garden book 1766–1824. The American Philosophical Soc., Philadelphia.

De Vos, N.E. 1992. Artichoke production in California. HortTechnology 2(4):438–444.

Gerakis, P.A., D. Markarian, and S. Honma. 1969. Vernalization of globe artichoke, *Cynara scolymus* L. J. Amer. Soc. Hort. Sci. 94:254–258.

Harwood, R.R. and D. Markarian. 1968. Annual culture of globe artichoke (*Cynara scolymus* L.) I. Preliminary report. Proc. Amer. Soc. Hort. Sci. 92:400–409.

Hill, D.E. and A.A. Maynard. 1989. Globe artichoke trials 1987–1988. Conn. Agr. Expt. Sta. Bul. 867.

Maynard D.N. and T.K. Howe. 1986. Evaluation of specialty vegetable crops for production in West Central Florida. Proc. Fla. State Hort. Soc. 99:293–300.

Ryder, E.J., N.E. De Vos, and M.A. Bari. 1983. The globe artichoke (*Cynara scolymus* L.). HortScience 18(5):646–653.

Schrader, W.L. and K.S. Mayberry. 1992. 'Imperial Star' artichoke. HortScience 27(4):375–376.

Snyder, M.J., N.C. Welch, and V.E. Rubatzky. 1971. Influence of gibberellin on time of bud development in globe artichoke. HortScience 6:484–485.

Physical Properties of Hawaiian Golf Course Sands

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Additional index words. USGA, coral sand, recreational turf, turfgrass

Summary. Physical properties (particle size distribution, bulk density, capillary pore space, non-capillary pore space, hydraulic conductivity, and water retention) of three imported silica sands (Perth, Malaysian, and Newcastle), a man-made sand product (Mansand), and coral sand alone and in peatmoss mixtures were determined to evaluate their suitability as golf-green substrates. Based on laboratory evaluation of physical properties, the silica sands amended with peatmoss (15%) were superior to coral sand or crushed basalt (Mansand) amended with 15% peatmoss for use in high-traffic turfgrass areas.

Soils provide anchorage for plants, the oxygen necessary for root growth, adequate water storage capacity, and the essential mineral elements for plant growth. Ideally, soils would be composed of ≈50% solid particles and 50% pore space. The solid portion of the soil would be ≈95% mineral particles (sand, silt, and clay) and 5% organic matter. The pore space should be about half large (non-capillary) and half small (capillary). This ratio of large and small pore space provides good rootzone aeration, yet stores enough water to make frequent irrigation unnecessary.

Turfgrass sites subjected to heavy or constant traffic, such as golf putting greens or athletic fields, should be constructed with sand or mixtures dominated by sand. Sand retains sufficient large pore space for adequate rootzone aeration and drainage. Sand particles are relatively large and are not easily compactable. Rootzone mixtures dominated by silt or clay particles may have adequate large pore space when uncompacted because many particles may be grouped into aggregates. The aggregates act as one large particle. The forces binding these particles into aggregates, however, are relatively weak, so they are broken quickly into individual fragments when compacted.

Sand has been the physical soil amendment of choice for construction of high-traffic turfgrass areas. The term sand, however, simply refers to the size of the individual particles and does not indicate the chemical composition of the material. In continental areas, silica sand is plentiful and is the most common amending material. Turfgrass researchers and soil physicists have characterized the properties of sand suitable for turfgrass areas. This research has resulted in the present recommendations of the United States Golf Assn. (USGA) Green Section on golf greens construction (U.S. Golf Assn. Green Section Staff, 1974). They specify that sands with particle sizes ranging from 1.0 to 0.1 mm in diameter are suitable for use in constructing golf putting greens. They further recommend that a minimum of 75% of the particles should be in the "medium" sand classification (0.5 to 0.25 mm in diameter).

Although tropical islands usually have broad sandy beaches, the sand on these beaches is composed of broken coral that has been ground to sand size by wave action. There are no deposits of silica sand in Hawaii or other Pacific islands. While coral sand may in some instances have desirable physical properties, it is composed primarily of calcium carbonate. This results in some undesirable chemical properties. The pH of turfgrass rootzones constructed of coral sand is usually 7.5 to 9.0. The high pH results in reduced availability of several essential elements, especially micronutrients such as Fe, Zn, and Mn.

