Moss Infestations in Putting Greens

Eradication by electromotive destruction of chlorophyll.

BY ARTHUR P. WEBER AND THOMAS O. McAVOY

The proliferation of moss infestations in putting greens can be correlated to the asymptotic lowering of mower heights in the pursuit of "fast green speeds." The side effect, stressing and thinning the turf cover, promotes the invasion of undesirable species, e.g., moss, to impair the consistency of the green surface as a putting medium (1).

Of the about 9,500 purported moss variations, *Bryum argentium*, commonly known as silvery thread moss, has been identified as the dominant invasive species. The botanical phylum *Briophata* includes mosses and liverworts, the simplest of land-dwelling plants which, from fossil records dating back some 400 million years, prevail as enduring primitive species whose morphology, growth, and survival characteristics differ radically from higher plants, e.g., the putting green turfgrasses within which they coexist.

BIOLOGY

Mosses do not have roots and, in their absence, the plants anchor to a surface with rhyzoids attached to a substrate. Consequently, mosses can thrive on surfaces as dissimilar as rocks, concrete walks, and masonry walls. Neither do mosses have a defined vascular system for water and nutrient delivery or, conversely, as a pathway to facilitate control or eradication.

Mosses survive long periods of drought, dehydrate, and sustain prolonged dormancy, to then resume photosynthesis upon rehydration. Receptors and patterns of water uptake have been advanced, the modus operandi of which remain obscure. Uniquely, water uptake by *Bryum argentium* is comparatively rapid, categorizing the plant as being ectohydric (2,3,4,5).

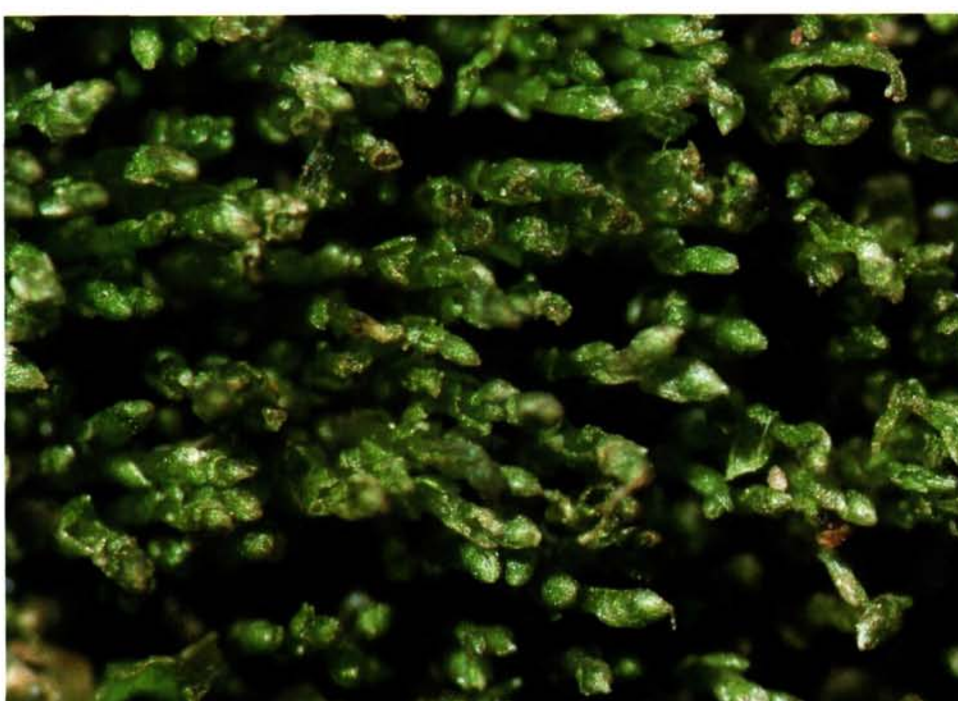


Figure 1. When moss is viewed in cross-section, it has a sponge-like appearance and is densely packed with very small voids.

