium silicate against *P. ultimum* were unequivocal (Fig. 1). Interestingly, despite the healthy appearance of the Si+P+ plants, *P. ultimum* was reisolated from all solutions and root samples taken from that treatment.

In terms of the variables measured, the beneficial effects of a Si amendment were evident in both experiments. However, the differences were more readily observable in experiment 2. Indeed, the nutrient solution temperature in experiment 1, which was done in the summer, frequently averaged 25 C, resulting in faster development of seedlings and less acute infections than in experiment 2, probably because *P. ultimum* has a growth optimum of about 20 C. Nonetheless, inoculated plants treated with silicate (100 and 200 ppm) developed significantly more dry matter, as measured by aerial and root weight, than inoculated controls (Table 1). Because we found no interaction between cultivars and treatments, data were pooled for further analyses. In terms of fruit produced, at the end of the experiment all fruit had been harvested (marketable or not), and there were no significant differences in the total number among the treatments (Table 1). However, significant differences were observed when the number of fruit was assessed on the basis of quality. In fact, plants treated with 100 and 200 ppm of silicate yielded nearly 40% more class 1 fruit than the inoculated controls (Table 1). For all variables measured, there was no significant difference between 100- and 200-ppm treatments, and inoculated

Table 1. Average shoot dry weight, root dry weight, number of fruit, and number of class 1 fruit per plant of long English cucumber cvs. Corona and Marillo grown for 12 wk in a recirculating nutrient solution amended with different concentrations of potassium silicate and noninoculated or inoculated with *Pythium ultimum*

Treatment[y]	Shoot dry weight (g)	Root dry weight (g)	Number of fruit	
			Total	Class 1
Si−P−	125.0 ab[z]	19.5 a	7.5 a	4.6 ab
Si−P+	112.2 b	17.8 b	6.7 a	3.5 b
Si+P+	140.0 a	19.7 a	7.7 a	4.8 a
Si++P+	132.0 a	20.4 a	7.7 a	4.9 a

[y] Si− = 0 ppm, Si+ = 100 ppm, and Si++ = 200 ppm of potassium silicate; P− = noninoculated and P+ = inoculated with *P. ultimum*. Each treatment represents an average of 24 plants.
[z] Means in the same column followed by a different letter are significantly different according to Duncan's multiple range test ($P \leq 0.05$).

Table 2. Average shoot dry weight, root dry weight, number of fruit, and number of class 1 fruit per plant of long English cucumber cv. Corona grown for 12 wk in a recirculating nutrient solution with or without potassium silicate and noninoculated or inoculated with *Pythium ultimum*

Treatment[y]	Shoot dry weight (g)	Root dry weight (g)	Number of fruit	
			Total	Class 1
Si−P−	221.5 a[z]	24.4 ab	13.1 ab	8.2 a
Si−P+	135.8 b	16.4 c	5.8 c	3.8 b
Si+P−	223.9 a	25.6 a	15.0 a	7.3 a
Si+P+	163.3 b	21.0 b	11.5 b	6.5 a

[y] Si− = 0 ppm and Si+ = 100 ppm of potassium silicate; P− = noninoculated and P+ = inoculated with *P. ultimum*. Each treatment represents an average of 24 plants.
[z] Means in the same column followed by a different letter are significantly different according to Duncan's multiple range test ($P \leq 0.05$).

plants treated with silicate were always as productive as noninoculated plants (Si−P−). Despite the precautions taken to avoid contamination among treatments, *Pythium* was isolated from the Si−P− treatment 5 wk before the end of the experiment, which most likely explained the poor performance of the control.

In experiment 2, in which only cv. Corona seeds and a 100-ppm concentration were used, symptoms on the inoculated controls (Si−P+) were more pronounced than in experiment 1 because conditions were more favorable for development of *P. ultimum*. This resulted in significantly greater production of silicate-treated plants (inoculated or not) and control plants in all variables measured (Table 2). In terms of number of fruit and number of class 1 fruit produced (Table 2), all treatments nearly doubled the overall production of the inoculated plants. *P. ultimum* was once again reisolated from the Si+P+ treament at all sampling times. The pathogen also was detected in the Si−P− and Si+P− treatments, but not until 2 wk before the end of the experiment. Interestingly, these latter treatments did not differ significantly, indicating that the amendment of Si alone did not influence the productivity of the plants.