Unfortunately, it is not possible to adjust the pH of rootzones constructed of coral sand. Acidic materials added to the soil simply react with the coral until the acid is neutralized. This results in dissolution of some of the

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coral sand and eventually the formation of a cement-like layer at the bottom of the rootzone. This hardpan is impervious to water and has a severe impact on plant growth and management.

In 1976, the Hawaii State Legislature passed a law prohibiting dredging of sand below the permanent high-water mark on beaches. Coral sand was then obtained from dune deposits inland, or by mining prehistoric inland coral deposits and grinding the coral into sand-sized particles. Coral sand dune deposits are very fine to fine particles, because the coral sand was carried by wind currents. Dune sand is not generally suitable for constructing greens to USGA specifications. Ground coral particles are highly variable in size and tend to pack together tightly.

In addition to dune and ground coral sand, crushed basaltic rock (Mansand) and cinders have been used for constructing turfgrass areas in Hawaii. Mansand is not ideally suited for greens construction because the particles are larger than ideal and have sharp edges, which results in tight packing when compacted. The particle sizes of cinders are very variable within a given location. Cinders are also not very resistant to compaction.

In the past few years, development of golf courses and the corresponding demand for sand have increased dramatically in Hawaii and throughout the Pacific Rim. Increased demand has led to bulk shipping and a parallel reduction in shipping and material costs for silica sands imported from the mainland United States and other countries.

Several suppliers of local sand products and imported silica sand are presently operating in Hawaii. Differences in cost and physical and chemical properties of the materials have led to questions from contractors and developers. To answer some of these questions, we compared the physical properties of commonly available imported sands used in golf course construction and management with those of locally produced ground coral sand and Mansand.

Two silica sands imported from Australia (Perth and Newcastle sands) and one from Malaysia (Malaysian sand) were obtained from commercial sources. These are typical imported sources for greens construction sands in Hawaii and the Pacific Rim. Ground coral and crushed basaltic rock (Mansand) were used as standard locally available construction materials. Each sand was evaluated with and without a hand-shredded sphagnum peat amendment, 15% by volume.

Table 1. ***Particle size distribution of selected silica sands (Perth, Malaysian, and Newcastle), ground coral sand, and crushed basalt (Mansand) used in Hawaii. USGA recommendations: acceptable range 1.0 to 0.1 mm; ideally 75% 0.5 to 0.25 mm.***

	Sand				
Sieve opening (mm)	Perth	Malaysian	Newcastle	Coral	Mansand
	Particles retained (%)				
2.0–1.0 (very coarse)	1.8	5.4	0.0	2.2	62.9
1 .0–0.5 (coarse)	17.6	18.2	2.8	26.9	13.7
0.5-0.25 (medium)	72.5	61.7	86.7	57.9	16.3
0.25-0.1 (fine)	7.9	14.1	10.4	12.8	6.0
<0.1 mm (very fine)	0.2	0.6	0.1	0.2	1.1

Particle size distribution of the sands only was obtained by sieving 500-g dry samples through a series of ASTME-11 specification stainless steel sieves for 30 min using a sieve shaker (W.W. Tyler, Mentor, Ohio). Bulk density (weight per unit volume) was measured for each sand and sand–peatmoss mixture. Percent total porosity was calculated as [(particle density – bulk density)/particle density] × 100.

Total, capillary, and non-capillary pore space at 40 cm (16 inches) tension were determined by a pressure plate (Klute, 1968). This tension was selected because the rootzone of golf greens constructed to USGA specifications are ≈ 40 cm (≈ 16 inches) in depth. At field capacity, water in these greens therefore would be under ≈ 40 cm (≈ 16 inches) tension. Capillary pore space was calculated as the weight of water remaining in the medium at 40 cm (16 inches) tension. Non-capillary pore space represents the total pore space at 40 cm (16 inches) minus capillary pore space.

Hydraulic conductivity ($cm{\cdot}h^{-1}$), the amount of water passing through the medium in a given time, was determined using laboratory infiltrometers (McNeal and Reeve, 1964). Water retention ($cm{\cdot}m^{-1}$ substrate depth) was calculated from water in capillary pore space.

Physical properties of each sand and sand-peatmoss mixture were compared to those recommended by the USGA. All measurements were replicated three times.