MORPHOLOGY

Bryum argentium moss infestations prevail as sponge-like biomasses which, when microscopically viewed in cross-section, provide a densely packed labyrinth of minuscule voids and interstices. Photomicrographs, depicted in Figure 1, were taken at 10x, 30x, and 63x magnification to correspondingly decreasing 22mm, 13mm, and 3.5mm fields of view, using a Nikon SMZ Zoom Stereo Microscope with a 1x objective lens and Nikon Coolpix 4500 4 megapixel digital camera.

Given that the surface-to-volume ratios of voids vary inversely with size and shape, *Bryum argentium* infestations comparatively interface to their ambient environment with an extraordinarily high biomass surface relative to volume. This key attribute, in the absence of root hairs to absorb water and leaf stomata to respire carbon dioxide and oxygen, serves to sustain photosynthesis by extended surface adsorption and absorption.

ECOLOGY

Although *Bryum argentium* persists within a broad divergence of ambient parameters, remarkable exceptions have been metal-contaminated soils. The toxicity sequence has been found to be Hg > Cu > Pb > Ni > Cd > Zn >

Mg, the heavy metals being the most toxic. Mercury (Hg) based management controls, particularly, had been found to be highly effective but were discarded for not being environmentally viable. Recently, application programs using copper hydroxide-based fungicides have been advanced for post-emergence moss control (6,7,8,9,10,11,12,13,14,15,16).