DISCUSSION

The use of potassium silicate (or metasilicate) as an amendment to nutrient solution is currently gaining wide acceptance among cucumber and rose producers (28). However, while some producers have reported a yield increase as a result of its use, several have failed to report beneficial effects. Our results showed no significant differences between Si+P− and Si−P− treatments. The mechanisms responsible for a growth stimulation by silica are unclear (13). Horst and Marschner (9) and Marschner et al (16) suggested that these effects could be related to increased tolerance to high manganese concentrations or to an imbalance in phosphorus and zinc supply. Yoshida et al (31) and Adatia and Besford (1) concluded that improvement in plant growth results from a higher mechanical stability of stems and leaves and thus better light interception and higher photosynthetic capacity. From a nutritional standpoint, however, no reports link Si with nutritional properties (29,30). On the other hand, many other reports are in agreement with the idea that the beneficial effect of Si is related to an increased resistance to fungal infection (18–20). According to our results, the former explanation seems implausible, since the silicon-free nutrient solution used was not deficient in phosphorus or zinc and because no signs of manganese toxicity were observed on control plants.

To our knowledge, this is the first study to report the beneficial effect of Si on the control of root rot diseases caused by *P. ultimum*. Several other studies have associated the presence of Si with a decreased severity of disease caused by foliar pathogens. For instance, supplemental silicate treatments resulted in a significant reduction of powdery mildew infection in barley (12), wheat (15), and cucumber (18). A beneficial effect of Si also was reported for Helminthosporium blight (2) and for blast disease of rice caused by *Pyricularia oryzae* (3). Most of these studies reported the effect of Si on pathogenic fungi that infect aerial parts of different monocotyledonous and some dicotyledonous plants, where silica ($SiO_2 \cdot nH_2O$) accumulation is very high. By contrast, no information is available on the effects of Si on the receptivity of Si-nonaccumulating plant tissues to fungal pathogens. Our results strengthen the observations reported by Miyake and Takahashi (20) concerning Si effects on Fusarium wilt disease in naturally infected cucumber; an application of silicate fertilizer considerably reduced the number of wilted plants. Miyake and Takahashi (19) and Adatia and Besford (1) reported a consistent decline in silica content of tissues of cucumber plants, progressing from leaves to roots. Although Si is present at relatively low amounts in cucumber roots, our results provide further evidence that it can reduce the severity of fungal infections. These results are in line with the idea that the total Si in plant tissues is not as important as the available, mobile Si at the time of infection. Samuels et al (22), studying the mobility and deposition of Si in cucumber leaves by means of scanning electron microscopy and energy dispersive X-ray analysis, observed that once deposited in cucumber tissues, Si could not be remobilized by the plant. They found that Si deposited in the leaves of cucumber plants previously treated with 100-ppm Si nutrient solution was not available to enhance disease resistance 24 hr after they stopped feeding the plants with the Si-amended solution. These reports support the recommendation that Si applied in hydroponic nutrient solutions should be used on a constant basis at 100 ppm from transplanting onward. Intermittent Si supply may not control fungal infections effectively.

The mode of action of foliar-, feed-, and soil-applied Si in reducing the severity of fungal infection is not known. However, from the results of previous studies and our experiments, it appears that Si acts systemically in the outcome of the host-pathogen interaction in that it is able to enhance resistance in the aerial as well as the underground parts of the plant. The present study suggests that control of *P. ultimum* could not be attributed to a direct detrimental effect of potassium silicate on zoospore germination or hyphal growth because the pathogen was reisolated from all the Si-amended solutions, from the first week of inoculation to the end of the experiments. However, the mechanisms of pathogen suppression by the host are not known. At this time, two hypotheses have been proposed: 1) Si accumulation in plant cell walls hinders fungal growth and penetration of plant tissues (6,14) and 2) Si stimulates and changes the timing of host natural defense mechanisms, e.g., phenolic production (17,21). From the results of the present study, the first hypothesis appears less probable, since *P. ultimum* was reisolated from all root samples of Si-treated plants. These two hypotheses may not be mutually exclusive, however. Ultrastructural and biochemical studies are needed to clarify the beneficial role of Si in the interaction of *P. ultimum* with cucumber.