Particle size distribution. Siev-

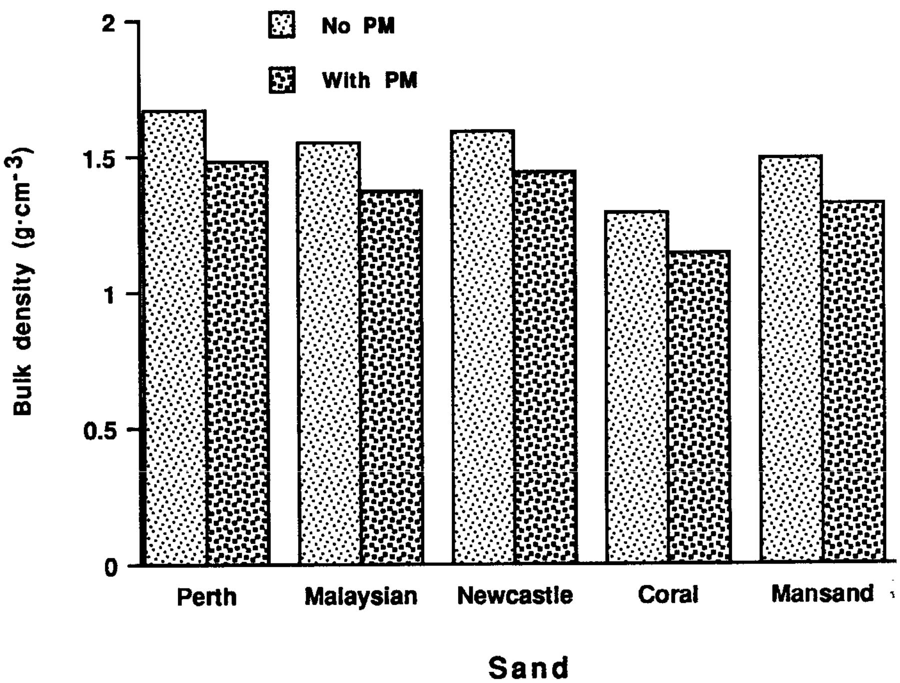

Fig. 1. *Bulk density ($g{\cdot}cm^{-3}$) of sands and sand-peatmoss (PM) (15%) medium evaluated. The USGA recommends a bulk density of 1.25 to 1.4 $g{\cdot}cm^{-3}$ for a greens substrate.*

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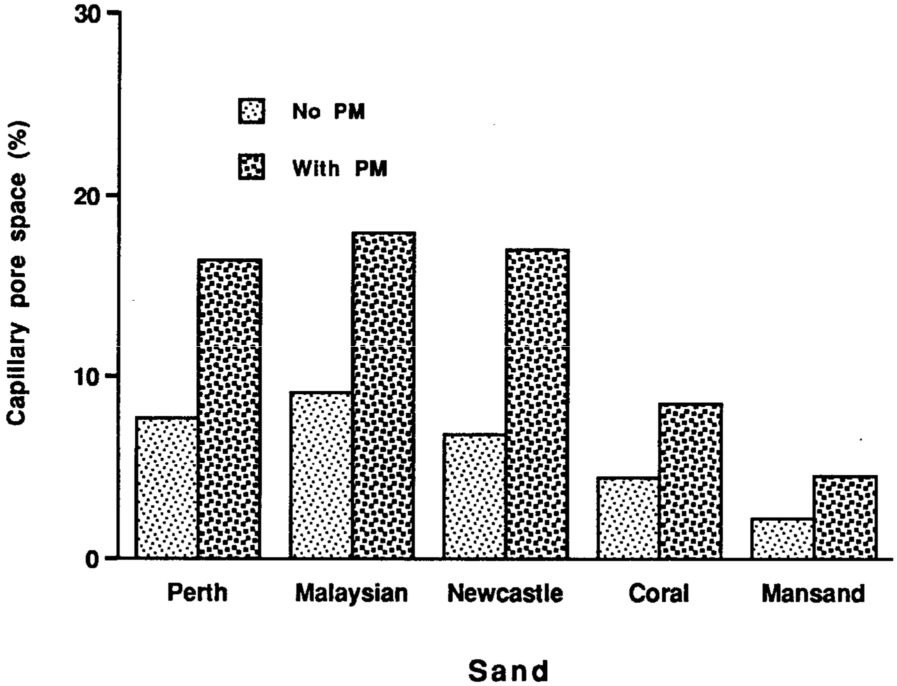