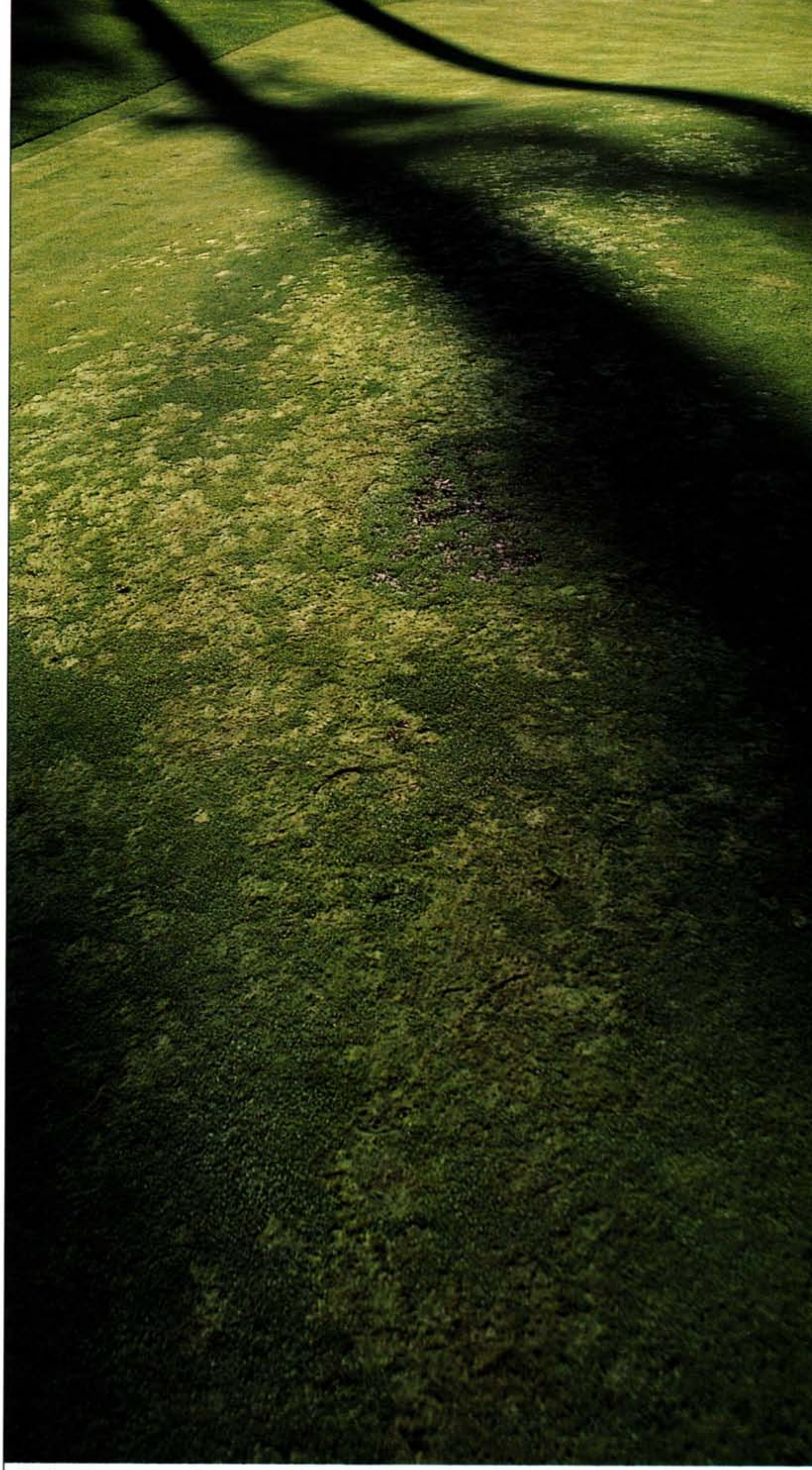
ELECTROCHEMISTRY

The toxicity response to metals by *Bryum argentium* parallels the Activity Series, i.e., an arrangement of metals in the order of their tendency to react with water and acids so that each metal in the series displaces from solution those below it and is displaced by those above it. Because the displacements involve the transfer of electrons from the reducing agent to the oxidizing agent and may be used as a source of electric current, the Activity Series is also known as the Electromotive Series.

To obtain this result, the oxidation/reduction reaction must take place in an appropriate apparatus, e.g., a battery cell, so constructed that the transfer of electrons from one atom to the other, as a current between electrodes, takes place along an intervening conductor. However, sufficient energy, in the form of a relative potential difference between the electrodes, must be made available as an electromotive force to overcome any interposed resistance to the electron current flow from the reducing agent to the oxidizing agent.

METAL ELECTRODE POTENTIALS

In order to compare the electrode potentials between metals and their solutions, it is customary to use solutions in which the concentration of the metal ions is "Normal," i.e., molar. As a basis for comparison, inasmuch as absolute electrode potentials cannot be determined with reasonable accuracy, the potential of a platinum electrode saturated with hydrogen gas under one atmosphere pressure against a solution that is "Normal" with respect to the



Shade and contours on this green contribute to a poor growing environment. As the area is scalped, moss becomes more competitive, dominating the area.

Figure 2
Activity Series a/k/a Electromotive Series
Potentials of elements in contact with normal concentration of the ion at 25°C

Element	Ion	Potential in Volts	Element	Ion	Potential in Volts
K	K^+	–2.92	H_2	H^+	0.00
Na	Na^+	–2.71	Sb	SB^{+++}	+0.10
Ca	Ca^{++}	–2.5(?)	As	As^{+++}	+0.3(?)
Mg	Mg^{++}	–1.55	Cu	Cu^{++}	+0.34
Al	Al^{+++}	–1.34	Cu	Cu^+	+0.47
Zn	Zn^{++}	–0.75	Hg	Hg^+	+0.79
Fe	Fe^{++}	–0.44	Ag	Ag^+	+0.80
Cd	Cd^{++}	–0.40	Hg	Hg^{++}	+0.86
Co	Co^{++}	–0.24	Au	Au^+	+1.5(?)
Ni	Ni^{++}	–0.22	O_2	OH^-	+0.11
Sn	Sn^{++}	–0.14	I_2	I^-	+0.62
Pb	Pb^{++}	–0.12	Br_2	Br^-	+1.08
Fe	Fe^{+++}	–0.04	Cl_2	Cl^-	+1.35
			F_2	F^-	+1.9(?)

hydrogen ions is called zero. Figure 2 comparatively tabulates the relative electrode potentials, expressed in volts, of various elements at 25°C in contact with solutions that are "Normal" with respect to their ions, thereby electromotivally quantifying the Activity Series.

From Figure 2, the limiting potential difference across a battery cell, measured in volts, can be calculated. For example, metallic magnesium, in contact with a "Normal" Mg^{++} ion solution, acquires a negative potential of -1.55 volts, while mercury in contact with a "Normal" Hg^+ ion solution acquires a positive potential of +0.79 volts. The limiting voltage, therefore, across the electrodes of such a magnesium/mercury battery cell would be the algebraic difference between the relative electrode potentials: +0.79 - (-1.55) = 2.34 volts.