ACKNOWLEDGMENTS

We thank J. Charbonneau and M. Lüscher for their help and technical assistance throughout this project, C. Labbé for help in analyzing the data and preparing the manuscript, and J. G. Menzies and T. C. Paulitz for helpful discussion and critical review of the manuscript. This work was supported by a grant from the program Entente auxiliaire Canada-Québec sur le développement agro-alimentaire.

LITERATURE CITED

1. Adatia, M. H., and Besford, R. T. 1986. The effects of silicon on cucumber plants grown in recirculating nutrient solution. Ann. Bot. 58:343-351.
2. Akai, S. 1953. Studies on *Helminthosporium* blight of rice plants. VII. On the relation of silicic acid supply to the outbreak of *Helminthosporium* blight or blast disease in rice plants. Ann. Phytopathol. Soc. Jpn. 17:109-112.
3. Aleshin, N. E., Avakyan, E. R., Dyakunchak, S. A., Aleshkin, E. P., Baryshok, V. P., and Voronkow, M. G. 1986. Role of silicon in resistance of rice to *Pyricularia*. Dokl. Akad. Nauk SSSR 291:499-502.
4. Anonymous. 1991. Loi sur les normes des produits agricoles du Canada. Pages 1-24 in: Réglement sur les fruits et les légumes frais. Consolidated Regulation of Canada.
5. Bélanger, R. R., Chérif, M., and Tremblay, J. 1991. Control of *Pythium* root rot in greenhouse grown cucumbers with soluble silicon amendments. (Abstr.) Phytopathology 81:120.
6. Carver, T. L. W., Zeyen, R. J., and Ahlstrand, G. G. 1987. The relationship between insoluble silicon and success or failure of attempted penetration by powdery mildew (*Erysiphe graminis*) germlings on barley. Physiol. Mol. Plant Pathol. 31:133-148.
7. Chérif, M., Benhamou, N., and Bélanger, R. R. 1992. Ultrastructural and cytochemical studies of fungal development and host reactions in cucumber plants infected by *Pythium ultimum*. Physiol. Mol. Plant Pathol. 39:353-375.
8. Favrin, R. J., Rahe, J. E., and Mauza, B. 1988. *Pythium* spp. associated with crown rot of cucumbers in British Columbia greenhouses. Plant Dis. 72:683-687.
9. Horst, W. J., and Marschner, H. 1978. Effect of silicon and manganese tolerance of bean plants (*Phaseolus vulgaris* L.). Plant Soil 50:287-303.
10. Jeffers, S. N., and Martin, S. B. 1986. Comparison of two media selective for *Phytophthora* and *Pythium* species. Plant Dis. 70:1038-1043.
11. Jenkins, S. F., Jr., and Averre, C. W. 1983. Root diseases of vegetables in hydroponic culture systems in North Carolina greenhouses. Plant Dis. 67:968-970.
12. Jiang, D., Zeyen, R. J., and Russo, V. 1989. Silicon enhances resistance of barley to powdery