Fig. 2. *Capillary pore space (%) of sands and sand-peatmoss (PM) (15%) medium evaluated. The USGA recommends a capillary pore space between 15% and 25% for a greens substrate.*

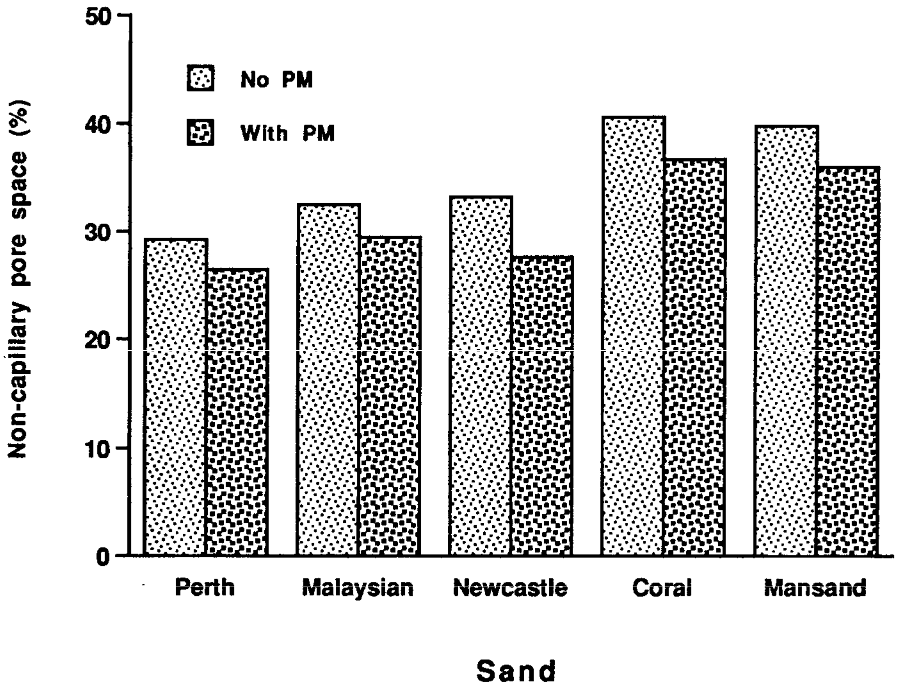

Fig. 3, *Non-capillary pore space (%) for sands and sand-peatmoss (PM) (15%) mixtures evaluated. The USGA recommends a non-capillary pore space of 15% to 25% for a greens substrate.*

ing revealed that the Newcastle sand had the most desirable particle size distribution (Table 1). The USGA recommends that sands for golf greens construction have a particle size range from 1.0 to 0.1 mm in diameter. Ideally, a minimum of 75% of the particles should be in the "medium" sand range (0.5 to 0.25 mm in diameter). Perth sand was very close to the USGA recommendations, with 72. 5% of the particles in the medium sand range. Malaysian sand had a wider range of particle sizes than did the other silica materials. The wider range of particle sizes would likely result in diminished large pore space and a greater tendency to compact over time.

Neither coral sand nor Mansand had desirable particle size distributions. Coral sand had a wide range of particle sizes. Cord sand contained ≈ 27% coarse sand, 60% medium sand, and 13% fine sand. The crushed basalt (Mansand) contained ≈ 63% very coarse sand, 14% coarse sand, and 16% medium sand.

Bulk density. USGA recommendations for bulk density of suitable sands range from 1.25 to 1.4 $g \cdot cm^{-3}$. All unamended silica sands (Perth, Malaysian, and Newcastle) had bulk densities greater than the USGA recommendations (Fig. 1). When peatmoss was added, however, the bulk densities of all sands, except coral sand, were in or very near the recommended range.

Capillary pore space. None of the unamended sands provided the minimum capillary pore space recommended by USGA (Fig. 2). However, when peatmoss was added, all three silica sands were slightly above the minimum recommended capillary pore space. Neither coral sand nor Mansand provided adequate capillary pore space, even with 15% peatmoss. This indicated that rootzone mixtures of coral sand or crushed basalt (Mansand) and peat would require more frequent watering to prevent drought stress to turfgrasses.