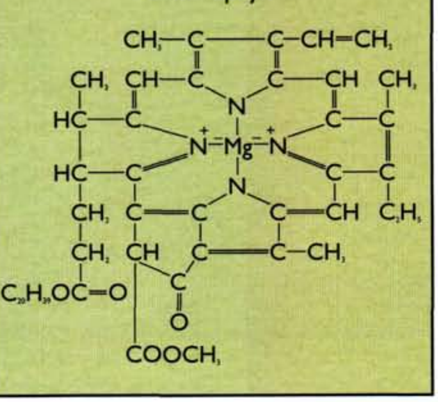
CHLOROPHYLL

The green pigment essential to photosynthesis, chlorophyll, is a porphorin structured molecule containing a hydrophilic carbocyclic ring with a lipophilic phytyl tail, nitrogen bridged from a negatively charged magnesium ion at the core of the molecule (see Figure 3). It is a photoreceptor up to 700mm and transfers such radiant energy to its chemical environment, thus acting as a transducer in photosynthesis (17).

HYPOTHESIS

Heavy metals elicit a toxic response from *Bryum argentium* because of the electromotive destruction of the chlorophyll. The electrical resistance between the negatively charged magnesium ion at the core of a chlorophyll molecule and, say, a surface interfaced positively charged mercury ion is such that the relative potential difference between the ions is large enough to permit the Mg^- ion to be oxidized by losing and transporting its electron to reduce the Hg^+ ion to metallic mercury.

Figure 3
Chlorophyll



The decreasing relative electrode potential difference between the metals of higher ranking than mercury in the Activity Series is apparently insufficient as a driving force to overcome the molecular binding energy of the Mg^- electron in chlorophyll and resistance to the conduction of the electron in *Bryum argentium*, wherein chlorophyll functions as the negative electrode of a galvanic cell. Significantly, copper was empirically found to be the nearest toxicity competitor to mercury and, as it turns out, ranks just above mercury in the Activity Series, with a relative Cu^{++} cupric ion electrode potential of +0.34 volt, or relatively 0.79 - 0.34 = 0.45 volt less than a mercuric ion.

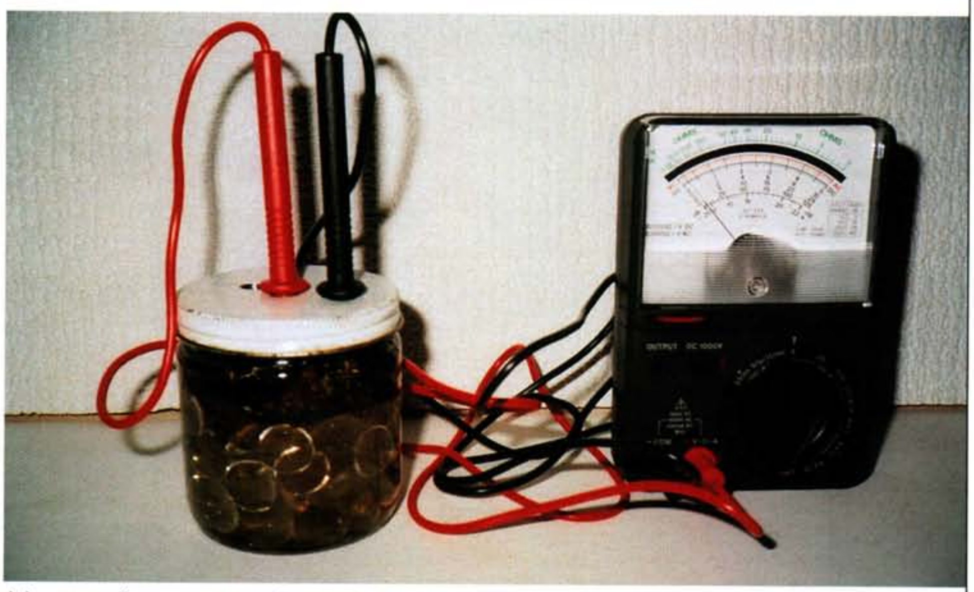
Theoretically, the Activity Series forecasts that silver, developing at least the same relative electrode potential as mercury, would galvanically destroy the chlorophyll in *Bryum argentium* as effectively as mercury.