mildew (*Erysiphe graminis* f. sp. *hordei*). (Abstr.) Phytopathology 79:1198.
13. Jones, L. H. P., and Handreck, K. S. 1967. Silica in soils, plants, and animals. Adv. Agron. 19:107-149.
14. Kunoh, H., and Ishizaki, H. 1975. Silicon levels near penetration sites of fungi on wheat, barley, cucumber and morning glory leaves. Physiol. Plant Pathol. 5:283-287.
15. Leusch, H.-J., and Buchenauer, H. 1989. Effect of soil treatments with silica-rich lime fertilizers and sodium trisilicate on the incidence of wheat by *Erysiphe graminis* and *Septoria nodorum* depending on the form of N-fertilizer. J. Plant Dis. Prot. 96:154-172.
16. Marschner, H., Oberle, H., Cakmak, I., and Römheld, V. 1990. Growth enhancement by silicon in cucumber (*Cucumis sativus*) plants depends on imbalance in phosphorus and zinc supply. Plant Soil 124:211-219.
17. Menzies, J. G., Ehret, D. L., Glass, A. D. M., Helmer, T., Koch, C., and Seywerd, F. 1991. The effects of soluble silicon on the parasitic fitness of *Sphaerotheca fuliginea* on *Cucumis sativus*. Phytopathology 81:84-88.
18. Menzies, J. G., Ehret, D. L., Glass, A. D. M., and Samuels, A. L. 1991. The influence of silicon on cytological interactions between *Sphaerotheca fuliginea* and *Cucumis sativus*. Physiol. Mol. Plant Pathol. 39:403-414.
19. Miyake, Y., and Takahashi, E. 1983. Effect of silicon on the growth of solution-cultured cucumber plant. Soil Sci. Plant Nutr. 29:71-83.
20. Miyake, Y., and Takahashi, E. 1983. Effect of silicon on the growth of cucumber plant in soil culture. Soil Sci. Plant Nutr. 29:463-471.
21. Samuels, A. L., Glass, A. D. M., Ehret, D. L., and Menzies, J. G. 1991. Distribution of silicon in cucumber leaves during infection by powdery mildew fungus (*Sphaerotheca fuliginea*). Can. J. Bot. 69:140-146.
22. Samuels, A. L., Glass, A. D. M., Ehret, D. L., and Menzies, J. G. 1991. Mobility and deposition of silicon in cucumber plants. Plant Cell Environ. 14:485-492.
23. Stanghellini, M. E., Stowell, L. J., and Bates M. L. 1984. Control of root rot of spinach caused by *Pythium aphanidermatum* in a recirculating hydroponic system by ultraviolet irradiation. Plant Dis. 68:1075-1076.
24. Stanghellini, M. E., and Tomlinson, J. A. 1987. Inhibitory and lytic effects of a nonionic surfactant on various asexual stages in the life cycle of *Pythium* and *Phytophthora* species. Phytopathology 77:112-114.
25. Stanghellini, M. E., White, J. G., Tomlinson, J. A., and Clay, C. 1988. Root rot of hydroponically grown cucumbers caused by zoospore-producing isolates of *Pythium intermedium*. Plant Dis. 72:358-359.
26. Tomlinson, J. A., and Faithfull, E. M. 1979. Effects of fungicides and surfactants on the zoospores of *Olpidium brassicae*. Ann. Appl. Biol. 93:13-19.
27. Van Der Plaats-Niterink, A. J. 1981. Monograph of the genus *Pythium*. Studies in Mycology No. 21. W. Gams and R. P. W. M. Jacobs, eds. Centraalbureau voor Schimmelcultures, Baarn, Netherlands.
28. Vaughan, J., and O'Neill, T. 1989. The effect of silicon in greenhouse-grown cucumbers. Grower 10:37-39.
29. Voogt, W. 1989. Bemesten: Silicium voedingselement voor plantengroei? (Fertilization: Silicon nutrient element for plant growth?) Groenten Fruit 44:32-33.
30. Voogt, W. 1989. Komkommer: Silicium als meststof toedienen nog niet mogelijk in praktijk. (Cucumber: Application of silicon as fertilizer not yet possible in commercial practice.) Groenten Fruit 44:34-35.
31. Yoshida, S., Nasavero, S. A., and Ramirez, E. A. 1969. Effect of silica and nitrogen supply on some leaf characters of the rice plant. Plant Soil 31:48-56.
32. Zinnen, T. M. 1988. Assessment of plant diseases in hydroponic culture. Plant Dis. 72:96-99.