Non-capillary pore space. All sands and sand–peatmoss mixtures had non-capillary pore space exceeding USGA recommendations (Fig. 3). Non-capillary pore space of all silica sand–peatmoss mixtures (Perth, Malaysian, and Newcastle) were moderately above this recommendation level and would likely cause no significant problems in turfgrass culture. Non-capillary pore space of coral sand and Mansand was excessive, even with 15% peatmoss. This reflects the relative coarseness of these sands compared to the silica materials. Mixtures of coral sand or Mansand would be well-drained, as indicated by the limited capillary pore space. However, they would not provide sufficient water storage capacity to prevent frequent irrigation during periods of high water consumption.

Hydraulic conductivity. The hydraulic conductivity of all sands and amended sands exceeded USGA recommendations (Fig. 4). This is related to the high non-capillary pore space (Fig. 3). The addition of peatmoss to silica sand (Perth, Malaysian, and Newcastle) resulted in hydraulic conductivities only slightly above the maximum recommended 43 $cm \cdot h^{-1}$ (17 inches/h). Hydraulic conductivity

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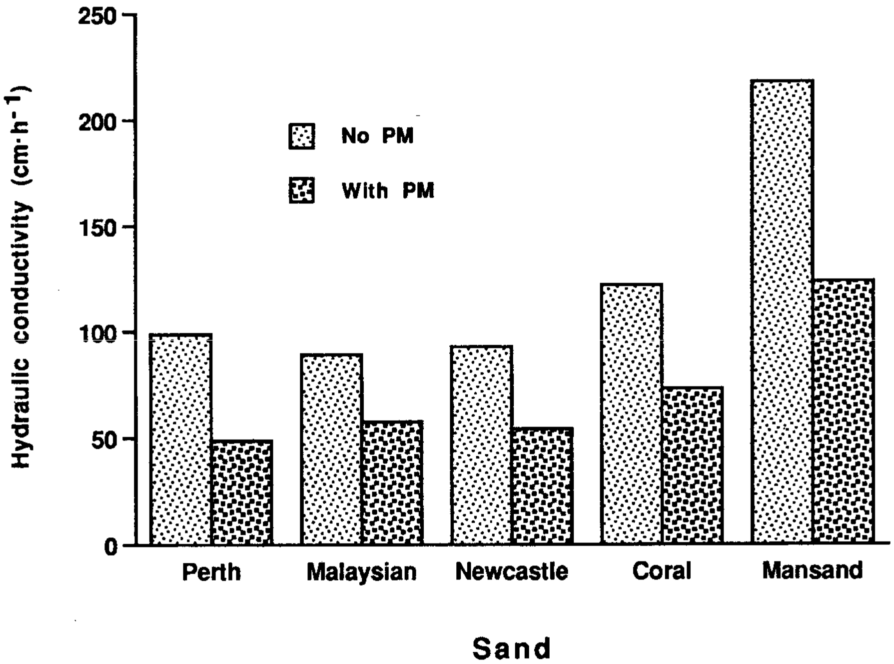

Fig. 4. *Hydraulic conductivity (cm·h^{-1}) of sands and sand-peatmoss (PM) (15%) medium evaluated. The USGA recommends a hydraulic conductivity (cm·h^{-1}) of 25 to 43.*