VERIFICATION

In support of the hypothesis, moss infestations at the Old Westbury Golf and Country Club, Old Westbury, New York, were totally and permanently eradicated by spot drenching with low application rates of highly diluted aqueous solutions of silver nitrate. Surrounding grass plants remained vigorous inasmuch as the topical application and penetration of the required silver dosage attenuated short of the grass plant rootzones. By-product nitrate in solution remained as a turf repair nutrient.

To experimentally verify that the chlorophyll had been electromotivally destroyed, a battery cell was assembled. Harvested *Bryum argentium* moss outcroppings (the cathode) were steeped in water containing a trace of salinity as a conductive electrolyte and were separated by a diaphragm from aqueous silver nitrate solution (the anode). The induced electron current flow was indicated by a voltage difference across the immersed cathode and anode terminals of a calibrated multi-meter. Chlorophyll destruction caused the moss to blacken around the cathode terminal and metallic silver to deposit on the anode terminal.

The battery was assembled within a 6 fl. oz. transparent glass screw-top jar, 2⅜ in. diameter by 2¾ in. high. The diaphragm, a hollow cardboard cylinder, centrally positioned and epoxy affixed within the jar, was ¾ in. outside diameter by 1/16 in. thick, and stood 2¾ in. high. To displace excess volume, the annulus around the cylindrical diaphragm was half-filled with glass beads, on top of which 10 grams of harvested *Bryum argentium* was steeped in 100 ml of a 0.01% saline aqueous solution. The core of the cylindrical diaphragm was filled with 23 ml of 0.22% silver nitrate solution (0.14% silver). The multi-meter indicated a direct current voltage that peaked and dwelled at 0.6 volt for some 90 minutes before gradually diminishing as the chlorophyll was destroyed and the battery cell exhausted.



A battery cell was constructed to verify that the chlorophyll had been electromotively destroyed.

FIELD TRIALS

The putting greens in the study, constructed in 1962, were the "push-up" type, sand amended, approximately 70% creeping bentgrass (Pencross) and 30% annual bluegrass (*Poa annua*), double cut daily at ⅛ in. mower bedknife height to not less than 9½ ft. Stimpmeter speed, fed 1½ lbs. of nitrogen per 1,000 sq. ft. per year, preventively fungicide treated, verticut, and topdressed bimonthly in season. The trials remained ongoing throughout the 2002 calendar year.

Only one application, with a minimum aqueous solution concentration of 0.22 weight percent silver nitrate (0.14 weight percent silver), prepared by dissolving 1 gram of silver nitrate in 16 fl. oz. of water, and spot treated by drenching at the rate of 1 fl. oz. per 6 sq. in. of moss outcroppings, in every instance and under all environmental and ecological conditions successfully eradicated moss infestations, without semblance of reemergence. Treated and eradicated moss outcroppings appear as darkened areas.

SUMMARY

Establishment of silvery thread moss (*Bryum argentium*) populations in putting greens has been exacerbated by the lowering of mower bedknife heights to comply with golfers' preference for fast greens.

In the absence of roots or a defined vascular system, but configured with an uncommonly high biomass surface-to-volume interface, moss populations sustain photosynthesis by ectohydric hydration and respiration within broad environmental conditions. Remarkable exceptions have been metal-contaminated soils.

The toxicity response of *Bryum argentium* to metals correlates to the relative electrode potentials of metals and their solutions in the Activity Series, a/k/a the Electromotive Series. The heavier the metal, the greater, too, is the relative potential difference with the porphorin structured magnesium core of chlorophyll molecules essential to photosynthesis. Consistent with the toxicity correlation of the Activity Series, mercury-based controls have been effective, but not being environmentally acceptable, they have been discarded. Copper, the metal ranked immediately above mercury in the Activity Series, falls short of the mark.