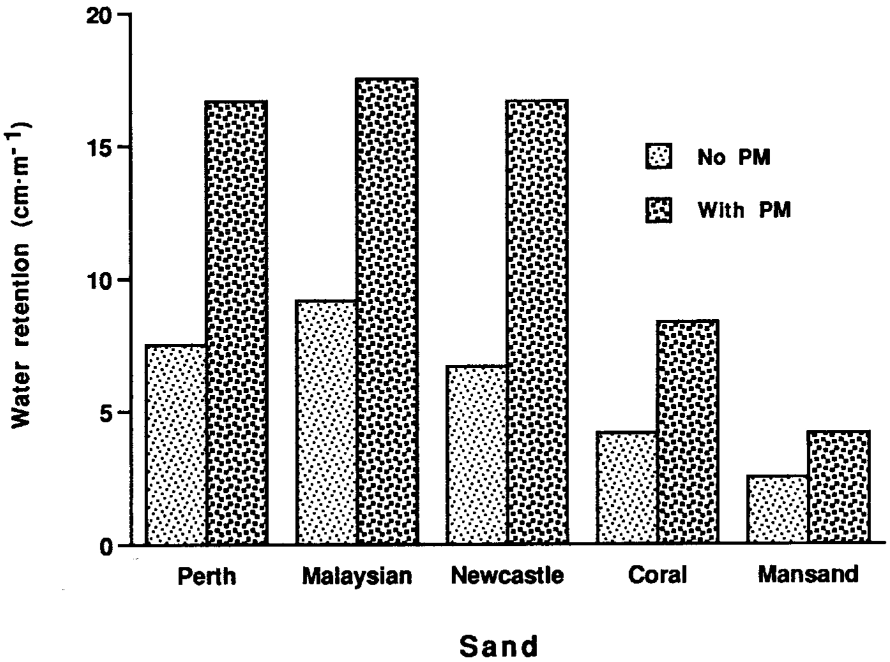

Fig. 5. *Water retention (cm·m^{-1}) for sand and sand-peatmoss (PM) (15%) medium evaluated. USGA recommends water retention for greens mixtures between 11.9 and 18.6 cm·m^{-1} for a greens substrate.*

should decrease over time after turfgrasses are established on the substrate (Schmidt, 1980; Waddington et al., 1974). However, these values might not be excessive for an established green. Mansand and, to a lesser extent, coral sand had excessive hydraulic conductivity values with or without addition of peatmoss. These values are again a reflection of the larger particle sizes of these sands and the resulting non-capillary pore space.

Water retention. Water retention per meter of depth is an expression of the amount of capillary pore space. It is useful to predict irrigation scheduling under different water demands. As expected, none of the sands alone provided the recommended water retention of 11.9 to 18.6 cm·m^{-1} (1.4 to 2.2 inches/ft) (Fig. 5). When 15% peatmoss was added, all silica sands (Perth, Malaysian, and Newcastle) were well within the recommended 11.9 to 18.6 cm·m^{-1} (1.4 to 2.2 inches/ft). Managers often schedule irrigation when about half the available water has been depleted. Media with the recommended USGA water retention level would require watering every 3 to 4 days at about maximum turfgrass water use (evapotranspiration) rates [0.6 cm (0.25 inch) per day].

These data show, based on laboratory analysis of physical properties, that the silica sands amended with peatmoss(15%) were superior to coral sand and Mansand amended with 15% peatmoss for use in turfgrass greens. Coral sand also has highly undesirable chemical properties. It is ≈ 98% calcium carbonate. Golf putting greens constructed of coral sand commonly have a pH of 8.0 to 9.0. High pH interferes with nutrient availability, especially micronutrients such as Fe. The pH of coral sand greens cannot be lowered with acid-forming materials such as S. The coral reacts with the acid, dissolving some of the sand and leaving the pH unchanged. Over a period of time, enough coral dissolves and moves through the rootzone to form an impervious cement-like layer at the base of the green. Although the cost of imported silica sand is greater than coral sands or crushed basaltic rock (Mansand), imported silica sands should be economically advantageous over time due to the improved physical properties when amended with peatmoss. Turfgrass performance should be superior with fewer inputs of fertilizer and water.

Literature Cited

Klute, A. 1986. Water retention: Laboratory methods. Methods of soil analysis. Agronomy 9:635-662.

McNeal, B.L. and R.C. Reeve. 1964. Elimination of boundary-flow errors in laboratory hydraulic conductivity measurements. Soil Sci. Soc. Amer. Proc. 28:713–714.

Schmidt, R.E. 1980. Bentgrass growth in relation to soil physical properties of Typic Hapludalfs soil variously modified for a golf green. Proc. 2nd Intl. Turfgrass Res. Conf. Amer. Soc. Agron., Madison, Wis. p. 205-213.

U.S. Golf Assn Green Section Staff 1974. Sand for golf courses. USGA Green Section Record. 12(5):12–13.

Waddington, D.V., T.L. Zimmerman, G.J. Shoop, L.T. Kardos, and J.M. Duicb. 1974. Soil modification for turfgrass areas. Penn. State Univ. Agr. Expt. Sta. Prog. Rpt. 337.

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