We hypothesize that the toxic response to heavy metals results from the electromotive destruction of the chlorophyll. The Activity Series forecasts that silver would as effectively destroy the chlorophyll in *Bryum argentium* as does mercury, the relative potential difference being sufficient to electromotively cause the negatively charged magnesium ion core of chlorophyll to oxidize and release its electron to reduce a positively charged silver ion to metallic silver. The assembly of a working *Bryum argentium*/silver nitrate battery cell experimentally confirmed both the hypothesis and the forecast.

Silvery thread moss in 70% bentgrass/30% annual bluegrass putting greens was successfully eradicated during ongoing year-round field trials, at low application rates of highly diluted silver nitrate solutions, without adversely affecting the vigor of surrounding grass plants (patent pending).

BIBLIOGRAPHY

1. Happ, Keith A. 1998. "Moss Eradication in Putting Green Turf," *USGA Green Section Record*, Sept./Oct. 1998.

Top: Over the years, golf course superintendents have tried iron sulfate as a control for moss encroachment, but oftentimes the result was incomplete control of the problem. Above: Silver nitrate was used to spot-treat moss in the research plots. Treated and eradicated moss outcroppings appeared as darkened areas.

2. Moore, C. S., and G.A.M. Scott. 1979. *J. Bryol.*, 10:291-311.
3. Bunch, H. 1945. "Uber die Wasser-und Mineralstoff-versongung der moose," Commentat, *Biol. Sci.*, Fenn 9(16), 1-44.
4. Chopra, R. N., and P. K. Kumra. 1988. "Alternative Pathways in Life Cycle," *Biology of Bryophysics*, 5:107-127.
5. Chopra, R. N., and P. K. Kumra. 1988. "Alternative Pathways in Life Cycle," *Biology of Bryophysics*, 12:308-311.
6. Richardson, D.H.S. 1981. "Structure and Classification," *Biology of Mosses*, Halsted Press U.S.A., 1:1-5; 10:155-161.
7. Neibocor, E., and D.H.S. Richardson. 1980. "The Replacement of the Nondescript Term Heavy Metals by a Biologically and Chemically Significant Classification of Metal Ions," *Environmental Pollution* (ser. B), 1:3-26.
8. Coombes, A. J., and N.W. Lepp. 1974. "The Effect of Cu and Zn on the Growth of *Marchantia polymorpha* and *Funaria hygrometrica*," *Bryologist*, 77:447-452.
9. Hummel, Norman W. 1988. "An Integrated Approach to Moss Control in Golf Course Greens," Research Experiment, Cornell University.
10. Simola, L. K. 1977. "Growth and Ultrastructure of *Sphagnum fimbriatum* Cultured with Arsenate, Fluoride, Mercury, and Copper Ions," *J. Hattori Bot. Lab.*, 79:147-155.
11. Shaw, J. A. 1991. "Ecological Genetics, Evolutionary Constraints, and the Systematics of Bryophytes," *Advances in Bryology*, 4:29-74.
12. Taylor, J., and K. Danneberger. 1996. "Moss on Greens When the Rolling Stone Stops," *Golf Course Management*, 64(9):53-56.
13. Golf Course Superintendents. 1997. "Moss Control Survey," *Northern Ohio Turfgrass Newsletter.*
14. Hummel, Norman W. 1994. "Methods for Moss Control," *Golf Course Management Research Report*, 65(3):106-110.
15. Rossi, F. S. 2002. "Moss Control Research at Cornell University," *Summary of 2002 Research.*
16. Dudones, D.W. 2002. "Silvery Thread Moss (*Bryum argentium*) Population Reduction Strategies for Golf Course Putting Greens," M.S. Thesis, Cornell University.
17. *Condensed Chemical Dictionary, 12th Ed.*, Richard J. Lewis, Sr., Van Nostrand Reinhold, N.Y.

DR. ARTHUR P. WEBER, *a chemical engineer, has been a member of the USGA Green Section Committee since 1984.* THOMAS O. MCAVOY, CGCS, *is superintendent at Old Westbury Golf Club (New York).*